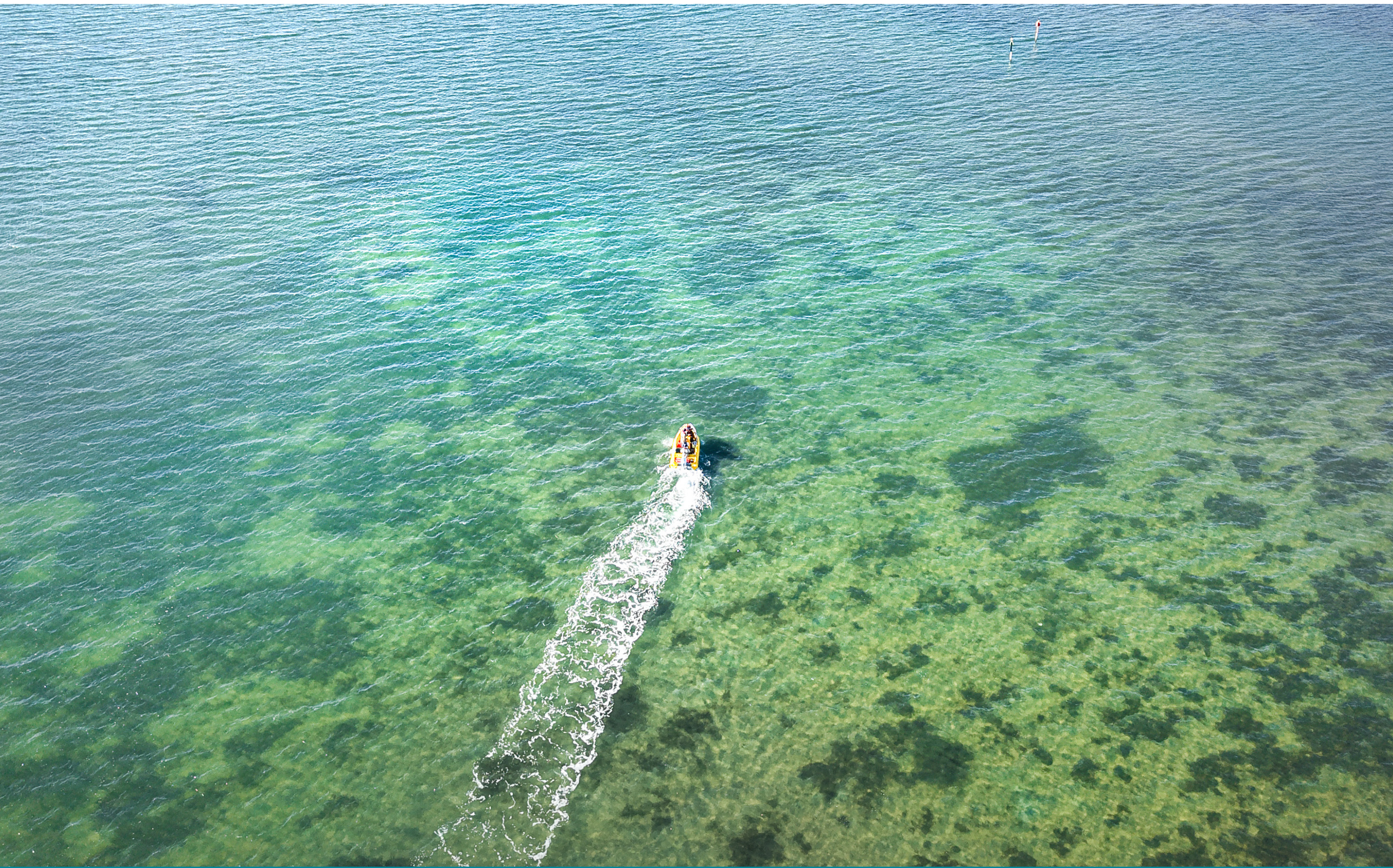
Department of **Water and Environmental Regulation**
Department of **Primary Industries and Regional Development**

GOVERNMENT OF WESTERN AUSTRALIA

Quantifying seagrass and macroalgae in the Bindjareb Djilba (Peel-Harvey estuary), Western Australia: a comparison of methods



HEALTHY ESTUARIES WA

Delivering on the Bindjareb Djilba Peel-Harvey estuary Protection Plan

Water Science technical series

Report WST91
September 2025

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Cover photograph: Seagrass patches near Dawesville foreshore looking south-west in the Harvey Estuary (Department of Water and Environmental Regulation).

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Summary

Seagrass and macroalgae communities are prominent features of the Bindjareb Djilba (Peel-Harvey estuary). However, excessive growth of macroalgae – driven by nutrient and sediment runoff from the catchment – can smother seagrass beds and disrupt ecological balance. Management efforts to reduce catchment runoff are crucial to support healthy aquatic ecosystems. Long-term monitoring of seagrass and macroalgae plays a key role in determining whether these management efforts are succeeding.

Monitoring of macroalgae and seagrass in the Bindjareb Djilba began in 1978, amid high levels of nutrient pollution causing persistent algal blooms in the estuary. For the next 43 years, the government contracted Murdoch University's Marine and Freshwater Research Laboratory (MAFRL) to conduct 64 repeat surveys of the estuary. In 1994, the government constructed an artificial opening (the Dawesville Cut) to increase marine water exchange for diluting and flushing nutrients out to sea.

In 2021, MAFRL and the Department of Water and Environmental Regulation (the department) assessed seagrass and macroalgae in the Bindjareb Djilba using different methods[1]. MAFRL used the historical **biomass method**, whereby snorkellers or divers collect cores from the bottom of the estuary. The department used the **cover method** (which it applies in other south-west estuaries) in which the survey team makes visual assessments from a boat.

This report uses data from both 2021 surveys to compare the two assessment methods for seagrass and macroalgae distribution and condition. In addition, this report summarises – for the first time – the historical biomass surveys showing changes in the amount, distribution and diversity of seagrass and macroalgae over 43 years.

Overall, the two survey methods found similar spatial distribution and dominant species of seagrass and macroalgae.

The 2021 **cover survey** showed the presence of seagrass and macroalgae across the estuary in similar proportions (55 per cent and 58 per cent respectively), though their spatial distribution varied. *Ruppia megacarpa* was the main seagrass species and *Chaetomorpha linum* was the main macroalga. Seagrass and macroalgae were mostly absent in the central Peel Inlet. The height of the seagrass canopy was also lower in the central Peel than its margins.

The 2021 **biomass survey** showed the presence of a greater proportion of seagrass (73 per cent) in the total biomass than macroalgae (27 per cent), with the Peel Inlet having greater biomass of both compared with the Harvey Estuary. As in the cover survey, *Ruppia megacarpa* and *Chaetomorpha linum* were the dominant species present.

The **cover survey** provided greater spatial coverage in the estuary, enabling 457 sites to be assessed compared with the **biomass survey**'s 51 sites. Such extensive spatial coverage enabled detection of a fourth species of seagrass, *Posidonia australis*, which the biomass survey missed.

Importantly, this first recorded presence of *Posidonia australis* in the Peel-Harvey estuary indicates long-term changes in salinity producing a more stable marine environment. This increased stability

[1] To distinguish between the datasets of MAFRL and the department, we refer to them in bold as **cover method/survey** and **biomass method/survey** respectively. To distinguish between the type of measure, we simply use lower case for 'cover' of seagrass or 'biomass' of seagrass.

is likely due to a combination of factors, including the Cut, which has enhanced marine water intrusion, and climate change, which has reduced river flows and increased water-retention time in the estuary (Huang et al. 2023; Petrone et al. 2010).

While the **biomass survey** had less spatial coverage, it demonstrated greater taxonomic resolution, identifying 25 genera compared with the **cover survey**'s 14 genera. We attribute this difference to the biomass survey's approach of identifying species in the laboratory, allowing for more precise classification.

Of total seagrass biomass, *Ruppia megacarpa* made up the largest proportion (51 per cent), followed by *Heterozostera/Zostera* sp. (18 per cent) and *Halophila ovalis* (5 per cent) (MAFRL 2022). This ranking contrasts with the order of species based on frequency of observations recorded by both survey methods.

For the **biomass survey**, this discrepancy is likely because of differences in plant size and growth form – smaller species may weigh less but occupy a larger area, influencing their frequency of detection. In contrast, the **cover survey** consistently recorded fewer instances of seagrass and macroalgae than the biomass survey. We attribute this to some of the limitations of a visual assessment method, whereby taller species can obscure smaller ones, floating macroalgae can conceal species below, and poor water clarity can reduce visibility – especially for small or sparsely distributed species.

A statistical comparison of data from the two surveys revealed a moderate relationship – but one which was insufficient to predict biomass from known cover. This might be partly due to the growth form of the main seagrass (*Ruppia megacarpa)*.

From the late 1970s the **biomass survey** tracked the change from macroalgal dominance to seagrass dominance, as well as changes in seagrass species. *Ruppia megacarpa* is now more abundant than *Halophila ovalis*. This work shows that the estuary's species diversity has risen: 30 taxa were identified in 2021, largely red and brown macroalgae thriving in the more marine environment, compared with five to six taxa before the Cut was built. These changes may be related to the change in salinity and water residence time in the estuary.

When the most recent biomass sampling conducted in 2018 and 2021 was compared with the historical data, a worrying increase in macroalgae became apparent for both the Peel Inlet and Harvey Estuary. It also found that in the same years, the Harvey Estuary had at least 50 per cent more macroalgal biomass than all but four of the other 62 estimates made since monitoring began in 1978. This was regardless of season.

Notably, total seagrass biomass in the Peel Inlet in 2021 exceeded any previous estimate in any season from 1978 to 2018. This is likely because coverage of *Ruppia megacarpa* is now widespread – a species with a large growth form that has the potential for high biomass.

We recommend using the **cover method** to assess seagrass and macroalgae productivity and diversity changes because of its regular application across key south-west Western Australian estuaries and its greater spatial coverage. Revisiting the **biomass survey** perhaps every five to 10 years would also have value as it offers a long-term dataset to evaluate macrophyte productivity and diversity in relation to climate change.

Overall, maintaining surveillance over aquatic vegetation communities in the Bindjareb Djilba remains crucial for understanding ecosystem condition and guiding management efforts amid environmental changes in a drying climate. Such ongoing monitoring informs catchment actions to improve water quality, such as optimising fertiliser use on grazing farms through the *Bindjareb Djilba – A plan for the protection of the Peel-Harvey estuary* (DWER 2020) and Healthy Estuaries WA.

1 Introduction

1.1 Seagrass and macroalgae

Seagrass and macroalgae communities are vital elements of an estuary and fulfil key ecological functions. Both types of communities are primary producers, forming the base of complex food webs that provide food directly or indirectly for aquatic fauna. They also oxygenate water, provide underwater habitat for some animal species, store carbon, and stabilise shorelines by reducing the impacts of erosion due to wind and waves.

Seagrasses are flowering plants (angiosperms), with leaves, roots and rhizomes like plants on land. They can take up nutrients both from the water column and sediment porewater. Seagrasses rely on good water and sediment quality to thrive, which is why we use them as measures of estuary health. Macroalgae, on the other hand, are not plants as they lack specialised structures such as leaves, stems and roots, although they may have holdfasts, stipes and blades. They can be free-floating, attached to solid surfaces (like rocks or reefs) or grow from the estuary bed. Macroalgae take up nutrients directly from the water column. They are divided into groups based on the pigments of their tissues. The main groups[2] are green (Chlorophyta), red (Rhodophyta) and brown algae (Ochrophyta).

While macroalgae are an important part of the ecosystem, an over-abundance can indicate an imbalance, with excess nutrients being a typical cause. Some species respond very rapidly to nutrient inputs, resulting in nuisance blooms, usually from fast-growing green macroalgae. They can also have lower light requirements than seagrass, giving them a competitive advantage (Lavery et al. 1995). These nuisance blooms can smother seagrass, clog waterways and accumulate in wracks on the shoreline. Estuarine ecosystems that are seagrass dominated, as opposed to those that are green-algae dominated, tend to reflect a healthier system.

In this report we also discuss aquatic vegetation such as cyanobacteria and stonewarts. Collectively, along with seagrass and macroalgae, we refer to them as ‘macrophytes’ (e.g. Wilson et al. 1995; Lukatelich & McComb 1989; Valesini et al. 2023a).

1.2 History of seagrass and macroalgal growth in the Bindjareb Djilba

Bindjareb Djilba (the Peel-Harvey estuary) is located about 100 km south of Perth. It is the largest estuary in south-west Western Australia with an area of about 133 km^2. It consists of two shallow lagoons with a maximum depth of about 2 m – the basin-like Peel Inlet in the north and the elongated Harvey Estuary in the south (Figure 1). These lagoons are linked to the ocean in two places: through the natural Mandurah Channel on the northern shore of Peel Inlet and the engineered Dawesville Channel in the west where it meets the Harvey Estuary.

[2] For taxonomic names we used the World Register of Marine Species.

Figure 1 Key features of the Bindjareb Djilba (Peel-Harvey estuary), including the historical delineation of the Peel Inlet from the Harvey Estuary (white dashed line south of the Dawesville Channel)

In Figure 1 a white dotted line shows where the Peel Inlet and Harvey Estuary are delineated. This delineation forms the basis of the aquatic vegetation literature on the Bindjareb Djilba, both before and after the Cut (see a comprehensive list in Valesini et al. 2023b).

The Bindjareb Noongar people have looked after the estuary and its surrounds for 50,000 years based on governance and lore. They hold a creation story for the Bindjareb Djilba where the Waugal (great serpent) formed the Peel Inlet and Harvey Estuary, and her babies formed the Serpentine, Murray and Harvey rivers. They continue to hold a life commitment and cultural responsibility for the preservation of these waterbodies (Nannup et al. 2019).

As described earlier, macroalgae can grow rapidly in the presence of high nutrient concentrations. An extreme version of this scenario occurred in the Bindjareb Djilba from the mid-1960s until the early 1990s before the Dawesville Cut was built. Application of superphosphate fertiliser to agricultural lands on sandy soils meant excess nutrients could enter the lagoons from the rivers and drains (McComb & Humphries 1992). This led to massive blooms of drift green macroalgae in the Peel Inlet, mostly *Cladophora montagneana* (now reclassified as *Willeella brachyclados*), which accumulated on the beaches and in the water. The blooms rotted on the beaches and released unpleasant odours, affecting nearby residents. In the water, the macroalgae clogged the propellers of boats and commercial fishing nets. Shorelines began to erode because seagrass and saltmarsh that had previously stabilised the sediment was being smothered (Hodgkin et al. 1981).

The blooms were not limited to macroalgae. In 1978, blooms of microalgae (phytoplankton) or – more precisely – the cyanobacterium *Nodularia spumigena*, also occurred. These blooms produced toxins that killed fish and crabs, the carcasses of which released noxious odours when decomposing. This occurred across the entire Harvey Estuary but often drifted into Peel Inlet as well (Lavery et al. 1995). The boom-and-bust cycle of the cyanobacteria in Harvey Estuary was intimately tied with new blooms of macroalgae in Peel Inlet, as the decomposing cyanobacteria released nutrients and their loss improved light levels (Lukatelich & McComb 1989).

Surveys of macroalgae and seagrass biomass started in 1978 as a response to the massive blooms in the Bindjareb Djilba. The biomass of macroalgae was measured as a proxy for productivity and a response to nutrient enrichment. It was reported in tonnes when tractors, front-end loaders and offshore harvesters were used to remove accumulations from the shore. The surveys were State Government funded by way of various agencies over time (Environmental Protection Authority, Waterways Commission, Water and Rivers Commission, Department of Water and, most recently, Department of Water and Environmental Regulation). Along with many other studies, the surveys informed the environmental management response to the problem.

The government’s management response at the time consisted of three actions:

1. **Construct the Dawesville Channel (the Cut)** to improve circulation and reduce water residence time within the estuary through increased ocean water exchange. Improving circulation and water exchange was intended to reduce nutrient retention, which in turn would reduce algal blooms.
2. **Reduce nutrient inputs from the catchment** to lower the risk of eutrophication and to prevent algal blooms.
3. **Harvest macroalgal accumulations** to reduce foul odours from rotting algae, clean the beaches and reduce nutrients re-entering the water.

Implementing the three actions resulted in varying degrees of success, as described below.

The Cut was opened in April 1994. Initially (1995–2000) macroalgal blooms in the estuary drastically reduced and seagrass extent increased (Lord & Associates 2002). The occurrence of fewer blooms was consistent with an initial decrease (1998–2004) in the modelled water-retention time and commensurate decrease in nutrient-retention time (Huang et al. 2023). However, since 2004 increased blooms have been observed in the eastern Peel and southern Harvey (Krumholz 2019). They are associated with extended water-retention times (2004–2016) in these areas, which have been returning to, or even exceeding pre-Cut times (Huang et al. 2023). This appears to be largely because climate change is reducing rainfall, and thus the river flows that used to flush nutrients out of the estuary (Petrone et al. 2010; DWER 2023).

Early management efforts reduced catchment nutrients from some agricultural and urban point sources, but these were limited in extent and progress was slow (DWER 2025). Concerted action to reduce nutrients began in 2016 with the Regional Estuaries Initiative and is continuing through Healthy Estuaries WA, supplemented with funding for the *Bindjareb Djilba – A plan for the protection of the Peel-Harvey estuary* (DWER 2020, DWER 2025).

When macroalgae was harvested in the 1980s, between 15,000 and 20,000 tonnes were removed each year. Volumes declined in the 1990s, before harvesting was finally stopped in the 2000s. While harvesting improved the aesthetic of the shoreline, it was not an effective management tool. Harvesting removed less than 5 per cent of the total macroalgal biomass in the estuary. The physical removal of macroalgae was also too expensive, impractical and reactive as a long-term solution to their accumulation. There were also concerns about animal by-catch, sediment compaction, beach erosion and loss of samphire vegetation.

1.3 Forty-three years of change in estuary seagrass and macroalgae

Between 1978 and 2021, 64 surveys were conducted at key seagrass and macroalgae habitats in the Bindjareb Djilba. During this period, sampling frequency and the number of surveyed sites changed along with the dominant seagrass and macroalgae species encountered.

Initially, surveys were conducted nearly every year across all four seasons. However, over time, the frequency of sampling declined. Winter surveys ended in 1992, and by 2000, sampling was reduced to just one season per year. After 2000, annual surveys ceased, creating a nearly decade-long gap before surveys resumed in 2009, with additional surveys in 2017–18 and 2021.

Sampling site numbers also fluctuated during the 43-year period. It started at 36 sites in the late 1970s, decreased to 30 in the early 1980s, and then increased to 42 by the mid-1980s. By 2017, the number of sites had grown to 51 and remained at that level to fill gaps from earlier surveys. Notably, Harvey Estuary had less macroalgal biomass before construction of the Cut, which led to lower sampling priorities in this waterbody.

See Table A 1 for the sampling year, month, season and number of sites sampled for macrophyte biomass.

The summary below describes historical changes in the dominant species of seagrass and macroalgae. We discuss the changes in species composition in relation to the Dawesville Cut – a modification which significantly altered key environmental factors such as salinity, tidal amplitude and residence times (Lord & Associates 2002). These environmental changes, in turn, affected nutrient dynamics and light availability, which played a crucial role in reshaping the dominance and composition of species in the Peel Inlet and Harvey Estuary (Lavery et al. 1995).

Seagrass changes

Pre-monitoring

Earliest reports suggest that seagrass was common and dominated by *Ruppia* sp. and *Halophila* sp. before the 1960s, but by the mid-1960s and through the 1970s, macroalgal blooms dominated as described previously (Bradby 1997).

Pre-Cut (1978 to 1994)

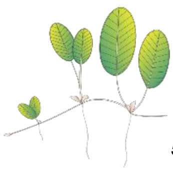
Once formal monitoring was instigated in 1978 and before the Cut was built in 1994, seagrass contributed relatively little to the total biomass of macrophytes in the estuary, typically accounting for only 15 to 30 per cent. The exception was in 1991, when seagrass biomass peaked at 68 per cent (Table 1). During the whole pre-Cut period, seagrass was completely absent from the southern Harvey Estuary. Both the Peel Inlet and Harvey Estuary were in a eutrophic state (Lavery et al. 1995), with seagrasses often smothered by macroalgae. While annual data on seagrass species was not consistently reported, a general summary indicated that *Ruppia megacarpa* and *Halophila ovalis* were the dominant species. Small beds of *Zostera* sp. were also found near the Mandurah Channel, and *Heterozostera* sp.[3] was located near Sticks Channel (Figure 1). In addition, *Lepilaena cylindrocarpa* was present among the *Ruppia* sp. in Austin Bay (Lavery et al. 1995).

Post-Cut (October 1994 to April 2021)

After the Cut was built, surveys began recording biomass for individual seagrass species. This revealed a shift in dominance: *Halophila ovalis* was the dominant species in the first six years post-Cut, while *Ruppia megacarpa* became dominant in later years. The only exception occurred in 2009, when *Zostera* sp. dominated the seagrass biomass (Table 1). In 2009, most of the biomass of *Zostera* sp. was found at a site in the Harvey Estuary, north of Mealup Point, with smaller areas near the Cut (Figure 1). Meanwhile, *H. ovalis* had the least biomass but covered the largest area, particularly in the Peel Inlet and north-western Harvey Estuary near Point Mortiff (Pedretti et al. 2011).

[3] Genus/species names used historically are reported in this section; however, please see footnote 23 on the use of *Heterozostera/Zostera sp*.

Table 1 Dominant seagrass species (✓) and per cent seagrass of total macrophyte biomass from historical biomass surveys in the Bindjareb Djilba (Peel-Harvey estuary).

Year	Dominant seagrass (by interpolated biomass)			% seagrass of total macrophyte biomass[4]
	Halophila ovalis  [5]	*Ruppia megacarpa* 	*Zostera* spp.[3] *(now known to be Heterozostera/Zostera* sp.) 	
Pre-Cut 1978 to 1994				
	✓	✓		15–68[6] (Peel)
Post-Cut Oct 1994 to Apr 2021				
1994–1995[7]	✓			<30 (Peel) <10 (Harvey)
1995–1996[8]	✓			<33 (Peel) <10 (Harvey)
1996–1997[9]	✓			24–53 (Peel) 30–57 (Harvey)
1997–1998[10]	✓			13–47 (Peel) 14–37 (Harvey)
1998–1999[11]	✓			46–77 (Peel) 13–18 (Harvey)
1999–2000[12]	✓			26–50 (Peel) 4–8 (Harvey)
2009[13]			✓	18 (Peel) 18 (Harvey)
2017–2018[14, 15]		✓		37–41 (Peel) 24–28 (Harvey)
2021[16]		✓		80 (Peel) 52 (Harvey)

4 Range given when more than one season sampled
5 All macrophyte graphic symbols in Table 1 and Table 2 courtesy of Integration and Application Network
6 Lavery et al. (1995)
7 Wilson, Latchford and Paling (1995)
8 Wilson, Latchford and Paling (1996)
9 Wilson, Latchford and Paling (1997)

Macroalgae changes

Pre-monitoring

In contrast to seagrass, macroalgae were not seen in the Bindjareb Djilba before the 1960s, but once they began to appear in the mid-1960s, seagrass became less common (Bradby 1997). In the 20 years before monitoring began, the system was dominated by large blooms of the green macroalga *Cladophora montagneana* (now known as *Willeella brachyclados*), causing major issues as previously described (Lavery et al. 1995).

Pre-Cut (1979 to March 1994)

Shortly after monitoring began in 1978, it was clear that *Cladophora montagneana* was no longer prevalent in the estuary. By 1981 it had been replaced by *Chaetomorpha linum,* which was often co-dominant with other species, notably *Ulva rigida* and *Enteromorpha* spp. (now known to be *Ulva* spp.). Later, red algae made an appearance (Table 2). The rapid change in dominance from *C. montagneana* to *C. linum* was attributed to major storm events and reduced light penetration (Lavery et al. 1995). Macroalgae accounted for between 32 and 85 per cent of total macrophyte biomass, with the proportion generally more than 70 per cent, except for winter 1991 when seagrass dominated.

Post-Cut (October 1994 to 2021)

After the Dawesville Cut was built, the green alga *Chaetomorpha linum* continued to dominate biomass in the Peel Inlet, with *Cladophora montagneana* and red algae appearing in the Harvey Estuary at various times (Table 2).

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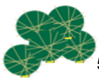
[10] Wilson, Hale and Paling (1998)
[11] Wilson, Hale and Paling (1999)
[12] Wilson, Hale and Paling (2000)
[13] Pedretti et al. (2011)
[14] Valesini et al. (2023a) and Krumholz (2019)
[15] *R. megacarpa* and *H. ovalis* found in the southern Harvey
[16] MAFRL (2022)

Table 2 Dominant macroalgae species (✓) and per cent macroalgae of total macrophyte biomass from historical biomass surveys in the Bindjareb Djilba (Peel-Harvey estuary).

Year	Dominant macroalgae (by interpolated biomass)					% macroalgae of total macrophyte biomass[4]
	Cladophora montagneana (now *Willeella brachyclados*)  [5]	*Chaetomorpha linum* 	*Ulva rigida* 	*Enteromorpha* spp. *(now Ulva* spp.*)* [17] 	Red algae 	
Pre-Cut 1960 – March 1994						32–85[6] (1978–1994)
1960–1979[6]	✓					
1979–1981[6, 18]						
1981–1982[6]		✓				
1983–1984[6]		✓	✓	✓		
1985–1986[6]			✓			
1987–1989[6]		✓	✓			
1990–1994[6, 19]		✓ Peel			✓ Harvey	
Post-Cut Oct 1994 to April 2021						
1994–1995[7]		✓				>70 (Peel) >90 (Harvey)
1995–1996[8]		✓				>67 (Peel) > 90 (Harvey)
1996–1997[9, 20]		✓ Peel			✓ Harvey	47–76 (Peel) 43–70 (Harvey)
1997–1998[10]	✓ Harvey	✓ Peel				53–87 (Peel) 63–86 (Harvey)
1998–1999[11]		✓ Peel			✓ Harvey	23–54 (Peel)

[17] Formerly *Enteromorpha* spp. predominantly *E. intestinalis*, all now part of genus *Ulva* (Potter et al. 2021, Supplementary material S1. Taxonomy and nomenclature of macroalgae in Peel-Harvey and Swan-Canning estuaries).
[18] Loss of *W. brachyclados.*
[19] Variable due to reduced seasonal sampling (e.g. no winter sampling from 1992 onwards and other inconsistent seasonal changes) but mostly dominated by *C. linum* (Peel Inlet) and red algae (Harvey Estuary).
[20] *Caulerpa* sp. first noted in Peel Inlet.

Year	Dominant macroalgae (by interpolated biomass)					% macroalgae of total macrophyte biomass[4]
	Cladophora montagneana (now *Willeella brachyclados)*  [5]	*Chaetomorpha linum* 	*Ulva rigida* 	*Enteromorpha* spp. *(now Ulva* spp.*)* [17] 	Red algae 	
						82–87 (Harvey)
1999–2000[12]	✓ Harvey	✓ Peel				50–74 (Peel) 92–96 (Harvey)
2009[13, 21]		✓				82 (Peel) 82 (Harvey)
2017–2018[14]	✓ Harvey					59–63 (Peel) 72–76 (Harvey)
2021[16]		✓				20 (Peel) 48 (Harvey)

1.4 About this report

Seagrass and macroalgae have been monitored intermittently in the Peel-Harvey estuary since 1978 (Wilson et al.1999; Krumholz 2019; MAFRL 2022; this report). Apart from one survey, all have used the **biomass method**. This involves taking macrophyte cores in the field and then sorting, drying and weighing them by species in the laboratory. The method has been used to monitor some other south-west Western Australian estuaries since 1981, some of the results have been summarised by Bennett et al. (2021).

In 2021, the Department of Water and Environmental Regulation (the department) used the per cent **cover method**. This is a method in which team members visually assess cover and identify species or genera using a viewing cone or drop camera in the field. Current and earlier versions of the method have been routinely applied in other south-west estuaries since 2006 (Bennett et al. 2021).

In this report, we compare the results of the department's **cover survey** with the Marine and Freshwater Research Laboratory (MAFRL) **biomass survey** conducted during the same growing period in 2021. The comparison highlights both the similarities and differences between the two surveys – with DWER reporting per cent cover and MAFRL reporting biomass in grams of dry weight per square metre.

The report also provides the department's total biomass estimates from the **biomass surveys** for the entire estuary, covering a 26-year period after the Dawesville Cut was opened. Furthermore, we discuss changes in species composition and diversity since 2009 when all seagrass and macroalgae, regardless of dominance, were first identified to species level. We consider those

[21] The charophyte *Lamprothamnion* sp. first noted in the Peel Inlet.

changes in the context of the estuary's altered hydrology post-Cut and climate-related reductions in river flow.

To distinguish between the DWER and MAFRL datasets, we refer to them in bold as **cover method/survey** or **biomass method/survey**. To distinguish between the type of measure, we simply use lower case for 'cover' of seagrass or 'biomass' of seagrass.

In the sections that follow we:

- describe both methods
- spatially compare seagrass cover/biomass including whole estuary estimates and distribution
- offer seagrass taxonomic comparisons as determined at the sites (i.e. *in situ*) and in the laboratory
- describe canopy height of the seagrass *Ruppia megacarpa* and epiphyte cover of seagrass at each site
- spatially compare macroalgal cover/biomass and community composition
- statistically analyse the results from the cover and biomass surveys
- summarise temporal changes in total estuary biomass (tonnes) and species composition of both seagrass and macroalgae from historical biomass surveys
- identify the strengths and weaknesses of each method
- make recommendations for future monitoring.

2 Comparison of cover and biomass methods

In 2021 seagrass and macroalgae were surveyed using two methods – with the aim to compare them. The **cover survey** was conducted from 22–26 and 29 March and the **biomass survey** from 14–16 and 19 April. See below for a synopsis and the Appendices for more details.

2.1 Cover method

The department's survey team assessed seagrass and macroalgal cover following the broadscale mapping methods described in Bennett et al. (2021). This approach enables macrophytes to be studied across a large area and the detection of long-term changes in their distribution and cover.

At almost 500 pre-determined locations (Figure 2), the team used a variable field of view to record total seagrass and total macroalgal cover (as percentage), and genus or species. They made observations from a survey boat with an underwater camera, or a viewing cone when the water was shallow and turbidity low. In addition, for the very shallow areas where boat access was not possible (such as Austin Bay), they conducted a targeted drone survey to infer the presence of seagrass and macroalgae.

The team identified species of macroalgae where possible; when in doubt, they recorded species as either red (Rhodophyta), green (Chlorophyta), brown algae (Ochrophyta) or other.

They estimated canopy height (length of leaves) of the seagrass *Ruppia megacarpa* visually in the field to the nearest 10 cm, and assessed epiphyte cover as 'none', 'low', 'medium' or 'high' at all sites with boat access.

Other measurements taken but not presented in this report were water depth, Secchi depth, light availability as photosynthetically active radiation, temperature, salinity, dissolved oxygen and turbidity.

During the survey, the team made 457 *in situ* observations across the estuary. They were able to make 40 further observations using the drone imagery taken over the inaccessible shallow areas, generating 496 observations in total. Because of unfavourable weather conditions for drone flying, they did not assess a small area in the south-east of the Peel Inlet.

The department then used ESRI ArcMap® software to map seagrass and macroalgal cover and distribution and to estimate the total area of the estuary covered with seagrass or macroalgae. We used the interpolation technique of inverse distance weighting (IDW) to create the maps.

We created seven cover classes, including one with 0 cover (Table B 1, to estimate cover in the variable field of view from the camera or viewing cone. We modified the classes by applying the Braun-Blanquet method used by Fourqurean et al. (2003). For the seagrass and macroalgal cover maps, we carried out IDW on cover category midpoints (Table B 1) with the processing extent being the seagrass/macroalgae-present area. We used six colour classes corresponding to the percentage cover categories (Table B 1) to display the output.

We did not classify seagrass and macroalgae into the percentage cover classes from the drone imagery. Instead, we inferred the presence or absence of seagrass or macroalgae. These data were included in the overall estimation of area of seagrass and macroalgal cover in the estuary.

For more details on the **cover survey** method see Appendix B — Cover survey additional information.

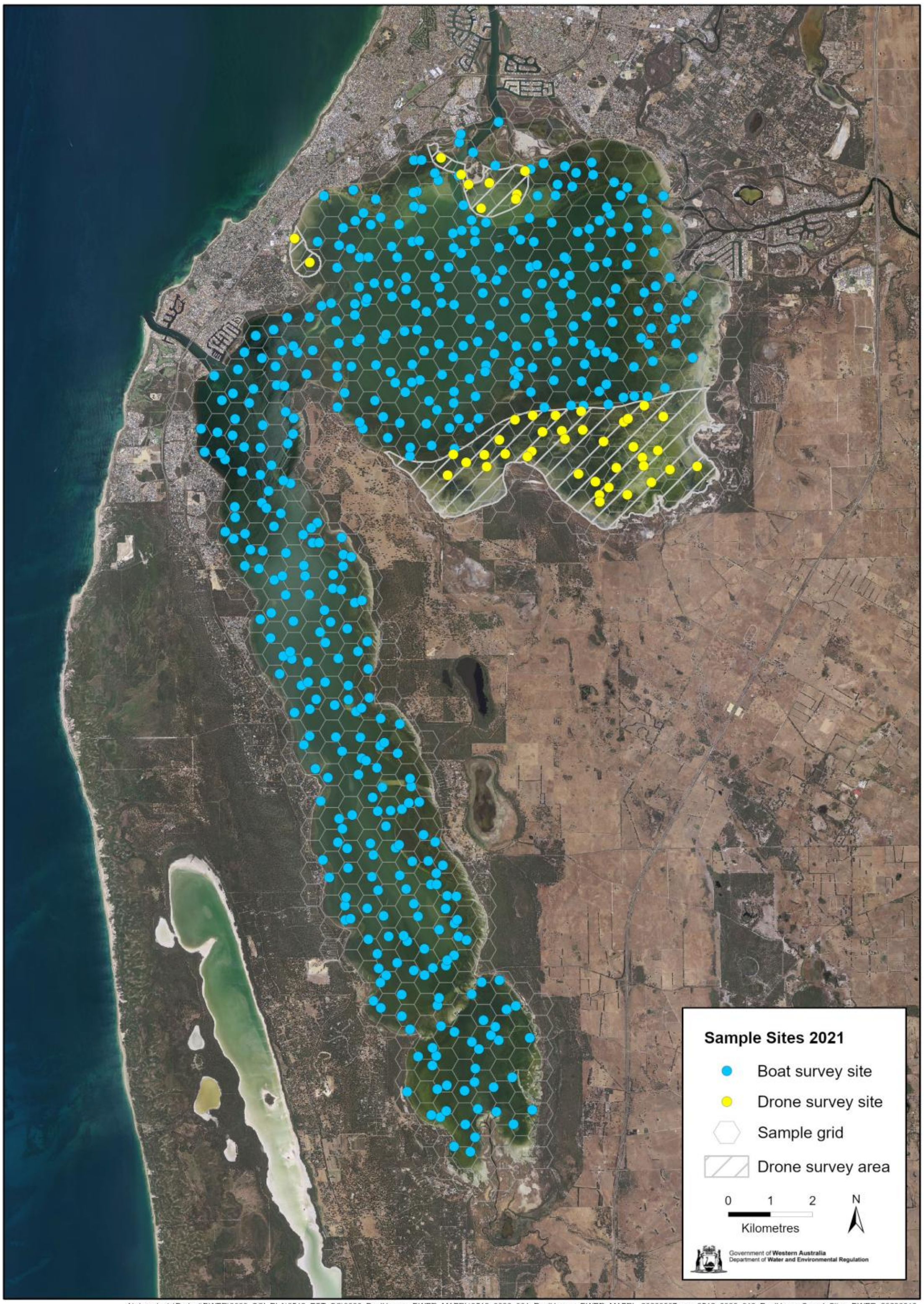


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Figure 2 Cover survey location of 496 sites viewed for cover and diversity of macrophytes in the Bindjareb Djilba (Peel-Harvey estuary).

2.2 Biomass method

The **biomass method** involved collecting cores of seagrass and macroalgae in the field using stratified sampling as described in Pedretti et al. (2011). The stratified sampling method is designed to make allowances for the unequal distribution of different phenomena – in this case macrophytes (Longley et al. 2005).

The MAFRL team collected cores for biomass assessment at 51 sites (Figure 3; with locations in Table C 1). These biomass sites have an historic basis – originally they were chosen to represent habitats present before the Cut was opened to the sea. It is worth noting that with the post-Cut changes in salinity and hydrology, the habitats are likely to have changed but the sites have remained the same.

Stratified sampling meant that the number of biomass cores sampled at each site varied to capture the patchy cover and diversity over a larger area than would be possible with a single core. The team took up to five cores at each site depending on cover. To get a feel for typical cover and makeup at a site, snorkellers or divers were first towed on a manta line behind a boat, making several passes at each site. The length of pass varied depending on the site, from 100 m to 200 m, or more for the deeper sites where visibility was poorer from the surface. At the fixed transects along the Harvey Estuary, their full length was always traversed – usually a few hundred metres to the shoreline (see map in Figure C 1 and Table C 2 for locations). The actual number of cores taken varied with the estimated percentage cover of macrophytes at each site. Each core represented 20 per cent cover. So if, for example, there was 60 per cent cover, the team took three cores, and if there was 100 per cent cover, they took five. Regardless of the number of cores taken, the average biomass was always calculated by dividing by 5.

The cores were taken by pushing a 9 cm diameter Perspex cylinder (area = 63.63 cm^2) at least 10–15 cm into the seabed to capture above and below ground biomass. The cylinder was removed, and contents sieved (500 µm mesh) to remove the sediment. Samples were transferred into a labelled bag and placed on ice before being transported to the laboratory where they were frozen.

Other measurements taken but not presented in this report were physical profiles of temperature, specific conductivity, salinity, depth, pH, turbidity and dissolved oxygen, light availability as photosynthetically active radiation, maximum depth, Secchi depth and cloud cover.

The MAFRL team recorded epiphytes on seagrass and/or macroalgae as ‘none’, ‘low’, ‘medium’ or ‘high’ in the field.

In the laboratory, the team defrosted, sorted and identified the samples to species level in most cases. They measured the length of seagrass leaves of key species (*Ruppia megacarpa*, *Heterozostera/Zostera* sp.[3] and *Halophila ovalis*) to the nearest 10 cm to estimate canopy height (only the results for the dominant seagrass *R. megacarpa* are presented here). All samples were then dried to a constant weight at 70ºC before weighing. Dry weight was measured in grams to two decimal places and converted into grams per meter squared (g/m^2). Average biomass (n=5) at each site was used for spatial interpolation.

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Figure 3 Biomass survey location of 51 sites sampled for biomass and diversity of macrophytes in the Bindjareb Djilba (Peel-Harvey estuary) (MAFRL 2022).

Nutrients (total phosphorus, total kjeldahl nitrogen, percentage nitrogen, percentage carbon) and isotopes (delta^{15}N and delta^{13}C) were analysed from seagrass and macroalgae species from a subset of sites. These data are not presented here.

The department performed spatial mapping of the average seagrass and macroalgal biomass and the total biomass of seagrass or macroalgae in the estuary using ARCGIS® software. We interpolated the sampling points based on the inverse distance weighting (IDW) used in Pedretti et al. (2011) and as described in more detail in Appendix C — Biomass survey additional information. Biomass can vary greatly across the sample sites; hence we used a logarithmic scale to create four colour classes for the seagrass and five for the macroalgae maps. Use of the log 10 scale allowed for direct comparison of the two.

For this report we focused on interpolating biomass only in areas where seagrass or macroalgae were present. By excluding locations lacking seagrass or macroalgae, the maps that the biomass interpolation method generated were more comparable to those from the cover interpolation method (which follows a similar approach).

Estimating total biomass of seagrass and macroalgae for the estuary has been done since the monitoring program began in 1978 (Lavery et al. 1995). The authors at that time and subsequently (e.g. Pedretti et al. 2011; MAFRL 2022) noted the interpolation of biomass between 51 sites in such a large area was likely to lead to overestimates. Yet they also noted that use of the same sampling sites and methods over the decades had produced a consistent representation of trends in total biomass for the estuary. In years when more sites were added, the estimates would likely improve. They also stated that total biomass across the Bindjareb Djilba should be considered a relative, rather than absolute measure, and should not be compared with other south-west estuaries using the same biomass interpolation method, since the ratio of sites to estuary areas differs. For example, in Derbal Elaap (the Leschenault Inlet) 32 sites were sampled over an area of about 27 km^2 (Lukatelich 1989) compared with only 51 sites in the Bindjareb Djilba covering an area more than four times greater at 133 km^2.

For more details about the **biomass survey** method see Appendix C — Biomass survey additional information.

3 Seagrass comparison

This section compares results from the **cover survey** with those of the **biomass survey** for distribution of seagrass cover, biomass and community composition. It also compares canopy height and epiphyte density of the seagrass measured in the two surveys.

3.1 Spatial cover and biomass

We estimated the distribution of seagrass across the Peel-Harvey estuary by interpolating data collected using the two methods discussed previously: cover (percentage) and biomass (dry weight g/m^2) (Figure 4). The two methods differed greatly as to their number of sites: cover was estimated at 457 *in situ* sites (Figure 2) and biomass at 51 historical sites (Figure 3). The interpolation excluded areas where cover was absent, or biomass was 0 g/m^2, by not including those sites in the processing extent. To make it easier to visually compare the resulting maps generated by the two types of interpolation, on both we have marked the sites with seagrass presence or absence.

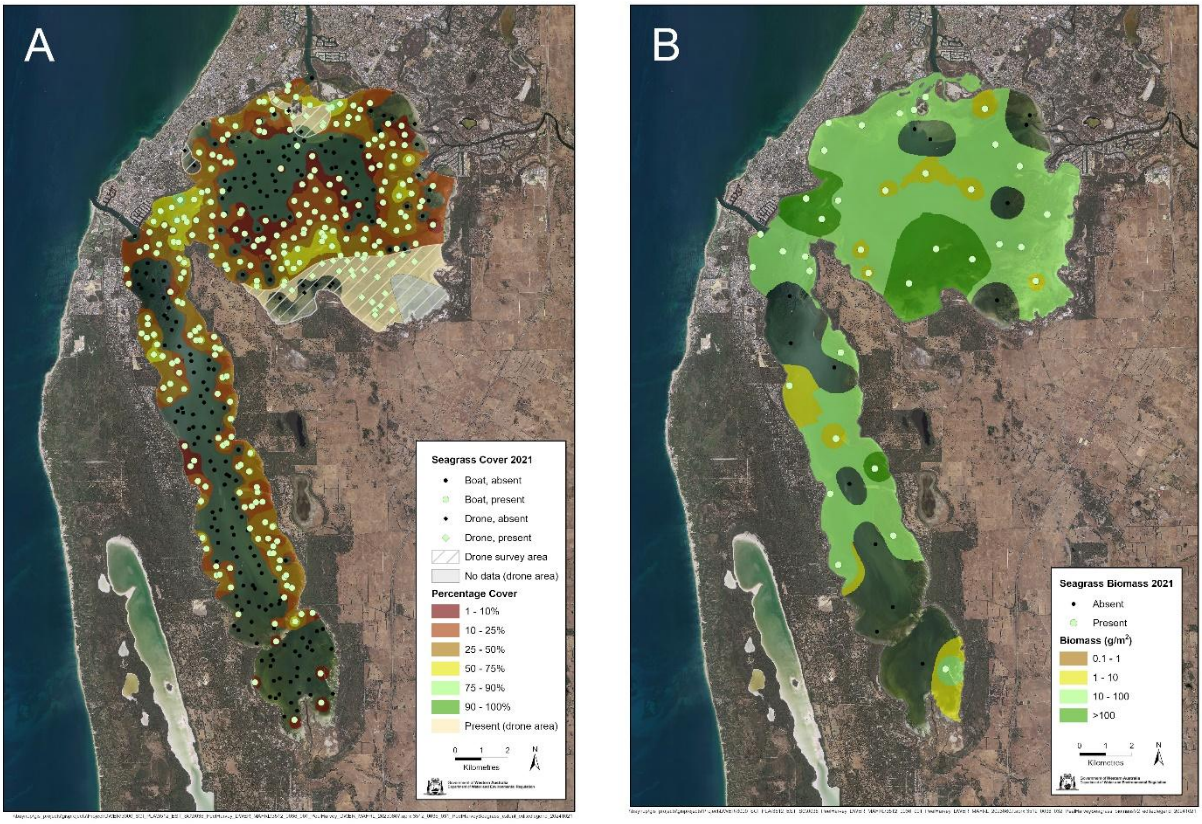

Figure 4 Interpolated seagrass distribution across the Bindjareb Djilba (Peel-Harvey estuary) showing A: cover survey (percentage); B: biomass survey (dry weight g/m^2).

The total area of seagrass, estimated by interpolating between observations made in the **cover survey**, was about 7,000 ha or about 55 per cent of the area of the estuary. This included the area estimated with drone imagery (Figure 4A).

The total biomass of seagrass, as calculated by interpolating among the sites in the **biomass survey**, was about 10,990 tonnes, with 83 per cent of it in the Peel Inlet and 17 per cent in the Harvey Estuary (Figure 4B).

We found the highest cover of seagrass in the shallow margins of the Peel Inlet, with 50–75 per cent cover near the Dawesville Cut, near the islands at the mouth of the Mandurah Channel in the north, near the mouth of the Serpentine and Murray rivers in the east, and around Robert Bay in the south (Figure 4A; and see Figure 1 for location). Seagrass was notably absent in parts of the Peel's western and eastern central basin.

In the Harvey Estuary, the percentage cover of seagrass was much lower, at 25–50 per cent, and concentrated in the shallow areas of the eastern and some parts of the western shores. Again, there was a noticeable absence of seagrass cover in the central channel, as well as the southern parts of the Harvey.

Areas of highest seagrass biomass (>100 g/m^2) (Figure 4B) generally coincided with the areas of highest seagrass cover in the Peel Inlet (Figure 4A). The situation was similar in the Harvey Estuary where areas of higher biomass occurred in areas with higher cover. Biomass of seagrass in the Harvey, however, was less than 100 g/m^2, except at one site on the central eastern shore.

Both survey methods showed seagrass was absent in the Harvey across a similar proportion of the total area. However, the distribution of this absence differed between surveys. In the **cover survey**, seagrass was consistently absent in the central channel, although it fringed the shallow margins. The **biomass survey** indicated that seagrass was more evenly spread across the central channel. Note the low number of sites examined by the **biomass method** for the area covered, as well as the logarithmic scale categories used to present the interpolation, influenced the latter result. On top of this, under the **biomass method**, tiny amounts of seagrass can be measured in the laboratory (e.g. as low as 0.01 g/m^2). These small amounts are more likely to be recorded as 'seagrass absent' under the **cover method** as they would be difficult to see under field viewing conditions.

3.2 Seagrass community composition

The **cover survey** identified four species[22] of seagrass and the **biomass survey** three species (Table 3). The three most common species were *Ruppia megacarpa*, *Halophila ovalis* and *Heterozostera/Zostera* sp.[23] (Figure 5).

Estuaries usually host smaller seagrass species known for their rapid turnover and ability to swiftly adapt to environmental shifts. This explains why *Ruppia* and *Halophila* species dominate most estuaries in south-west Western Australia – they can easily adjust to the dynamic conditions found within estuaries, including fluctuations in salinity across tidal and seasonal cycles. They are known as colonising species.

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[22] There was a possible observation near the Cut of *Amphibolis* sp. during the **cover survey**. However, this could not be verified because of poor weather conditions and wind and waves causing high sediment suspension. The survey team was unable to confirm if it was floating wrack or attached to the sea floor.

[23] The **cover survey** confirmed the presence of *Zostera muelleri* at one site and *Heterozostera polyclamys* at another site by sectioning stems of the two types and examining them under a microscope. The two species are difficult to tell apart without examining them at such a level of detail, as gross morphological features are not as distinct. It is therefore likely that *H. polyclamys* identified in the 2021 **biomass survey** includes some *Z. muelleri*. As such, in the remainder of this report, they will be referred to as *Heterozostera/Zostera* sp. because microscopic sections were not performed in the **biomass survey** and only two were performed in the **cover survey**.

Table 3 Presence (+) and absence (-) of each seagrass species in the Peel Inlet and Harvey Estuary (data from MAFRL 2022).

Magnoliophyta (seagrasses)	Cover survey		Biomass survey	
	Peel Inlet	Harvey Estuary	Peel Inlet	Harvey Estuary
Ruppia megacarpa	+	+	+	+
Halophila ovalis	+	+	+	+
Heterozostera sp./*Zostera* sp.	+	+	+	+
Posidonia australis	-	+	-	-

Figure 5 Peel Inlet. A. Mixed bed of *Halophila ovalis* with oval shaped leaves in the foreground and *Ruppia megacarpa* with long thin leaves in the background; B. *Heterozostera/Zostera* species.

The fourth species, *Posidonia australis,* was only found by the **cover survey** in the north-western part of the Harvey Estuary south of Stony Point (Figure 6; and see Figure 1 for locations). *Posidonia* species are known for their enduring distribution, slow regeneration, and slow adaptability to environmental shifts, making its presence in the Peel-Harvey estuary unusual. These seagrasses have long lifespans, require years to mature, and usually cannot withstand major salinity fluctuations – instead favouring stable marine environments. They are described as persistent species. Notably, two species of *Posidonia* (*P. australis* and *P. sinuosa*) thrive in Oyster Harbour. This south coast estuary close to the city of Albany, Western Australia, is a permanently open estuary and maintains a stable salinity akin to marine conditions.

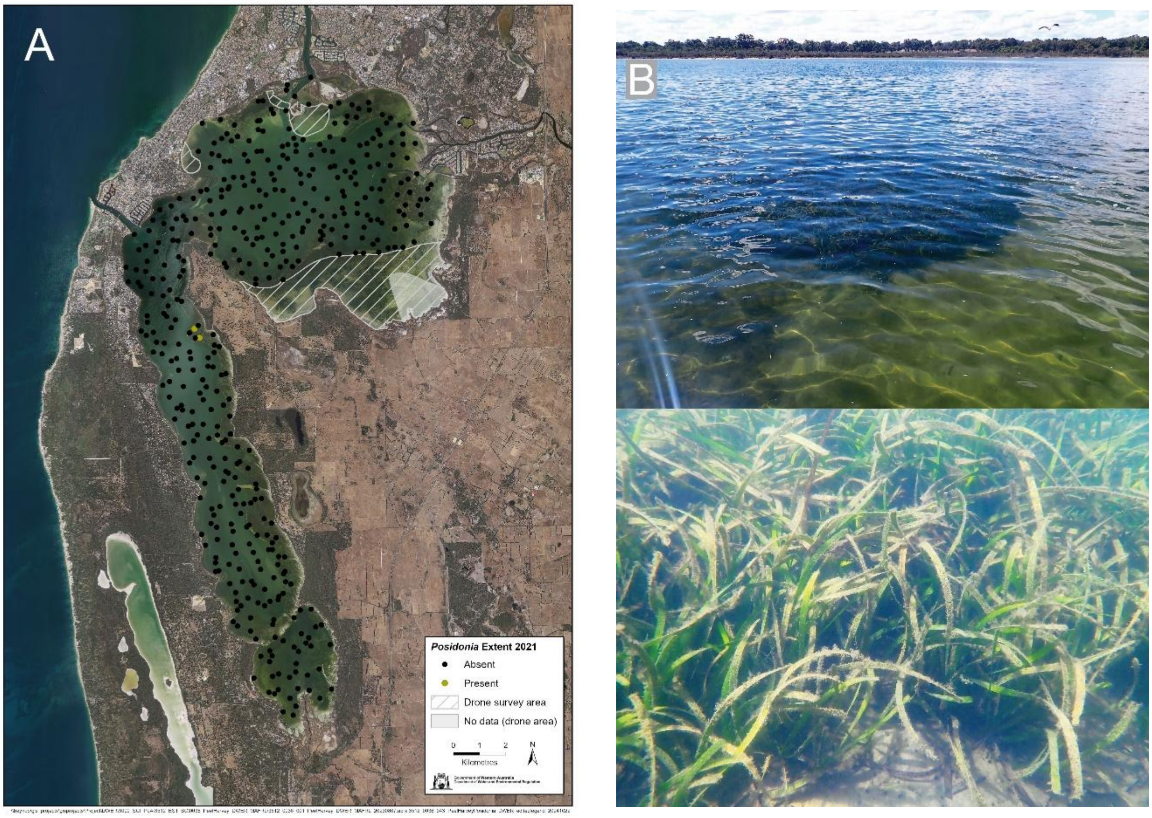

Figure 6 A. Location of *Posidonia australis* in the Bindjareb Djilba (Peel-Harvey estuary) and B. Images of *P. australis* in the Harvey Estuary (cover survey).

The most dominant species in both the **cover survey** and **biomass survey** was *Ruppia megacarpa* (Figure 7 A, B). In the **cover survey** this species was present throughout the Peel Inlet, except for an area in the slightly deeper central basin. In the Harvey Estuary, it was found along the eastern shoreline, as well as a few areas along the central western shoreline, but again was not present in the deeper central channel. Notably, some *R. megacarpa* was present in the shallow margins of the southern Harvey Estuary (Figure 7 A).

In the **biomass survey**, the distribution of *R. megacarpa* agreed with that of the **cover survey** (Figure 7 B.). Its absence from deeper sites, which were still only about 2 m in depth, suggests that light may be adequate but other factors such as sediment health may be more important. *R. megacarpa* was also absent from sites dominated by the green macroalga *Chaetomorpha linum* (MAFRL 2022, Figure 14), which may indicate some competition for light as *C. linum* floats above the sediment.

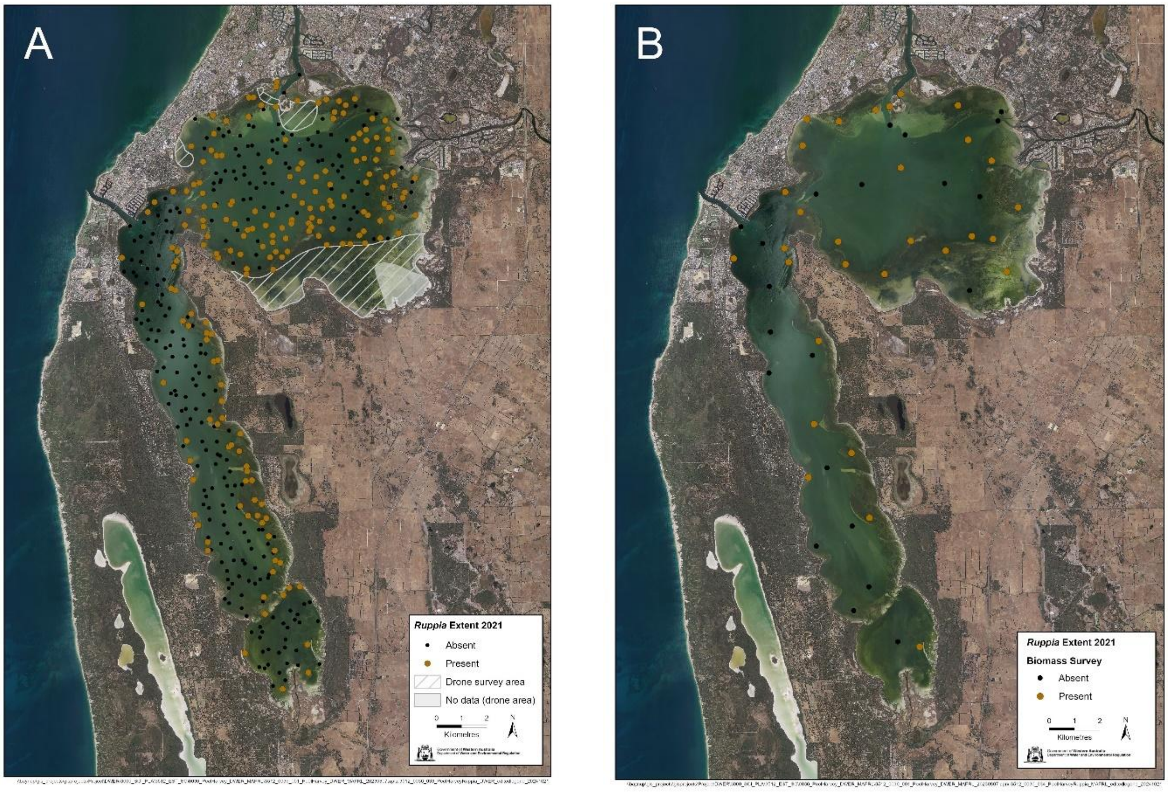

Figure 7 Presence/absence of the dominant seagrass *Ruppia megacarpa* across the Bindjareb Djilba (Peel-Harvey estuary): A. cover survey, B. biomass survey.

The **cover survey** found distribution of *Halophila ovalis* was restricted to beds in the northern Peel, around the Dawesville Channel, and in a large area of the eastern Peel (Figure 8). In the Harvey Estuary, the distribution of *H. ovalis* was like that of *R. megacarpa* along both shorelines, however unlike *R. megacarpa*, it was not present in the southern Harvey.

The **biomass survey** found *H. ovalis* in similar areas to the **cover survey**, except along the eastern shoreline of the Harvey Estuary. This is likely due to the small number of sites in this area. *Halophila ovalis* had the second greatest cover of the three main species and the third greatest biomass.

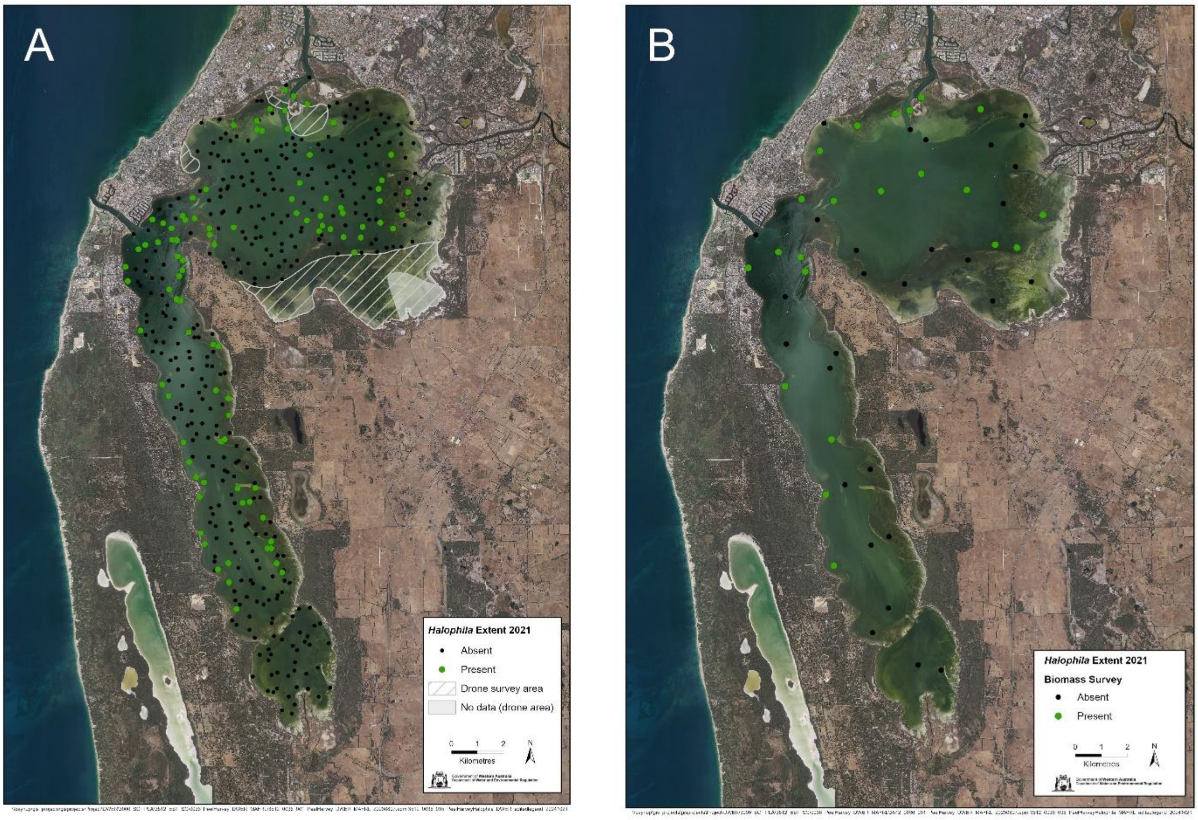

Figure 8 Presence/absence of *Halophila ovalis* across the Bindjareb Djilba (Peel-Harvey estuary): A. cover survey, B. biomass survey.

The third most dominant seagrass, by cover, was *Heterozostera/Zostera* sp., found mostly around the Dawesville Channel where salinities are more marine (Figure 9). It was also found along the eastern shore of the Peel Inlet and near the islands at the mouth of the Mandurah Channel. Distribution of *Heterozostera/Zostera* sp. was similar in the **biomass survey**, except in the Harvey Estuary where it was recorded at only one site on the western shoreline, midway along its length.

The discrepancy in the distribution of biomass in the Harvey Estuary may be because some seagrass beds may be quite small. For example, three **cover survey** sites within about 500 m of the **biomass survey** site with *Heterozostera/Zostera* sp., did not record any of this species. This finding highlights the variation in size of the seagrass beds and the large area that needs to be covered to find all instances of a species given the area examined is quite small compared with the size of the system.

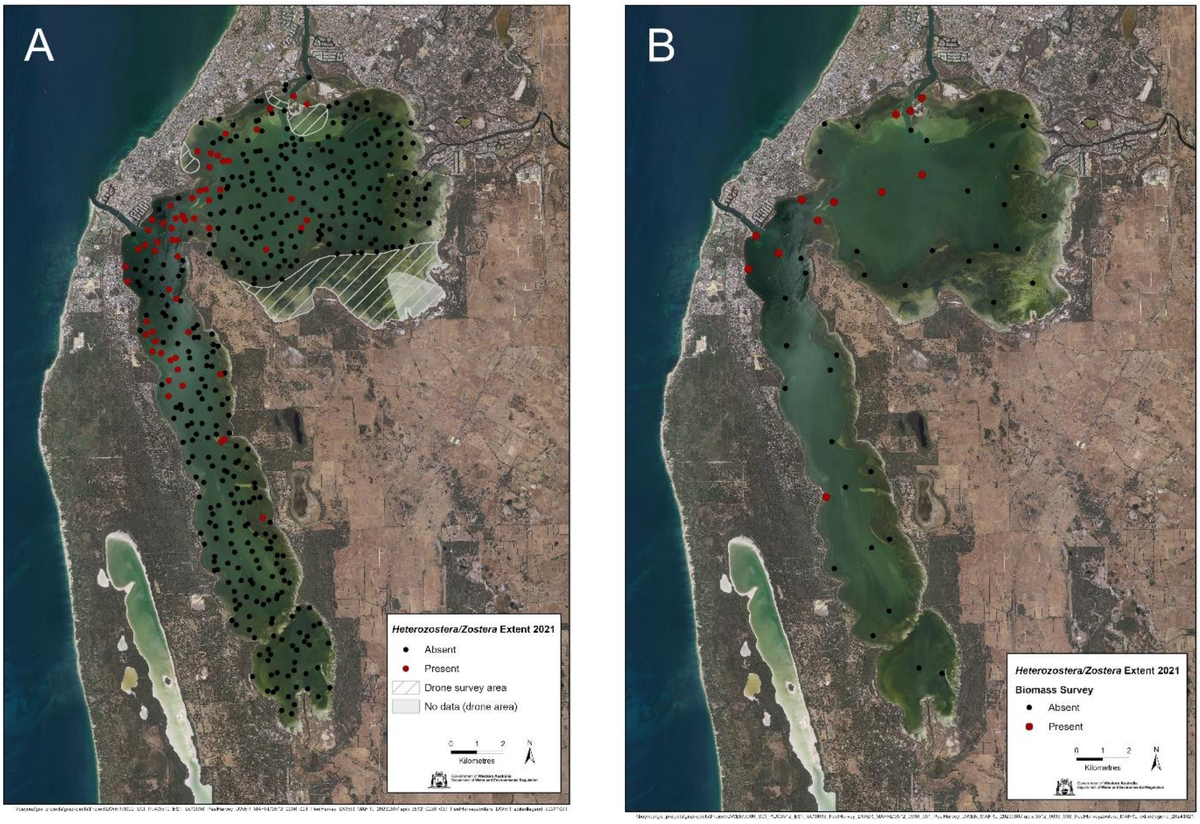

Figure 9 Presence/absence of *Heterozostera/Zostera* species across the Bindjareb Djilba (Peel-Harvey estuary): A. cover survey, B. biomass survey.

The presence in the Harvey Estuary of the least dominant seagrass species, *P australis,* identified by the **cover survey**, was verified during the **biomass survey** a few weeks later (although not measured because the species was not found at one of the pre-determined 51 sites). The discovery of *P. australis* in the Peel-Harvey estuary for the first time since the macrophyte surveys began in 1978 is a significant find. It suggests a change to a more stable salinity and better light conditions in the northern Harvey Estuary are supporting growth of this typically marine species. This is consistent with findings that since the Cut was built, salinities have become more stable and chlorophyll *a* concentrations are lower (Valesini et al. 2019). Lower chlorophyll *a* concentrations are associated with lower light attenuation and thus higher light levels reaching the seabed in both the Harvey Estuary and the Peel Inlet.

To assess the consistency of seagrass detection between the two methods, we compared the surveys based on the percentage of sites where the three main seagrass species were recorded. The **biomass survey** consistently detected a higher proportion of these species compared with the **cover survey**, whether considering only sites with seagrass or all sites (Figure 10 A and B). For sites with seagrass, the **biomass survey** detected 6 per cent more *R megacarpa*, 23 per cent more *H. ovalis*, and 8 per cent more *Heterozostera/Zostera* sp. (Figure 10 A). When considering all sites, the **biomass survey** detected even more of each species, particularly of *R. megacarpa* (17 per cent more) and *Heterozostera/Zostera* sp. (10 per cent more), with the same increase for *H. ovalis* (23 per cent more) (Figure 10 B).

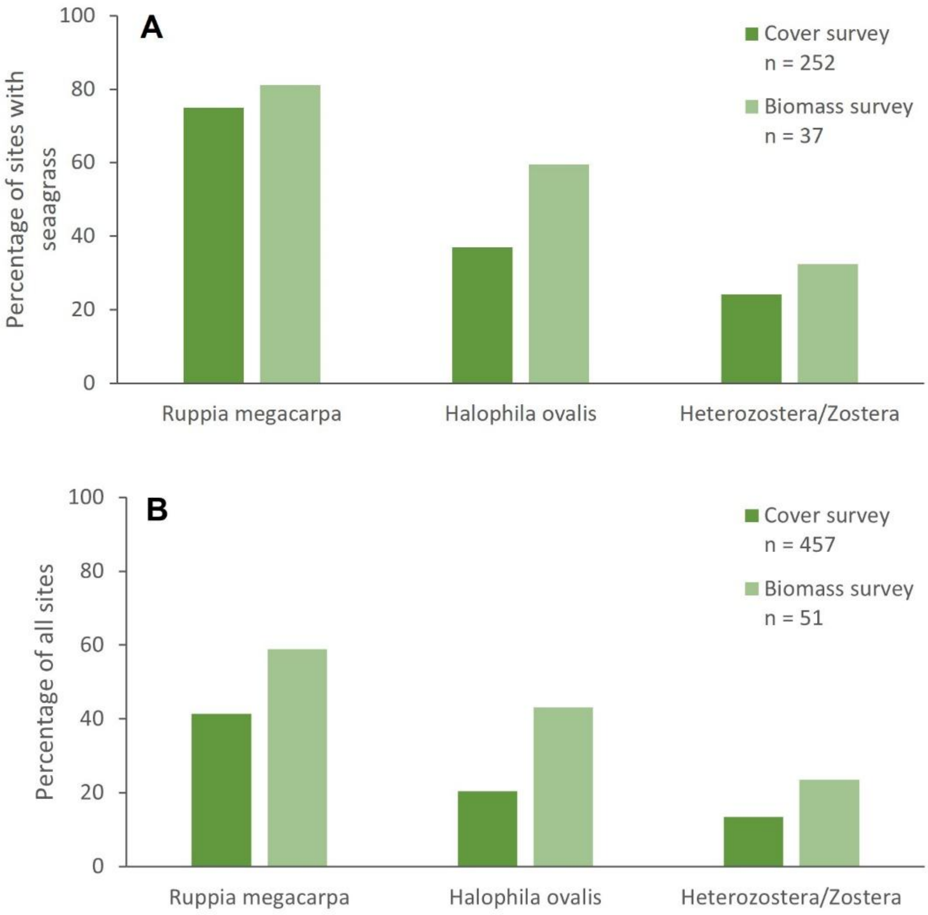

Figure 10 Comparison of seagrass identification by survey method: A. as a proportion of sites with seagrass; B. as a proportion of all sites. *Note:* Total of all three species may be greater than 100 per cent as there are often multiple species present at each site.

The lower detection of the different species in the **cover survey** may have been due to macroalgae obscuring seagrass at some of the sites when viewed with a viewing cone or camera. The same could occur with taller species of seagrass, such as *R megacarpa* obscuring shorter species like *H ovalis* or *Heterozostera/Zostera* sp. In addition, poor water clarity may also reduce detection of small or low-density species. These considerations are absent in the **biomass survey**, since every species is separated and identified from the core samples taken to the laboratory.

3.3 Canopy height of *Ruppia megacarpa*

Canopy height (length of seagrass leaves) when combined with percentage cover can provide a surrogate for biomass. It can also provide a measure of the structural role that seagrass plays in an ecosystem in terms of the habitat and refuge they offer to animals.

On average, the canopy height of *Ruppia megacarpa* estimated *in situ* during the **cover survey** was ~30 cm (n=188), ranging in height from 10 cm to 80 cm (Figure 11 A).

This was consistent with the laboratory measures of canopy height as part of the **biomass survey**, where the average was also 30 cm (n=27), but with a smaller range of 10 cm to 50 cm (Figure 11 B).

The difference in the range between the two surveys is likely due to factors such as variation in field versus laboratory conditions for assessing height, and the potential for errors in the field as the canopy height and depth increases. Another influence may be the vastly different number of sites visited in the **cover survey** compared with the **biomass survey**. Tall stands of *R megacarpa* may also have been missed in the **biomass survey**.

In general, in the **cover survey** the canopy height of *R. megacarpa* in the Peel Inlet was taller than that of the Harvey Estuary (Figure 11 A). This **biomass survey** had a similar finding (Figure 11 B). Taller plants were also observed along the margins of the Peel Inlet compared with the central basin during the **cover survey**.

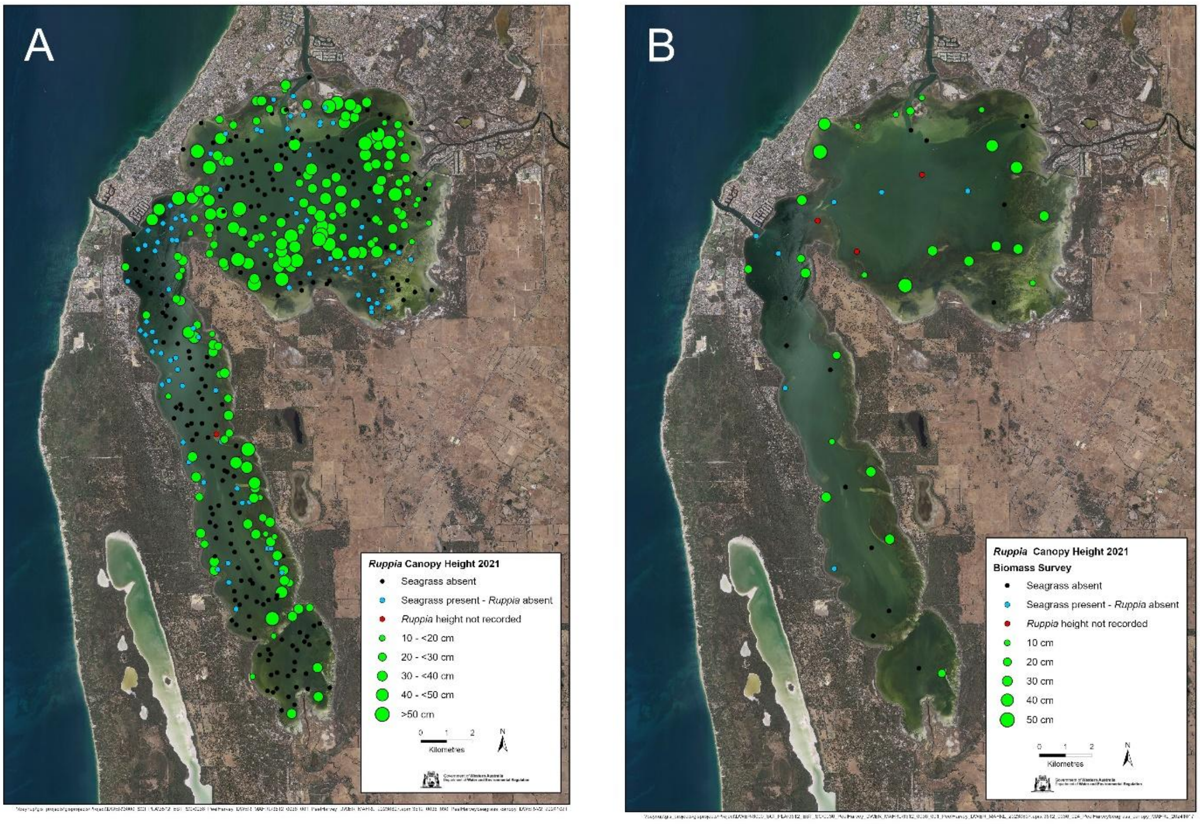

Figure 11 Canopy height of *Ruppia megacarpa* in the Bindjareb Djilba (Peel-Harvey estuary) as measured during A. cover survey and B. biomass survey.

3.4 Epiphyte density on seagrass

Epiphytes are organisms that grow on the surface of seagrass. They can reduce light availability and negatively affect seagrass growth. Data on the presence and density of epiphytes on seagrass leaves can be used to indicate areas under more stress; for example, high-density epiphyte areas can indicate excess nutrient inputs nearby.

The **cover survey** assessed 252 sites containing seagrass for epiphyte density (Figure 12 A). Of these sites, 16 per cent had no epiphytes, 24 per cent had low cover, 29 per cent had medium cover and 32 per cent had high cover (Table 4). The **biomass survey** assessed 37 sites and the results were similar: 14 per cent of the sites had no epiphytes, 27 per cent had low cover, 22 per cent had medium cover and 41 per cent had high cover (Figure 12 B; Table 4).

Higher epiphyte cover was recorded around the margins of both basins and near the Dawesville Channel in the western Peel Inlet – this was more noticeable in the **cover survey** where more sites were assessed (Figure 12 A). Better light conditions in the shallow margins of the basins are likely to have at least partially contributed to the higher epiphyte cover.

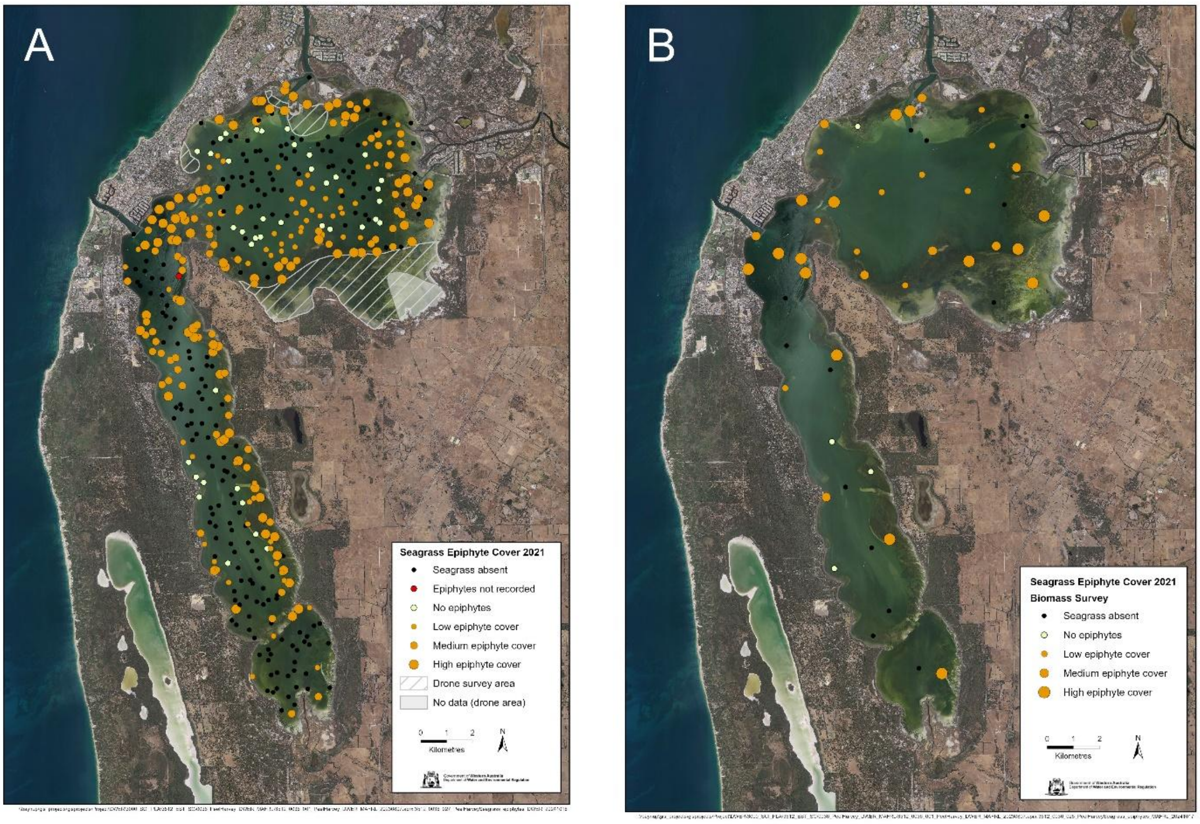

Figure 12 Epiphyte cover at sites in the Bindjareb Djilba (Peel-Harvey estuary) as measured during A. cover survey and B. biomass survey.

Table 4 Proportion of sites with different epiphyte cover on seagrass in the Bindjareb Djilba (Peel-Harvey estuary).

	Cover survey		Biomass survey	
	% of sites	No. of sites	% of sites	No. of sites
Epiphyte cover				
None	15	39	11	4
Low	24	60	27	10
Medium	29	72	22	8
High	32	80	41	15
Total number of sites with seagrass		**252**[24]		**37**

[24] One site with seagrass was not assessed for epiphyte cover.

4 Macroalgae comparison

This section compares results from the **cover survey** with those of the **biomass survey** for distribution of macroalgal cover, biomass and community composition.

4.1 Spatial cover and biomass

We estimated the distribution of macroalgae across the Peel-Harvey by interpolating data collected using the two methods discussed previously: cover (percentage) and biomass (dry weight g/m^2) (Figure 13). As for seagrass, the two methods differed greatly as to their number of sites: macroalgal cover was estimated at 457 *in situ* sites (Figure 2) and biomass at 51 historical sites (Figure 3). The interpolation excluded areas where cover of macroalgae was absent, or where biomass was 0 g/m^2, by removing them from the processing extent. To make it easier to visually compare the resulting maps generated by the two types of interpolation, on both we have marked the sites with macroalgae presence or absence.

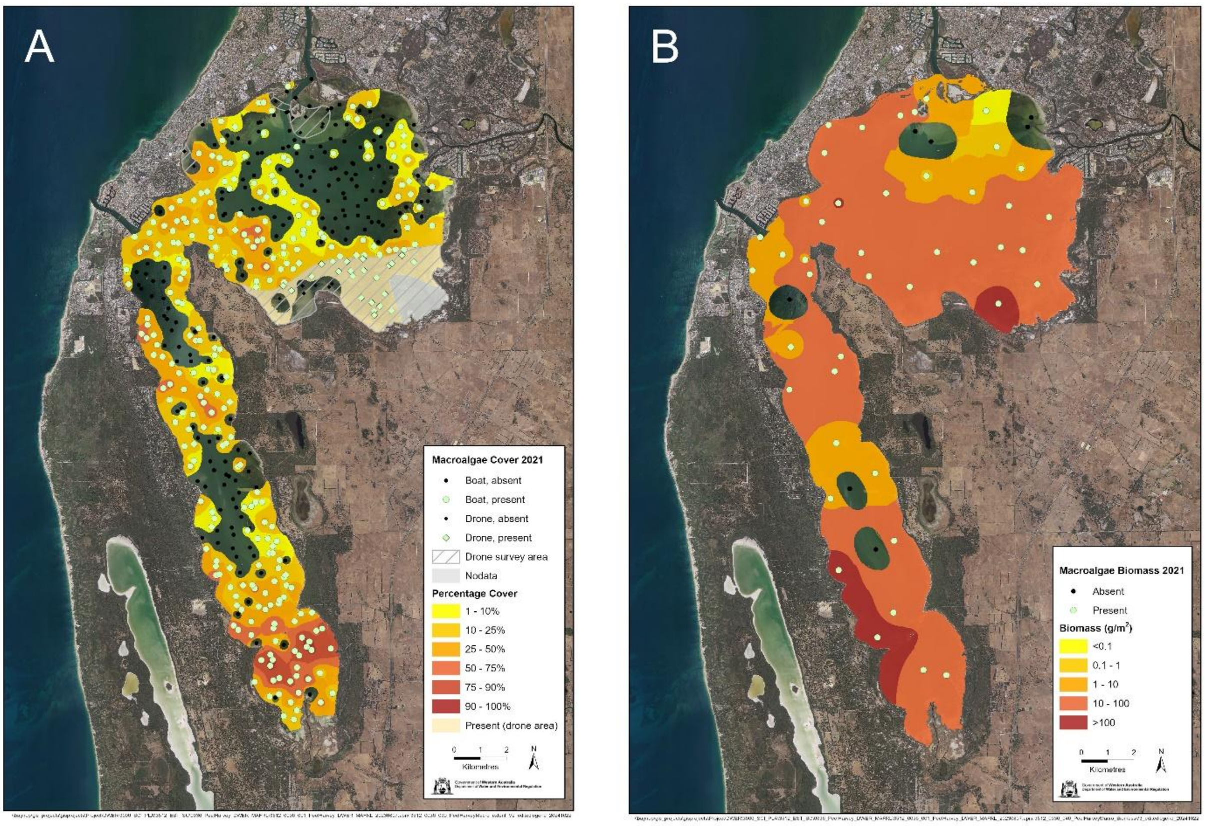

Figure 13 Interpolated macroalgae distribution with site presence and absence across the Bindjareb Djilba (Peel-Harvey estuary): A. cover survey, B. biomass survey (dry weight g/m^2).

The total area of macroalgae, estimated by interpolating between observations made in the **cover survey**, was about 8,000 ha or about 58 per cent of the estuary. This included the area estimated with drone imagery (Figure 13A).

The total macroalgal biomass, as calculated by interpolating among the sites in the **biomass survey**, was about 3,970 tonnes, with 57 per cent of it in the Peel Inlet and 43 per cent in the Harvey Estuary (Figure 13B).

In the **cover survey**, macroalgae were present in the southern Peel Inlet and around most of its margins. Macroalgae were notably absent in extensive areas of the western and eastern central basin, as well as in the northern Peel near the Sticks Channel and Creery Islands (see Figure 13A and Figure 1 for locations). Interestingly, seagrass was also absent in most of these areas. As with the seagrass observations, cover was typically below 50 per cent, with a few localised areas of higher cover (50–75 per cent) in the south-western and western Peel.

In the Harvey Estuary, macroalgal cover was observed along most of the waterbody's margins, except for a small area on the mid-eastern shoreline (Figure 13A). Cover in the southern Harvey was very high – 70 per cent of observations recorded more than 50 per cent cover, with about 44 per cent in the 90–100 per cent cover range. This high density of macroalgae coincided with the absence of seagrass in the southern Harvey. But other areas without macroalgae were also lacking seagrass, particularly in a large part of the central channel of the Harvey.

In the **biomass survey**, macroalgae were present in most of the Peel Inlet in moderate amounts (10–100 g/m^2), with lower to no biomass recorded in the northern Peel (Figure 13B). These lower biomass areas corresponded with areas where macroalgae were recorded as absent in the **cover survey**. However, in the central Peel macroalgae appear present with a higher biomass than expected from the **cover survey** map, where it is noted as absent in large parts. This may be due to drift algae moving between surveys. However, as described previously, it may also be due to a combination of the low number of sites sampled in the **biomass survey**, the logarithmic scale used for the colour categories, and the fine scale at which macroalgae are measured in the laboratory. In addition, the *in situ* visual observations of the **cover method** may be more difficult with boat movement subject to wind and currents and variable depth and water clarity. In contrast, the **biomass method**'s cores are processed in the laboratory, where visibility remains unaffected by external conditions.

Furthermore, in the field the **cover survey** could easily miss or describe as 'other browns' any small or cryptic macroalgae species such as *Feldmannia* sp. (previously named *Hincksia* sp.), yet the **biomass survey** could easily identify these in the laboratory from the cores collected. Similarly, given the challenge of field conditions for visual observation during a **cover survey**, macroalgae are more likely to be noted as absent even when they are present in low abundance, compared with the **biomass survey**.

4.2 Macroalgae community composition

In the **biomass survey** macrophytes were identified to species level in the laboratory, while the **cover survey** identified them mostly to genus level[25]. Consequently, only genus names are presented below to compare the taxa identified by both surveys (Table 5). Table D 1 contains the full species-level list from the **biomass survey**.

[25] For some species of macroalgae, identification is only possible in a laboratory with access to a microscope, and this level of identification is impractical in the field.

Table 5 Presence (+) and absence (-) of each macroalgae genus in the Peel Inlet and Harvey Estuary (data from MAFRL 2022).

Phylum	Cover survey		Biomass survey	
	Peel Inlet	Harvey Estuary	Peel Inlet	Harvey Estuary
Chlorophyta (green algae)				
Chaetomorpha sp.	+	+	+	+
Willeella sp. (formerly *Cladophora)*	+	+	+	+
Ulva sp.	-	+	-	+
Caulerpa sp.	+	+	+	+
Acetabularia sp.	+	-	+	-
Rhizoclonium sp.	-	+	-	-
Other greens	+	-	-	-
Rhodophyta (red algae)				
Gracilaria sp.	+	-	+	+
Acanthophora sp.	+	+	+	+
Chondria sp.	-	-	+	-
Laurencia sp.	+	+	+	+
Spyridia sp.	-	-	+	+
Lophocladia sp.	-	-	+	-
Hypnea sp.	-	-	+	-
Centroceras sp.	-	-	+	+
Crouania sp.	-	-	+	-
Polysiphonia sp.	-	-	+	+
Jania sp.	+	-	+	+
Other reds	+	+	+	-
Phaeophyta (brown algae)				
Dictyota sp.	+	+	+	+
Feldmannia sp. (formerly *Hincksia)*	-	-	+	+
Sirophysalis sp.	+	+	+	-
Sphacelaria sp.	-	-	+	-
Hormophysa sp.	-	-	+	-
Other browns	+	+	-	-
Charophyta (stonewarts)				
Lamprothamnion sp.	-	-	+	-
Cyanobacteria (blue-green algae)				
Calothrix sp.	-	-	+	+
Unidentified				
Epiphytic species	+	+		
Other[26]	+	+		

Collectively the surveys identified five phyla or groups of macrophytes: Chlorophyta (green algae), Rhodophyta (red algae), Phaeophyta (brown algae), Charophyta (stonewarts) and Cyanobacteria

[26] 'Other' from the **cover survey** related to macroalgae observations that could not be categorised as red, green or brown.

(blue-green algae). Those the **cover survey** could not identify were classified as 'epiphytic' or 'other'.

There were 25 genera collectively identified: 12 of which the **biomass survey** could identify but the **cover survey** could not. Those 12 genera were the red algae *Chrondria*, *Spyridia*, *Lophocladia*, *Hypnea*, *Centroceras*, *Crouania* and *Polysiphonia*; the brown algae *Feldmannia* (formerly *Hincksia*), *Sphacelaria* and *Hormophysa*; the stonewart *Lamprothamnion*; and the blue green alga *Calothrix*. These are likely to have been recorded in the **cover survey** as other reds, other browns, unidentified epiphytes and other.

The **cover survey** was able to identify only one genus of macroalgae that the **biomass survey** could not – the green alga *Rhizoclonium* sp. In the **cover survey**, it was present at eight sites in the mid-western margin of the Harvey Estuary, with the nearest **biomass survey** sites being 30, 1, Ha1 and 31 (see Figure 3 for locations). The eight **cover survey** sites were at least 600 m away from the nearest **biomass** sites, except for one which was 13 m away from **biomass** site 30. The sites 13 m apart had low per cent cover and low biomass. And with stratified sampling identifying 20 per cent cover at this site in the **biomass survey**, only one core was collected. This is probably why it was not found at **biomass** site 30. However*, Rhizoclonium* sp. was previously identified in **biomass surveys** conducted in 2009, 2017 and 2018.

Note that only two genera were represented by more than one species in the **biomass survey**: *Acetabularia* and *Caulerpa*. The species were *Acetabularia caliculus*, *Acetabularia peniculus*, *Caulerpa taxifolia* var. *distichophylla* and *Caulerpa cylindracea*.

The dominant macroalga observed during the **cover survey** in the Peel-Harvey estuary was the green alga *Chaetomorpha* sp. (Figure 14A). About 42 per cent of the macroalgae observations included a recording of *Chaetomorpha* sp. (either as the dominant species or a secondary macroalgae species). It was present over most of the lower Harvey Estuary and along the Peel Inlet's western, eastern and south-eastern margins and parts of the central basin.

The **biomass survey** showed a similar distribution in the Harvey and in the southern and eastern Peel, but with a lack of sites, *Chaetomorpha linum* was described as absent from the north-western and north-eastern basin (Figure 14B).

In 2021, in terms of total macrophyte biomass, the dominant macroalgae after *C. linum* were the red macroalgae *Jania pedunculata* and *Spyridia filamentosa* (MAFRL 2022).

The brown alga *Feldmannia* sp., which occurs with low biomass, is a common epiphyte on seagrass and macroalgae (reported as *Hincksia* sp. in Lavery et al. 1995). *Feldmannia* sp. may reduce light availability to these macrophytes and is likely the same epiphyte that was commonly seen in the **cover survey**.

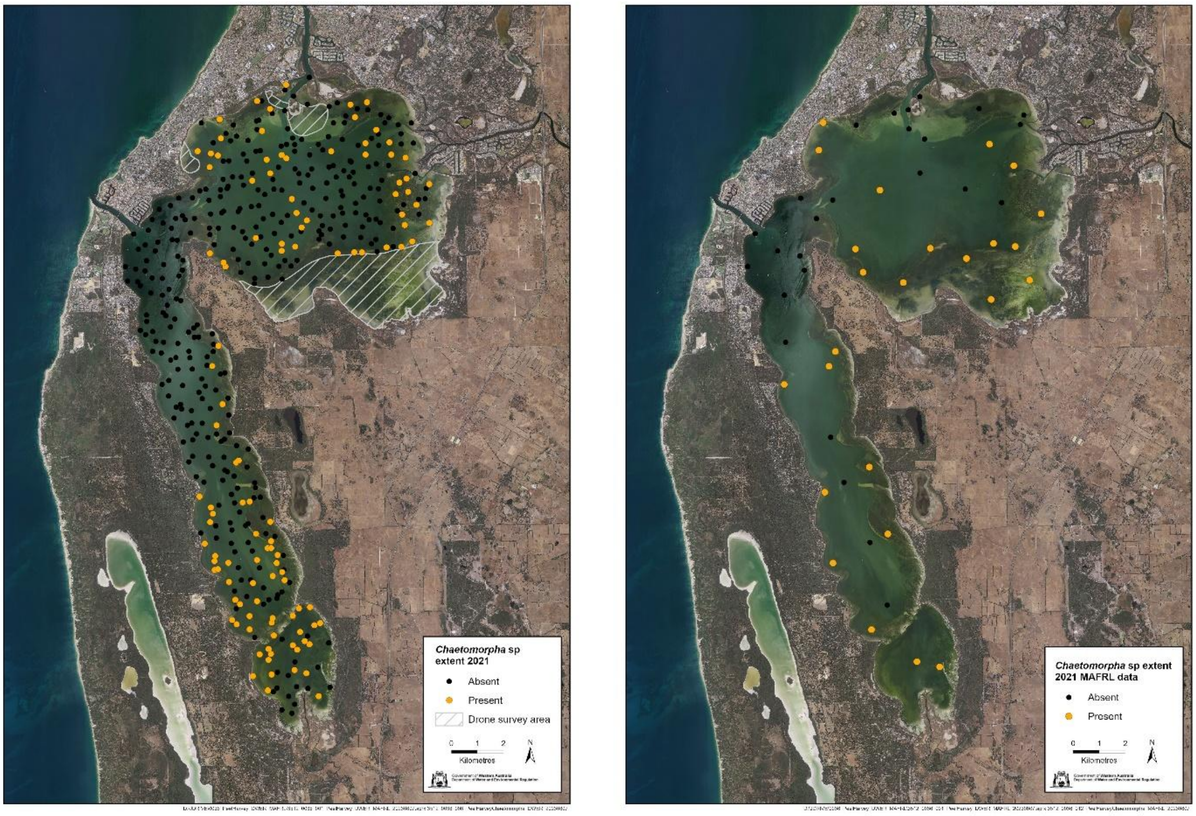

Figure 14 Presence/absence of the dominant macroalga *Chaetomorpha* sp. across the Bindjareb Djilba (Peel-Harvey estuary): A. cover survey, B. biomass survey.

5 Is there a relationship between cover and biomass data?

We investigated the relationships between cover and biomass of seagrass and macroalgae through fitting linear regression models. Both the department (DWER) and MAFRL assessed cover during their respective surveys. Only MAFRL measured biomass. Consequently, in this section, we introduce the terms DWER cover, MAFRL cover and MAFRL biomass to distinguish between the different types of data. For this analysis our objective was to verify whether the percentage cover sampled by DWER could be a proxy for the biomass sampled, or cover estimated by MAFRL. MAFRL cover was determined as part of stratified sampling for the **biomass survey** to determine how many cores to take, not as a measure of distribution. It was estimated by snorkellers or divers towed on a manta line behind a boat (for further details, see Section 2.2). It did not distinguish between the cover of seagrass and macroalgae as the DWER cover did, instead it was an estimate of cover of macrophytes (seagrass and macroalgae combined). We have used this data in one set of the comparisons described below.

We made three sets of comparisons with different variables. The first two sets were of biomass and cover, with seagrass and macroalgae data considered separately:

1. between MAFRL biomass and DWER cover using spatially interpolated data
2. between MAFRL biomass and DWER cover using actual data recorded at sites

The third set was of cover only from each survey, with seagrass and/or macroalgae data:

3. between MAFRL cover (seagrass/macroalgae combined) and DWER cover (seagrass and/or macroalgae) with actual data recorded at sites.

To perform these comparisons, we converted DWER percentage cover class to the mid-point class value, allowing this categorical variable to be considered as ordinal-type data. In this way, it could be treated as numeric, and a linear regression model could be fitted to the data (see Table B 1 for data conversion). When violation of the linear regression model assumptions occurred, even after data transformation, we used another test that was more suited to non-linearly related data – Spearman's rank correlation coefficient. This tests whether two datasets correlate monotonically; that is, one variable varies with the other, but not linearly. Note we did not attempt to determine the equation (e.g. quadratic equation) to describe the correlation.

As described earlier, MAFRL biomass data was collected at 51 sites, whereas DWER percentage cover was derived from 457 sites across the Peel-Harvey estuary. Although the department's survey team tried to take samples at the MAFRL site locations, field conditions made this difficult. This meant that only five sites from each survey were within less than 5 m of each other, while 34 sites were within 50 m of each other. To maximise data pairing between MAFRL and DWER, for the first set of comparisons we extracted derived MAFRL biomass data from the spatially interpolated maps. For the second and third sets of comparisons, we chose DWER sites within 50 m of MAFRL sites, assuming that within this distance, samples would likely come from the same meadow. This resulted in 34 sites available for comparison.

5.1 Statistical methods

We used a linear regression model to check the correlation between the two sets of data and the shape of the relationship between them. When the evaluation plots of the fitted model violated the linear regression assumptions, the Spearman's rank correlation coefficient was calculated. Significance was set at $p < 0.05$ and we reported the adjusted r squared (r^2 adj) of the linear regression model and, where appropriate, the correlation coefficient (rho) of the Spearman's rank correlation coefficient.

The three sets of comparisons, resulting in eight tests, are listed below with the number of sites compared in brackets, where SG stands for seagrass and MA for macroalgae:

1. Using the interpolated MAFRL biomass maps and DWER cover
    a. MAFRL biomass SG (derived) vs DWER cover SG (n = 457)
    b. MAFRL biomass MA (derived) vs DWER cover MA (n = 456)[27],
2. Using a subset of MAFRL sites that were within 50 m of a DWER site (n = 34)
    a. MAFRL biomass SG vs DWER cover SG
    b. MAFRL biomass MA vs DWER cover MA
3. Using a subset of MAFRL sites that were within 50 m of a DWER site (n = 34)
    a. MAFRL cover SG+MA vs DWER cover SG
    b. MAFRL cover SG+MA vs DWER cover MA
    c. MAFRL cover SG+MA vs DWER cover SG/MA – whichever has highest cover

5.2 Results

See Table 6 for the results from the linear regression model for each set of comparisons. Six of the seven tests were significant (shaded). The non-significant linear relationship was also not significant on the Spearman's rank correlation test.

1. Using the interpolated MAFRL biomass maps
    a. MAFRL biomass SG (derived) vs DWER cover SG (n = 457)
    b. MAFRL biomass MA (derived) vs DWER cover MA (n = 456)[27]

There was a weak relationship between the MAFRL interpolated biomass of seagrass and the DWER cover of seagrass, with the model explaining only 17 per cent of the variation in data. It was even weaker for macroalgae, with only 15 per cent of the MAFRL interpolated biomass explained by the DWER cover.

2. Using a subset of MAFRL sites that were within 50 m of a DWER site (n = 34)
    a. MAFRL biomass SG vs DWER cover SG
    b. MAFRL biomass MA vs DWER cover MA

MAFRL biomass of seagrass was related to DWER cover of seagrass, with the fitted model explaining 42 per cent of the data, but in the case of macroalgae only 28 per cent of the variability in the biomass and cover data was explained.

[27] Macroalgal cover was not recorded at one site

Table 6 Statistical comparisons of biomass and cover data. Shaded cells show comparisons that were significant p<0.05.

	Comparison	N data points	Model / test applied: data transformation	Intercept and coefficient of model fitted	Significance	Correlation rho / r^2_{adj}
1a	MAFRL interpolated SG biomass (y) *vs* DWER SG cover (x)	457	Linear: log(y+1) and log(x+1)	intercept = 2.576 coefficient = 0.294	$p < 0.05$	$r^2_{adj} = 0.17$
1b	MAFRL interpolated MA biomass (y) *vs* DWER MA cover (x)	456	Linear: log(y+1) and log(x+1)	intercept = 2.452 coefficient = 0.291	$p < 0.05$	$r^2_{adj} = 0.15$
2a	MAFRL SG biomass (y) *vs* DWER SG cover (x)	34	Linear: log(y+1) and log(x+1)	intercept = 1.156 coefficient = 0.730	$p < 0.05$	$r^2_{adj} = 0.42$
2b	MAFRL MA biomass (y) *vs* DWER MA cover (x)	34	Linear: log(y+1) and log(x+1)	intercept = 1.434 coefficient = 0.618	$p < 0.05$	$r^2_{adj} = 0.28$
3a	MAFRL SG+MA cover (y) *vs* DWER SG cover (x)	34	Spearman: no data transformation. Linear not significant ($p = 0.06$)	n/a	$p = 0.13$	rho = 0.26
3b	MAFRL SG+MA cover (y) *vs* DWER MA cover (x)	34	Linear: log(y+1) and x	intercept = 0.140 coefficient = 0.030	$p < 0.05$	$r^2_{adj} = 0.48$
3c	MAFRL SG+MA cover (y) *vs* DWER SG/MA cover (which ever highest) (x)	34	Linear: log(y+1) and x	intercept = 0.613 coefficient = 0.034	$p < 0.05$	$r^2_{adj} = 0.45$

3. Using a subset of MAFRL sites that were within 50 m of a DWER site (n = 34)
    a. MAFRL cover SG+MA vs DWER cover SG
    b. MAFRL cover SG+MA vs DWER cover MA
    c. MAFRL cover SG+MA vs DWER cover SG/MA – whichever has highest cover

There was no significant relationship between the MAFRL cover of seagrass plus macroalgae and the DWER cover of seagrass. However, there was a moderate relationship between MAFRL cover of seagrass plus macroalgae with DWER cover of macroalgae, explaining 48 per cent of the variability in the data, and with DWER cover of seagrass/macroalgae (whichever was greatest), explaining 45 per cent of the variability (Table 6).

5.3 Can DWER cover data be used to predict MAFRL cover or biomass data?

The data revealed some moderate relationships; however, we advise against using DWER cover data to predict biomass because it only explains up to 42 per cent of the variability.

Furthermore, results indicated that using data derived from biomass spatial maps weakened existing relationships compared with using directly collected data. This is likely due to the limited number of biomass sampling sites (51) and the patchy distribution of seagrass and macroalgae.

Other factors which were not considered in this study may be more influential in predicting biomass or cover such as plant morphology, depth, light, nutrients and sediment characteristics. For instance, with respect to plant morphology, the dominant seagrass *Ruppia megacarpa* has an upright growth form, so a tall plant might have high biomass but cover the same area as a shorter plant with lower biomass. The same tall seagrass species might also obscure smaller species underneath when assessing cover. Similarly, some macroalgae which form floating mats may obscure seagrass or other macroalgae underneath. The **cover method** does not include moving the seagrass fronds or macroalgae mats aside to check what is underneath. Meanwhile, the **biomass method** can account for these morphological differences because in the laboratory it is possible to separate individual species to weigh them.

All the factors mentioned above suggest that sampling was simply not designed for this statistical investigation. Ideally, a viewing cone assessment or underwater camera observation of cover should have been followed immediately by a core of biomass at the same location for a subset of sites.

6 Historical changes in seagrass and macroalgae

The dominant seagrass and macroalgae observed during the historical biomass surveys are summarised in Section 1.3. This section focuses on how total biomass of seagrass and macroalgae has changed since construction of the Dawesville Cut, examining shifts in biomass across the Peel Inlet and the Harvey Estuary. It also explores temporal changes in the abundance and composition of seagrass and macroalgae, and discusses their relationship to ocean connectivity, hydrology, light availability, and other environmental changes within the system.

6.1 Temporal changes in total biomass

In the first six years after the Dawesville Cut was built, researchers conducted surveys at least once a year to monitor how the productivity (in terms of biomass), distribution and diversity of macrophytes responded to the change in water movement and salinity. See Figure 15 for the biomass of seagrass and macroalgae (macrophytes) in summer/autumn from 1995 to 2021.

The total biomass of macrophytes in the Peel-Harvey estuary has increased significantly since the early post-Cut period. Almost 15,000 tonnes were present in the summer/autumn period of 2018 and 2021 (Figure 15). This is very similar to macrophyte biomass estimates made in summer/autumn before the Cut (Lavery et al. 1995). However, the most important change in the recent surveys is the dominance of seagrass as opposed to nuisance green macroalgae.

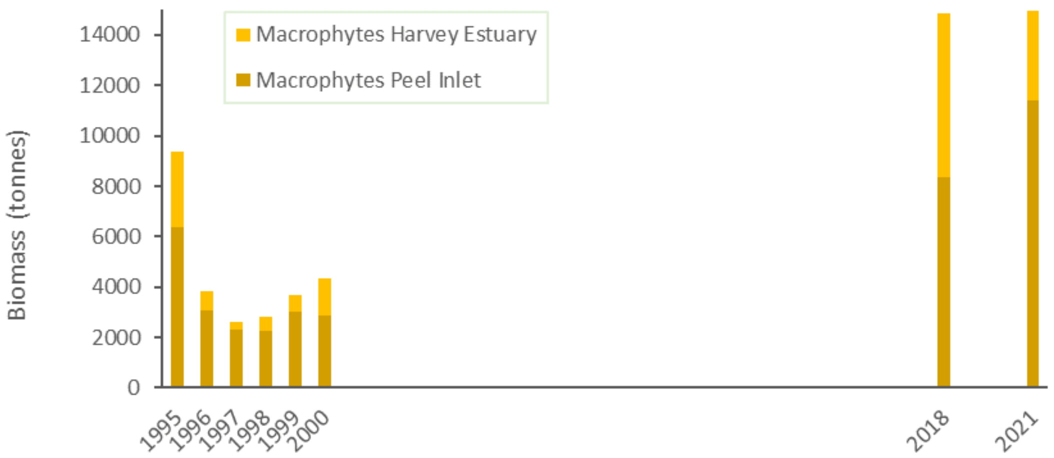

Figure 15 Biomass survey showing total biomass (tonnes) of macrophytes (seagrass and macroalgae) in summer/autumn in the Peel Inlet and Harvey Estuary after the Dawesville Cut was built in 1994.

The seagrasses *Ruppia* sp. and *Halophila* sp. were anecdotally reported as common in the Bindjareb Djilba before the 1960s. After this time, macroalgae began to proliferate and the presence of these seagrasses declined (Bradby 1997). Researchers attributed this decline to the smothering effect of the blooming macroalgae (Hodgkin et al. 1981). After the Dawesville Cut was built, ecologists predicted a gradual shift in the ecosystem – from one dominated by macroalgae to one where seagrass would become more prominent (Lavery et al. 1995). This transition has indeed taken place: macroalgae have decreased, while seagrass has become both more abundant and widespread (Krumholz 2019). We examine these changes in more detail below.

Seagrass biomass in the summer/autumn period remained relatively stable in the early years post-Cut (1995–2000), peaking at more than 2,000 tonnes in 1999 (Figure 16 A). Nearly 20 years later, seagrass biomass had increased five-fold, reaching 10,320 tonnes in 2018 and 10,990 tonnes in 2021. Although the biomass of macroalgae also increased compared with the early period, it remained less than half of the seagrass biomass in 2018 (4,530 tonnes of macroalgae) and 2021 (3,970 tonnes of macroalgae) (Figure 16 B). Notably, total seagrass biomass in the Peel in 2021 (9,070 tonnes) exceeds any previous measurement in any season over the 40 years from 1978 to 2018 (Lavery et al. 1995; Wilson, Hale & Paling 2000; Pedretti et al. 2011; DWER 2025) (Figure 15 A). This could be due to the dominance and widespread coverage of *Ruppia megacarpa,* which has potential for greater biomass per metre squared than *Halophila ovalis*.

Meanwhile macroalgal biomass decreased in both the Peel Inlet and the Harvey Estuary in the summer/autumn period between 1995 and 2000 (Figure 16 B). This occurred despite predictions that it would initially remain high or even increase with improved light levels from greater water exchange. At the same time high nutrient concentrations from river flow and sediment nutrient release were also expected to continue. The lower biomass observed immediately post-Cut was attributed to lower river flows (and therefore nutrients) in those years, with comparable biomass observed in low-flow years before the Cut (Wilson et al.1999) (Figure 16 B).

After the 1995–2000 period, there was a significant gap in sampling of almost two decades. The most recent sampling in 2018 and 2021 shows a worrying sign of an increase in macroalgal biomass in both the Peel Inlet and Harvey Estuary, compared with the previous sampling events. The average macroalgal biomass in 2018 and 2021 (4,250 tonnes) is almost double that of 1995–2000 (2,480 tonnes). In addition, the biomass in the Harvey Estuary in 2018 and 2021 (average of 2,010 tonnes) is often at least 50 per cent greater than all but four of the other 62 estimates made in any season since monitoring began in 1978 (Lavery et al. 1995) (Figure 16 B).

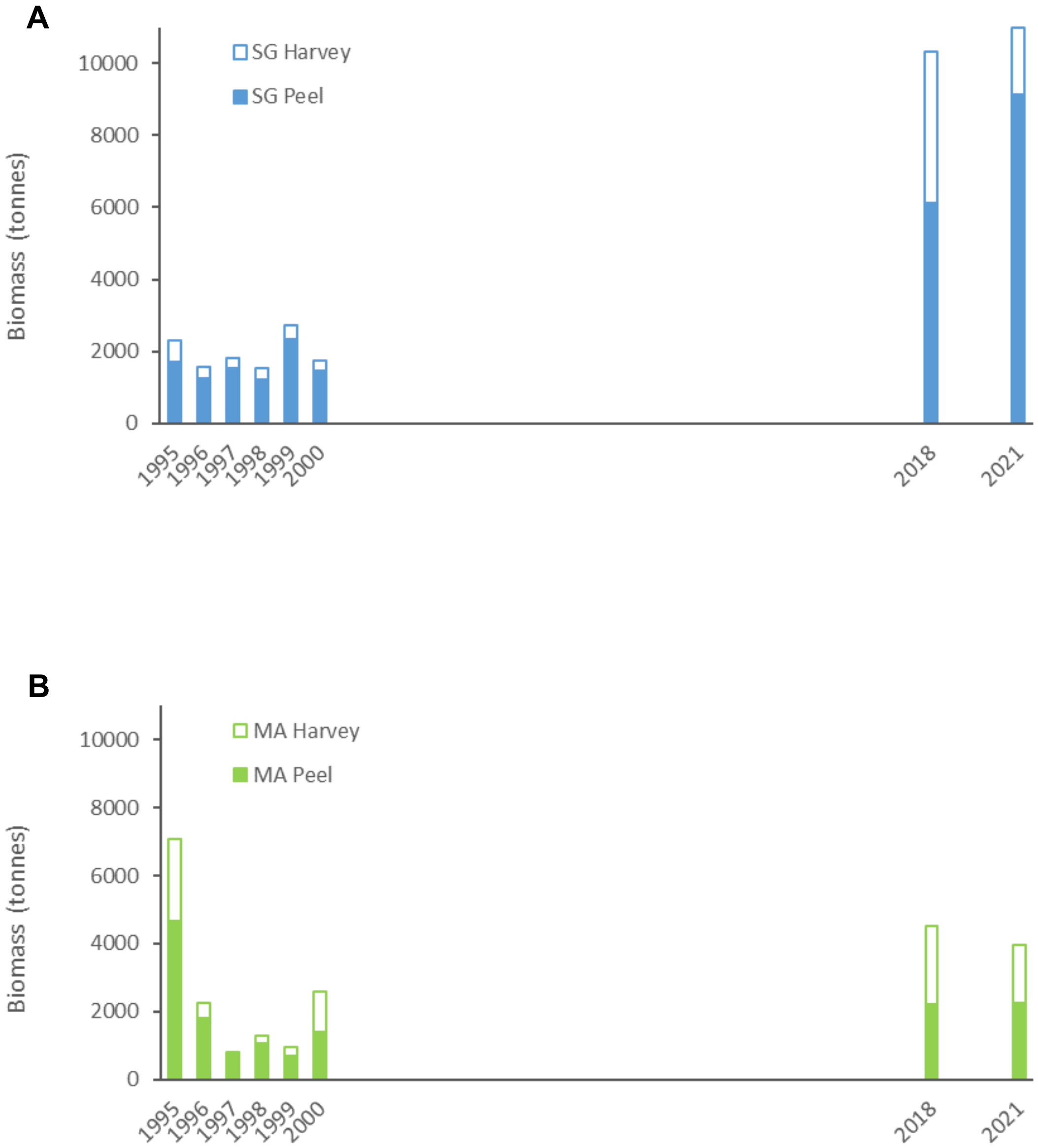

Figure 16 Biomass survey showing total biomass (tonnes) of seagrass (A) and macroalgae (B) in summer/autumn in the Peel Inlet and Harvey Estuary since the Dawesville Cut was built in 1994, SG = seagrass, MA = macroalgae.

6.2 Temporal changes in species

The number of species of macrophytes was predicted to rise post-Cut as a result of the increased opportunity for recruitment of macrophyte propagules from the ocean, greater marine influence over extended periods of time, lower extremes of salinity, and greater water clarity (Lavery et al. 1995). The number of species has increased from an average of about five to six pre-Cut to 10 to 11 in the first six years post-Cut (Wilson et al. 1999). Within a decade, the total number of seagrass, macroalgal, cyanophyte and charophyte species rose from 17 in 2009 (Pedretti et al. 2011) to 18 in 2017, 22 in 2018 (Krumholz 2019) and 30 species by 2021 (MAFRL 2022; DWER survey 2021). Most of the taxa were drift macroalgae species with attached macroalgae rare in the Bindjareb Djilba due to the limited availability of hard substrate for attachment. The drift macroalgae have increased from a few species of rapidly growing greens to more reds and browns that are thriving in the marine environment created by the Cut and reduced freshwater flows (Huang et al. 2023).

Dominant seagrass species have also changed post-Cut. *Halophila ovalis* prevailed initially, followed by *Heterozostera/Zostera* sp. in 2009, and then *Ruppia megacarpa*. This trend correlates with lower light levels and salinities early on favouring *H. ovalis* (Lavery et al. 1995; Valesini et al. 2019). The oval leaf shape of *H. ovalis* may allow it to harvest light more efficiently than the strap-like leaves of *R. megacarpa* and *Heterozostera/Zostera* sp. Combined with its low root-to-shoot ratio, this contributes to its minimal light requirements (Lee et al. 2007).

The colonising seagrass *Ruppia megacarpa* has remained dominant in the last three biomass surveys in 2017, 2018 and 2021. This is most likely due to preceding summer rainfall events that encouraged the germination of existing – and possibly new – seed banks (Carruthers et al. 1997), along with *R. megacarpa*'s greater tolerance for increasingly prevalent hypersaline conditions. At the same time, light conditions in the estuary have improved significantly, favouring *R. megacarpa* over *H. ovalis*, which previously held a competitive advantage under the lower light levels and salinities that existed before and shortly after the Cut (Lavery et al. 1995; Lee et al. 2007; Valesini et al. 2019). *R. megacarpa* may also shade smaller species once established, however it is also possible that the seed bank produced by *H. ovalis* has reduced over time.

The dominant green macroalgal species in the Peel-Harvey estuary have also shifted over time. From the late 1960s to the late 1970s, *Willeella brachyclados* (formerly *Cladophora montagneana*) was the dominant species, but it was later replaced by *Chaetomorpha linum*. However, *W. brachyclados* regained dominance during the high-river-flow years of 2017 and 2018. By 2021, *C. linum* had once again become the dominant species. In the Harvey Estuary, dominant macroalgal species sometimes differed from those in the Peel Inlet – particularly during the mid to late 1990s – when *W. brachyclados* alternated with various red algae.

7 Cover and biomass — how do the surveys compare?

In this section we compare the two surveys in terms of coverage of the estuary, time taken to conduct the survey, resources, taxonomy level, skills, reproducibility, historical data available and expected frequency of sampling for future surveys. See Appendix E — Comparison of cover and biomass surveys for more details.

Spatial coverage differed between the two surveys such that the **cover survey** was more intensive, observing 457 sites compared with 51 sites for the **biomass survey**. The greater number of observations in the **cover survey** enabled detection of smaller local populations of *Posidonia australis* and *Rhizoclonium* sp. which the **biomass survey** did not identify. However, despite these differences, the overall spatial pattern of abundance of seagrass and macroalgae was similar between the two survey methods.

The time taken to complete each survey also differed: the **cover survey** took more than double the time in the field to complete the more spatially intensive survey, but this was offset by not needing time in the laboratory. The **biomass method** needs two weeks to process cores of macrophytes in the laboratory (sort into species, dry and weigh).

Some specialist training is required for both surveys: skippering vessels (coxswains) and using GIS software. For the **cover survey** only, team members need field identification skills; in 2021, a qualified drone pilot and capability to process the captured images was needed. However, as mentioned previously, in future it is likely we will use imagery of the estuary available through Nearmap instead of drone footage. For the **biomass survey**, a diver and snorkeller are required as well as more advanced capability to identify macroalgae to species level.

Some of the resources required are similar between the two surveys, such as a large vessel for open water monitoring and a smaller vessel for the shallows, a water quality monitoring probe, light meter and GPS. Others are more specific to one survey or the other. The **cover survey** requires a drop camera and a viewing cone (and a drone in 2021). The **biomass survey** requires snorkelling and diving equipment, a manta board for towing in-water field staff, a Perspex corer, sieve, underwater point and shoot camera, and esky for cold storage of samples.

The different pieces of equipment used in the **cover survey** may add extra cost compared with those used in the **biomass survey**, but the in-water biomass surveys may increase the occupational health and safety risks for field staff compared with boat-based surveys.

The two surveys may differ in their reproducibility because of the qualitative versus quantitative measures used. The **cover survey** is more qualitative as it assesses percentage cover in a variable size of visual field (depending on viewing cone versus drop camera, depth, and turbidity of water) and has different observers estimating the cover. It also makes qualitative observations of the dominance of the seagrass and macroalgal genera/species present. On the other hand, the **biomass survey** empirically measures biomass of individual genera/species in a set area determined by the standard core diameter of 9 cm. Its use of stratified sampling and replication aims to reduce any bias brought about by the small sample area of the core in heterogeneous beds of macrophytes.

This difference in reproducibility is highlighted when comparing the frequency of observation of each of the three main species of seagrass. The proportion of sites with each of the seagrass species was greater in the **biomass survey**, with the **cover survey** underestimating presence and therefore cover of these seagrass species. Because the cover survey is observation based, macroalgae might obscure seagrass at some sites when viewed with a viewing cone or camera, while taller seagrass species might obscure shorter ones, and water clarity might prevent detection of small or less dense species. Laboratory viewing of species in the **biomass survey** prevents this from occurring since every species is separated and identified.

Taxonomy level differed between the two surveys, especially in relation to identifying macroalgal species to genus level. Using the **cover method**, small and cryptic species or types present in low cover are unlikely to be seen using the viewing cone or drop camera, particularly macroalgae species in small patches. Identifying some macroalgae to species level is also more complex, sometimes requiring microscopy which is not practical in the field. It is also likely that shorter-leaved seagrass such as *Halophila ovalis* might be missed if the bed is dominated by macroalgae or a relatively tall species such as *Ruppia megacarpa*.

The **biomass survey** identified 12 more macroalgal genera compared with the **cover survey**. Two macroalgal genera identified in both surveys contained two different species, but these were only identified in the **biomass survey**. The 2021 **biomass survey** also identified a macroscopic cyanobacterium *Calothrix* sp. and a stonewart – the Charophyte *Lamprothamnion* sp. In historical biomass surveys, the only other mention of cyanobacteria, other than *Nodularia spumigena*, was in the spring 1999 survey where *Schizothrix mexicana* and *Blennothrix lyngbyacea* (previously *Microcoleus lyngbyaceus*) were identified (Wilson et al. 1999). Conversely, the **cover survey**, because of its greater density of observations, identified one seagrass species and one macroalga not seen in the **biomass survey**.

Historical data available for looking at trends in macrophytes is available from the biomass surveys. As of 2025, a total of 64 biomass surveys and two cover surveys have been conducted. The biomass surveys were conducted over a period of 43 years, with temporally intensive surveys capturing seasonal and annual differences over a shorter period of 22 years from 1978 to 2000. After the temporally intensive period, sampling was reduced to ad hoc surveys when funding was available.

8 Conclusion

In this report we assessed the **cover survey** and **biomass survey** for similarity of distribution and diversity of seagrass and macroalgae, tested whether the **cover method** could predict biomass, and compared the strengths and weaknesses of the two methods. In addition, we summarised the outcomes of historical biomass surveys to assess changes in distribution and diversity of macrophytes over a 43-year period. Both survey methods have strengths and weaknesses, and the results of these comparisons have informed our recommendations on choice of method and future monitoring program frequency.

Overall, seagrass covered an estimated 55 per cent of the estuary's area and macroalgae occupied a similar area of 58 per cent. There was broad agreement for distribution of macrophytes, including at genus level, between the two surveys. Seagrass cover was largely absent from the mid-basin area of the Peel Inlet and through the central channel and the southernmost part of the Harvey Estuary. Macroalgae was present in most places except for parts of the central Peel.

In the **cover survey** the three most dominant species of seagrass observed (including in mixed meadows), in order of greatest to least, were *Ruppia megacarpa*, *Halophila ovalis* and *Heterozostera/Zostera* sp. A fourth seagrass species, *Posidonia australis*, was identified in the **cover survey** but not in the **biomass survey**. The dominant macroalgae observed from greatest to least were the greens *Chaetomorpha linum* and *Caulerpa taxifolia* and then a tie between observations of brown algae (not distinguished) and the red alga *Acanthophora* sp.

Seagrass biomass dominated total macrophyte biomass in the whole estuary, constituting 73 per cent, while macroalgae made up the remaining 27 per cent. The Peel had 80 per cent of the seagrass biomass and the Harvey the remaining 20 per cent. For macroalgal biomass, the proportions in each estuary were more similar: the Peel had 52 per cent and the Harvey 48 per cent.

In terms of total seagrass biomass, *Ruppia megacarpa* contributed the highest proportion (51 per cent), followed by *Heterozostera/Zostera* sp. (18 per cent) and then *Halophila ovalis* (5 per cent) (MAFRL 2022). This ranking contrasts with the order of species based on frequency of observations recorded by both survey methods. This is most likely related to plant size and growth form (e.g. smaller species weighing less and spreading growth forms observed more frequently than clumped ones). In the case of the **cover survey**, there was also the potential for taller species, floating macroalgae or poor water clarity to obscure smaller or less dense ones.

The dominant macroalga *Chaetomorpha linum* represented 55 per cent of the total macroalgal biomass, followed by *Caulerpa taxifolia* and the red *Spyridia filamentosa*.

Statistical comparison of the data from the two methods showed it was not possible to confidently predict biomass from assessment of cover alone. A suitable experimental design where the two methods are compared simultaneously at the same sites would be needed to verify this finding.

The strengths and limitations of the two surveys highlighted the need to:

- increase the spatial intensity of sites
- broaden site distribution
- use quantified areas to generate more representative estimates of total cover
- improve detection of species that may be present in smaller, localised areas (e.g. the seagrass *Posidonia australis*.

In addition, using a laboratory to process macrophytes in the **biomass survey** enabled more taxonomic groups to be identified and resolved to a greater level of taxonomic detail than field observations. This method also prevented underestimation of species presence and therefore cover.

Long-term monitoring of macrophytes in the Peel-Harvey estuary revealed a significant increase in species richness, from an average of five to six species before construction of the Dawesville Cut in 1994 to 30 species by 2021. This increase includes the presence of charophytes and cyanophytes. The observed increase in macrophyte diversity is likely attributed to several factors. The Cut enhanced marine exchange, leading to greater marine influence in the estuary. In addition, reduced river flows have increased water retention time, as modelled by Huang et al. (2023). Other significant contributors include improved water clarity (Valesini et al. 2019) and the opportunity for recruitment of new species through ocean exchange (Lavery et al. 1995).

Interrogating historical biomass data showed dramatic changes in the dominant species of both seagrass and macroalgae and worrying signs of increased macroalgae in the Harvey Estuary, tempered in 2021 by the most seagrass biomass ever recorded in the 64 surveys conducted to date.

8.1 Recommendations for future monitoring

We recommend that monitoring of both seagrass and macroalgae be continued in the coming years, using the **cover method** described in this report and Bennett et al. (2021). This method is being used across key estuaries in south-west Western Australia, and it provides greater spatial resolution than the **biomass method**. The **cover method** assesses the density and distribution of seagrass and macroalgae, providing a valuable metric for evaluating the effectiveness of water quality improvement initiatives such as those in the *Bindjareb Djilba – A plan for the protection of the Peel-Harvey estuary* (DWER 2020) and the catchment management and sustainable agriculture practices implemented through Healthy Estuaries WA.

Assessing macrophyte biomass at less frequent intervals – such as every five to 10 years – could still provide valuable insights. Maintaining the historical network of 51 monitoring sites would offer a consistent dataset to evaluate macrophyte productivity and diversity in relation to climate change. This extensive record, spanning more than 43 years, uniquely captures how macrophyte communities have responded to climatic shifts, particularly in the context of declining river flows and rainfall in south-western Australia. Furthermore, it will improve understanding of productivity by providing data to examine the relationship between biomass and cover.

Appendices

Appendix A — 1978–2021 biomass surveys

Table A 1 Summary of macrophyte biomass surveys of the Peel-Harvey estuary from 1978 to 2021. Updated from Lavery et al. (1995) and Krumholz (2019).

Year	Month	Spring	Summer	Autumn	Winter	No. sites sampled
1978	March			x		36
1978	August				x	36
1979	March			x		36
1979	September	x				36
1981	July				x	30
1981	October	x				30
1982	February		x			30
1982	May			x		30
1982	July				x	30
1982	October	x				30
1984	January		x			30
1984	April			x		30
1984	August				x	30
1984	November	x				30
1985	February		x			30
1985	May			x		30
1985	August				x	42
1985	November	x				42
1986	February		x			42
1986	May			x		42
1986	September	x				42
1986	November	x				42
1987	February		x			42
1987	May			x		42
1987	August				x	42
1987	November	x				42
1988	February		x			42
1988	May			x		42
1988	August				x	42
1988	November	x				42
1989	February		x			42
1989	May			x		42
1989	August				x	42

Year	Month	Spring	Summer	Autumn	Winter	No. sites sampled
1989	October	x				42
1990	February		x			42
1990	May			x		42
1990	August				x	42
1990	October	x				42
1991	February		x			42
1991	May			x		42
1991	August				x	42
1992	April			x		42
1993	March			x		42
1994	March			x		42
1994	October	x				42
1995	February		x			42
1995	May			x		42
1995	November	x				42
1996	January		x			42
1996	April			x		42
1996	November	x				43
1997	January		x			43
1997	April			x		43
1997	November	x				43
1998	January		x			43
1998	April			x		43
1998	November	x				43
1999	February		x			43
1999	November	x				43
2000	January		x			43
2009	Nov/Dec	x				44
2017	October	x				51
2018	April			x		51
2021	April			x		51
Total surveys	**64**	**19**	**15**	**20**	**10**	

Appendix B — Cover survey additional information

Table B 1 Seagrass and macroalgal cover classes with respective percentage cover range and the midpoint

Cover class	Percentage cover %	Midpoint %
0	0	0
1	<10	5
2	10 to <25	17.5
3	25 to <50	37.5
4	50 to <75	62.5
5	75 to <90	82.5
6	>90 to 100	95

Additional information collected but not presented here

During the **cover survey**, additional information was collected at about 30 per cent of the sites: water depth, Secchi depth, and other *in situ* data using the Marine Optics MS9 for measurement of photosynthetically active radiation (PAR), and the Pro DSS YSI multi-parameter sonde for water quality variables of temperature, salinity, dissolved oxygen and turbidity.

Drone survey

For the areas of the estuary that were too shallow to be assessed by boat, a drone survey was designed. There were three zones in the Peel Inlet that met this criteria (Figure B 1). These were further divided into seven pre-programmed flight path areas. Two were in the north-western Peel and five in the south-eastern Peel. All but one of the pre-programmed areas was assessed, which was in the farthest south-eastern area. The drone flew along transect lines in each area, keeping to a height of 120 m. Images were stitched together, and site locations overlain. At each site, it was determined if seagrass and macroalgae were present or absent. A cover category was not assigned due to doubt about the accuracy of these assumptions without proper ground truthing. In future, it is planned to use the aerial images obtained from Nearmap to assess the presence and absence of seagrass and macroalgae, since these provide high-quality stitched imagery compared with the drone footage. They are available for the Peel-Harvey in sufficient temporal frequency to feel confident that a suitable image can be acquired.

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Figure B 1 Drone areas surveyed during 2021 cover survey.

Maps of cover – generation and interpolation

Sample data were provided in MS Excel ® with site ID, location coordinates (GDA94 MGA Zone 50), seagrass and macroalgae presence or absence (expressed numerically as present = 1 and absent = 0), seagrass/macroalgal cover class midpoints (Table B 1) and species information for each site. These were imported into ArcMap ® and exported to a geodatabase as a point feature class.

Inverse distance weighting (IDW) determines values for areas where no sampling was undertaken. It does this by using nearby data points and weighting the importance of the nearby data for each calculated value depending on the distance from it. The importance is reduced the further away from the calculated value. ESRI ArcMap ® V10.8 with the Spatial Analyst tool was used for the interpolations.

A modified polygon derived from Landgate's medium-scale topography water polygons was used as the processing extent for the IDW interpolation. Modifications included clipping to the spatial extent of the study area, dividing the area into drone observation (present/absent), boat observation (present/absent) and no data areas.

Interpolation rasters of seagrass and macroalgae extent (area covered) were created using 20 m x 20 m grid cells and a search rule using only the 12 nearest points with the Peel-Harvey polygon as the processing extent. The rasters were classified with values equal to or less than 0.5 converted to 0 (absent) and greater than 0.5 converted to 1 (present). The reclassified raster was converted to polygons, separating the boat sample area and drone sample area. An assumption was made that the presence or absence of seagrass or macroalgae was uniform across the 20 m x 20 m grid.

Data sources used

Hydrography – Landgate 2023

Roads – Landgate 2023

Aerial imagery – Peel-Harvey estuary – Landgate 2017

Sample sites – DWER (2022)

Cover data – DWER (2022)

Appendix C — Biomass survey additional information

This section shows the latitudes and longitudes of the 51 sites sampled for the **biomass survey** (Table C 1). It also shows a map (Figure C 1) and the latitudes and longitudes (Table C 2) of the transects used for estimating macrophyte cover in the Harvey Estuary and the western part of the Peel Inlet.

Table C 1 Coordinates for the 51 sites in the biomass survey of the Peel-Harvey estuary from Pedretti et al. (2011)

Site	Latitude	Longitude	Site	Latitude	Longitude	Site	Latitude	Longitude
1	-32.68348	115.676100	**18**	-32.60684	115.76345	**35**	-32.65887	115.67577
2	-32.60120	115.678140	**19**	-32.63636	115.74254	**36**	-32.5825	115.74262
3	-32.57685	115.709730	**20**	-32.62984	115.7584	**37**	-32.72712	115.67641
4	-32.57581	115.755320	**21**	-32.6004	115.66508	**38**	-32.57256	115.75679
5	-32.6181	115.752650	**22**	-32.60756	115.67142	**39**	-32.56577	115.71436
6	-32.63015	115.70664	**23**	-32.6186	115.65533	**40**	-32.57434	115.67461
7	-32.59221	115.71401	**24**	-32.6239	115.64299	**41**	-32.61254	115.64628
8	-32.58388	115.67273	**25**	-32.62047	115.66444	**42**	-32.62641	115.69018
9	-32.57138	115.70374	**26**	-32.65033	115.65813	**43**	-32.57531	115.68815
10	-32.59801	115.69753	**27**	-32.6538	115.67844	**58**	-32.63402	115.65789
11	-32.57024	115.70954	**28**	-32.66496	115.65735	**3a**	-32.58042	115.71606
12	-32.61833	115.68718	**29**	-32.72014	115.69167	**Ha1**	-32.69400	115.691750
13	-32.61838	115.7179	**30**	-32.71727	115.69905	**Ha2**	-32.69917	115.681370
14	-32.60283	115.74732	**31**	-32.74193	115.69844	**Ha3**	-32.70253	115.673450
15	-32.59008	115.75244	**32**	-32.75037	115.69185	**Ha4**	-32.76360	115.719630
16	-32.62207	115.73263	**33**	-32.76169	115.71034	**Pe1**	-32.57013	115.738520
17	-32.61697	115.74379	**34**	-32.62544	115.66619	**Pe2**	-32.59797	115.732500

Pedretti et al 2011 Transects

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Figure C 1 Map of transects in the Bindjareb Djilba (Peel-Harvey estuary) used for estimating cover in the MAFRL's biomass survey. Coordinates from Pedretti et al. (2011).

Table C 2 Coordinates for the transects in the Bindjareb Djilba (Peel-Harvey estuary) used for estimating macrophyte cover in the biomass survey (data from Pedretti et al. 2011)

Projection	Estuary	Site	Start-x	Start-y	End-x	End-y
WGS84	Peel	34	374926	6388698	374299	6388663
WGS84	Peel	25	375152	6389446	374473	6389493
WGS84	Peel	24S	372889	6388715	373498	6389168
WGS84	Peel	24	372541	6389463	373237	6389550
WGS84	Peel	jetty	372541	6389829	373185	6389881
WGS84	Peel	25N	374978	6390142	374369	6389951
WGS84	Peel	41	372454	6390508	373168	6390473
WGS84	Peel	Cut N	373675	6392003	374345	6391569
WGS84	Peel	21S	374415	6391872	374425	6392371
WGS84	Harvey	32	376858	6375492	377572	6376380
WGS84	Harvey	32N	376266	6377720	376928	6378121
WGS84	Harvey	32NN	375639	6378138	376423	6378608
WGS84	Harvey	island	378703	6375736	378320	6376223
WGS84	Harvey	HP	379190	6376676	378338	6376850
WGS84	Harvey	31	379121	6378939	378059	6378678
WGS84	Harvey	30	378285	6380802	377241	6380697
WGS84	Harvey	37	375274	6379914	376075	6379896
WGS84	Harvey	res	377920	6381846	376945	6381794
WGS84	Harvey	1W	374665	6383065	375256	6383099
WGS84	Harvey	1E	376788	6383239	376127	6383065
WGS84	Harvey	35	376928	6384485	376353	6384485
WGS84	Harvey	28	373986	6385390	374578	6385303
WGS84	Harvey	27	376753	6385773	376075	6385721
WGS84	Harvey	26W	373063	6386922	373933	6386992
WGS84	Harvey	Stony Pt	375744	6387200	375065	6386818
WGS84	Harvey	59	373202	6388315	373829	6388419

Additional information collected but not presented here

During the **biomass survey**, additional information was collected at all sites: below-ground biomass, water depth, Secchi depth, and other *in situ* data using the Marine Optics MS9 for measurement of photosynthetically active radiation (PAR), and the YSI multi-parameter sonde for water quality variables of temperature, salinity and dissolved oxygen.

At a subset of sites, tissue nutrients (total P, total kjeldahl nitrogen, per cent N, per cent C) and isotopes (delta ^{15}N and delta ^{13}C) were collected from dominant species of seagrass and macroalgae. The locations of samples were chosen to represent the continuum from the river mouths to the Dawesville Cut.

Maps of biomass – generation and interpolation

Sample data were provided in MS Excel with Site ID, coordinates (WGS84), average macroalgal biomass, average seagrass above ground biomass, total macrophyte cover, seagrass and macroalgae presence or absence (expressed numerically as present 1 and absent: 0) and species information. These were imported to ArcMap and exported to a geodatabase as a point feature class and projected to GDA94 MGA zone 50.

A modified polygon derived from Landgate's medium-scale topography water polygons, was used as the processing extent for the inverse distance weighting (IDW) interpolation.

Further modifications included clipping to the spatial extent of the study area and dividing the area into those where seagrass or macroalgal biomass was present or absent.

As described previously, IDW determines values for areas where no sampling was undertaken. It does this by using nearby data points and weighting the importance of the nearby data for each calculated value depending on the distance from it. The importance is reduced the further away from the calculated value. ESRI ArcMap ® V10.8 with the Spatial Analyst tool was used for the interpolations.

Interpolation raster for biomass was created using 20 m x 20 m grid and search rule using only the nearest six points, with the Peel-Harvey estuary polygon as the processing extent. The rasters were symbolised using the following classes in grams per metre squared: <0.1; 0.1–1; 1–10; 10–100; >100 g/m^2.

Total macrophyte biomass

The spatial interpolation technique used to derive values for total mean biomass (tonnes) and generate maps with mean distribution patterns were created based on the data from the 51 sites discussed in Section 2.2. Information on total biomass provided in sections 3.1, 4.1 and 6.1 should be viewed with caution, as the number of sites sampled was low compared with the large area (133 km^2) over which the interpolation took place. There was also an insufficient number of sites to allow for independent validation. Typically, one would use 70 per cent of sites for interpolation and the remaining 30 per cent for validation for the interpolated surfaces (MAFRL 2022). Future work should investigate ways to achieve some form of validation.

Data sources used

Hydrography – Landgate 2023

Roads – Landgate 2023

Aerial imagery – Peel-Harvey estuary – Landgate 2017

Sample sites – MAFRL (2022)

Biomass data – MAFRL (2022)

Appendix D — Macrophyte species names recorded in 2021 in the Peel Inlet and Harvey Estuary in the biomass survey

Genus was often the lowest level of taxonomic identification recorded in the **cover survey** and taxa were referred to as such in the main body of the report. However, in the **biomass survey** most macrophytes were identified to species level. These are presented here (Table D 1).

Table D 1 Presence (+) and absence (-) of each macrophyte species identified in the biomass survey in the Peel Inlet and Harvey Estuary, classified by phylum (data from MAFRL 2022).

	Biomass survey	
	Peel Inlet	Harvey Estuary
Magnoliophyta (seagrasses)		
Ruppia megacarpa	+	+
Halophila ovalis	+	+
Heterozostera/Zostera sp.[23]	+	+
Chlorophyta (green algae)		
Chaetomorpha linum	+	+
Willeella brachyclados (formerly *Cladophora montagneana*)	+	+
Ulva australis	-	+
Caulerpa taxifolia var. *distichophylla*	+	+
Caulerpa cylindracea	+	-
Acetabularia caliculus	+	-
Acetabularia peniculus	+	-
Rhodophyta (red algae)		
Gracilaria sp.	+	+
Acanthophora spicifera	+	+
Chondria sp.	+	-
Laurencia sp.	+	+
Spyridia filamentosa	+	+
Lophocladia kuetzingii	+	-
Hypnea sp.	+	-
Centroceras gasparrinii	+	+
Crouania minutissima	+	-
Polysiphonia sp.	+	+
Jania pedunculata	+	+
Other reds	+	-
Phaeophyta (brown algae)		
Dictyota furcellata	+	+
Feldmannia sp. (formerly *Hincksia*)	+	+
Sirophysalis trinodis	+	-

	Biomass survey	
	Peel Inlet	Harvey Estuary
Sphacelaria rigidula	+	-
Hormophysa cuneiformis	+	-
Charophyta (stonewarts)		
Lamprothamnion sp.	+	-
Cyanobacteria (blue-green algae)		
Calothrix sp.	+	+

Appendix E — Comparison of cover and biomass surveys

Table E 1 Comparison of cover and biomass surveys

Comparison	Method	
	Cover	Biomass
Days in field	Eight days	Four days
Dates	Boat survey (6 days) 22–26 March 2021 29 March 2021 Drone survey (two days) 20–21 April 2021	Boat survey (4 days) 14–16 April 2021 19 April 2021
Spatial coverage of estuary	Widespread	Limited with detailed measures of biomass and species identification
Sites	496 (*in situ* plus drone)	51
Unit of measurement	per cent cover by site (no fixed area) ha (interpolated) by estuary	g/m^2 of biomass by site tonnes (interpolated) by estuary
Vessels	1 x large vessel (~6.7 m) 1 x small (4.6 m Plaka)	1 x large vessel (6.6 m) 1 x small (dinghy)
Taxonomy level	Genus most of the time	Species most of the time
Reproducibility	Low for cover, as it is assessed in a variable visual field. Requires ground truthing to confirm this assessment. Medium for taxonomy, as in-field identification dependent on skills of personnel, field conditions and visibility	High for biomass as uses stratified sampling design and known area of core taken High for taxonomy, as identification done by one person in laboratory under controlled conditions with checks by taxonomist
Historical data as of 2021	0 years	24 years of data collected from 1978–2018
Expected frequency	3–5 years	5–10 yearly Historically (varied as funding available): 1978 to 2000: seasonal sampling, almost annually 2009, 2017–18, 2021: spring and/or summer

Shortened forms

Shortened form	Complete word/phrase
Biomass survey	Survey carried out in 2021 by the Marine and Freshwater Research Laboratory using cores to extract samples of macrophyte biomass from the estuary bottom.
Cover survey	Survey carried out in 2021 by the Department of Water and Environmental Regulation using visual observations of cover of seagrass or macroalgae on the estuary bottom.
DWER	Department of Water and Environmental Regulation, Western Australia
DWER cover	Department of Water and Environmental Regulation cover of seagrass or macroalgae as determined by using a viewing cone or underwater drop camera with no fixed area.
MAFRL	Marine and Freshwater Research Laboratory, Murdoch University, Western Australia.
MAFRL cover	Marine and Freshwater Research Laboratory cover data collected to inform its stratified biomass sampling. Estimated by snorkellers or divers towed on a manta line behind a boat (see Section 2.2 Biomass method). It did not distinguish between the cover of seagrass and macroalgae as the DWER cover did, instead it was an estimate of cover of macrophytes (seagrass, macroalgae, cyanobacteria and stonewarts combined) and was used in one set of statistical comparisons with DWER cover data.
MAFRL biomass	Marine and Freshwater Research Laboratory biomass data collected using a core of macrophytes, later separated into species, dried and weighed.

Glossary

Term	Definition
Bindjareb Djilba	Bindjareb Noongar name for the Peel-Harvey estuary.
Benthic	Bottom dwelling
Biomass	The weight of living matter often expressed per area; for example, grams dry weight per metre squared.
Canopy height	The height of a plant or plant-like flora.
Cover	The area covered by an organism often expressed as a per cent of the assessed surface area. In this report, area assessed at each site was not recorded and varied with depth and whether viewing cone or drop camera was used. Hence cover was not expressed as per cent per unit area.
Density	Number of individuals per unit area or volume.
Epiphyte	An organism that grows on the surface of a plant or plant-like organism.
Eutrophic	A biological state where accumulated nutrients support increased aquatic plant or plant-like growth which in turn reduces water quality. Human activities that contribute fertilisers and other high-nutrient wastes are often responsible for this state.
Macroalgae	Aquatic plant-like flora visible to the naked eye. Often called seaweeds.
Macrophyte	An aquatic plant (e.g. seagrass) or plant-like flora (macroalgae, cyanobacteria, stonewarts) visible to the naked eye.
Salinity	A measure of the dissolved salt content in water.
Seagrass	Aquatic plants belonging to the group angiosperms which produce flowers and seeds. Most land plants belong to this group too.
Secchi depth	A measure of water clarity such that the greater the depth, the clearer the water.
Sediment	Particulate matter that can be transported by water and eventually deposited as a layer of particles on the bed or bottom of a waterbody; for example, sand or mud.
Taxonomy	The classification of organisms
Total phosphorus	The particulate and dissolved phosphorus in a sample, such as plant tissue.
Total kjeldahl nitrogen	The particulate and dissolved nitrogen in a sample, such as plant tissue.
Water quality	Characteristics of water that determine its suitability for a particular use.

References

Bennett K, Sánchez-Alarcón M, Forbes V, Thornton H & Kilminster K 2021, 'Seagrasses in four estuaries in Western Australia's South West', *Water Science Technical Series*, report no. 86, Department of Water and Environmental Regulation, Western Australia.

Bradby K 1997, *Peel-Harvey, the decline and rescue of an ecosystem,* Greening the Catchment Taskforce (inc.), Mandurah, Western Australia.

Carruthers TJB, Wilshaw J & Walker DI 1997, *Ecology of* Ruppia megacarpa *Mason and its epiphytes in Wilson Inlet – the influence of physical factors,* a report to Water and Rivers Commission, Western Australia.

DWER (Department of Water and Environmental Regulation) 2020, *Bindjareb Djilba – A plan for the protection of the Peel-Harvey Estuary*, Perth, Western Australia.

— 2022, *Seagrass and macroalgae snapshot: Bindjareb Djilba (Peel-Harvey estuary) 2020–21*, Perth, Western Australia.

—2023, *Bindjareb Djilba Peel-Harvey estuary: Condition of the estuary 2016–19*, Perth, Western Australia.

— 2025, *Gabi Warlang Bidi – Water quality improvement plan for the Peel-Harvey estuary*, Perth, Western Australia.

Fourqurean JW, Boyer JN, Durako MJ, Hefty LN & Peterson BJ 2003, 'Forecasting responses of seagrass distributions to changing water quality using monitoring data', *Ecological Applications*, vol. 13(2), pp 474–489.

Huang P, Henning K, Busch B & Hipsey MR 2023, 'The changing hydrology of the Peel-Harvey estuary: past, present and future', In Valesini F, Hipsey MR, Cronin O'Reilly S & Huang P (Eds) 2023, *Balancing estuarine and societal health in a changing environment: A decision support framework for sustaining the Peel-Harvey estuary-catchment system in south-western Australia,* The University of Western Australia.

Hodgkin EP, Birch FB, Black RE & Humphries RB 1981, *The Peel-Harvey estuarine system study (1976–1980),* Department of Conservation and Environment, report no. 9, Perth, Western Australia.

Krumholz O 2019, Macrophyte communities in the Peel-Harvey estuary: Historical trends and current patterns in biomass and distribution, unpublished Honours thesis, School of Veterinary and Life Science, Murdoch University.

Lavery P, Hillman K, Bastyan G, McComb AJ & Paling EI 1995, *Changes in macrophyte abundance and composition in the Peel-Harvey estuarine system from 1978 to 1994*, Institute for Environmental Science, report no. MAFRA 95/11, Murdoch University, April 1995.

Lord DA & Associates Pty Ltd 2002, Dawesville Channel Monitoring Programme five year technical review, prepared for Water and Rivers Commission, report no. 96/009/2, unpublished, August 2002.

Longley PA, Goodchild MF, Maguire DJ & Rhind DW 2005, *Geographic information systems and science*, West Sussex, Wiley.

Lukatelich R 1989, *Leschenault Inlet macrophyte abundance and distribution,* report to the Waterways Commission, no. 15, June 1989.

Lukatelich R & McComb A 1989, *Seasonal changes in macrophyte abundance and composition in the Peel-Harvey estuarine system,* report to the Waterways Commission, no. 16, June 1989.

MAFRL (Marine and Freshwater Research Laboratory) 2022, *Macrophyte survey of the Peel Harvey estuary autumn 2021*, report to the Department of Water and Environmental Regulation, Marine and Freshwater Research Laboratory, report no. MAFRL 21-07, Murdoch University, May 2022.

McComb AJ & Humphries R 1992, 'Loss of nutrients from catchments and their ecological impacts in the Peel-Harvey estuarine system, Western Australia', *Estuaries*, vol. 15(4), pp 529–537.

Nannup H, Kearing G, Nannup F, Nannup J, Ugle R & Walley G 2019, *Bindjareb Gabi Wonga (Bindjareb Water Story)*, Mandurah, Western Australia.

Pedretti YM, Kobryn HT, Sommerville EF & Wienczugow K 2011, *Snapshot survey of the distribution and abundance of seagrass and macroalgae in the Peel-Harvey estuary from November/December 2009,* report to Department of Water, Institute for Environmental Science, report no. MAFRA 11/1, Murdoch University.

Petrone KC, Hughes JD, Van Neil TG & Silberstein RP 2010, 'Streamflow decline in southwestern Australia, 1950–2008', Geophysical research letters*, Hydrology and Land Surface Studies*, vol. 37(11), https://doi.org/10.1029/2010GL043102.

Potter IC, Rose TH, Huisman JM, Hall NG, Denham A & Tweedley JR 2021, 'Large variations in eutrophication among estuaries reflect massive differences in composition and biomass of macroalgal drift', *Marine Pollution Bulletin*, vol. 167, pp 1–14.

Valesini F, Hallett CS, Hipsey MR, Kilminster KL, Huang P & Hennig K 2019, 'Peel-Harvey estuary, Western Australia', In Wolanksi E, Day JW, Elliott M & Ramachandran R (Eds), *Coasts and Estuaries,* Burlington, Elsevier.

Valesini F, Krumholz O, Hallett CS & Kobryn H 2023a, 'Seagrass and macroalgal communities of the Peel-Harvey estuary from 1978 to 2018', In Valesini F, Hipsey MR, Cronin O'Reilly S & Huang P (Eds) 2023, *Balancing estuarine and societal health in a changing environment: A decision support framework for sustaining the Peel-Harvey estuary-catchment system in south-western Australia,* The University of Western Australia.

Valesini F, Hipsey MR, Cronin O'Reilly S & Huang P (Eds) 2023b, *Balancing estuarine and societal health in a changing environment: A decision support framework for sustaining the Peel-Harvey estuary-catchment system in south-western Australia,* The University of Western Australia.

Wilson C, Latchford J & Paling E 1995, *Macrophyte abundance and composition in the Peel-Harvey estuary from July 1994 to June 1995*, Institute for Environmental Science, report no. MAFRA 95/12, Murdoch University, June 1995.

Wilson C, Latchford J & Paling E 1996, *Macrophyte abundance and composition in the Peel-Harvey estuary from July 1995 to June 1996*, Institute for Environmental Science, report no. MAFRA 96/5, Murdoch University, June 1996.

Wilson C, Latchford J & Paling E 1997, *Macrophyte abundance and composition in the Peel-Harvey estuary from July 1996 to June 1997 with biomass comparisons before and after the construction of the Dawesville Channel*, Institute for Environmental Science, report no. MAFRA 97/6, Murdoch University, August 1997.

Wilson C, Hale J & Paling E 1998, *Macrophyte abundance and composition in the Peel-Harvey estuary from spring 1997, summer 1998 and autumn 1998*, Institute for Environmental Science, report no. MAFRA 98/7, Murdoch University, November 1998.

Wilson C, Hale J & Paling E 1999, *Macrophyte abundance, distribution and composition of the Peel-Harvey estuary: Comparisons before and after the opening of the Dawesville Channel (July 1985 to June 1999),* Institute for Environmental Science, report no. MAFRA 99/5, Murdoch University, November 1999.

Wilson C, Hale J & Paling E 2000, *Macrophyte abundance and composition in the Peel-Harvey Estuary in spring 1999 and summer 2000,* Institute for Environmental Science, report no. MAFRA 00/8, Murdoch University, November 2000.

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