Government of **Western Australia**
Department of **Water and Environmental Regulation**

Seagrasses in four estuaries in Western Australia's South West

2017–20

Department of Water and Environmental Regulation
Water Science Technical Series
Report no. 86
January 2021

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Cover photograph: Aerial view of seagrass meadows along the eastern shore of the Leschenault Estuary, March 2018 (photo credit: Ashley Ramsay)

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Summary

Within many estuaries, seagrasses are foundation species that provide important habitat and perform critical ecological functions within the ecosystem. A number of estuaries along the south-west and south coasts of Western Australia are in poor and degraded condition due to anthropogenic pressures from land clearing for agriculture, industry and urban development. Although the monitoring of seagrasses in south-west estuaries has been intermittent during the past few decades, the data collected nevertheless supports this current assessment of the status of seagrass in these systems.

The work described in this report has been supported by the Regional Estuaries Initiative (the initiative), a Government of Western Australia program that aims to improve the health of six estuaries in south-west Western Australia. As part of the Science for Management strategy, seagrass in these estuaries has been monitored to help inform decisions and guide estuary management.

Seagrass supports estuarine ecology and is a useful indicator of estuary health since it requires both good sediment and water quality to thrive. Seagrass loss can also be due to human-induced stressors (such as dredging or eutrophication), although these are potentially manageable. Seagrass is also influenced by climate change, including altered rainfall patterns, sea level rise and marine heatwaves – aspects that cannot be managed at the scale of a seagrass meadow or estuary. These aspects need to be considered together with the seagrass status to achieve a complete understanding of the information reported here.

This report focuses on monitoring that the department conducted in the summer months from 2017 to 2020, in which we assessed seagrass status in the Leschenault Estuary, Hardy Inlet, Wilson Inlet and Oyster Harbour. The broadscale information on seagrass status reported here is nested within a hierarchical monitoring design that captures data at different scales. We used underwater camera observations primarily to generate up-to-date seagrass coverage maps for these estuarine systems. We made more than 2,000 underwater observations to create these current maps of seagrass distribution across the four estuaries.

Seagrass distribution should not be a standalone measure of seagrass health. Greater understanding of the resilience and health of the seagrass population can be drawn from the other aspects of the hierarchical monitoring design. This monitoring focuses on inter-annual variability, but seasonal fluctuations are also expected given the dynamic nature of estuarine environmental conditions.

Reassuringly, for the estuaries assessed between 2017 and 2020, seagrass condition is generally stable and/or recovering in each system.

The status of seagrass in each of the estuaries we studied can be summarised as:

- **Leschenault Estuary –** the seagrass is on a recovery trajectory. Seagrass distribution within the estuary had declined when survey results from 2009 were compared with surveys in the 1980s and early 1990s. A further major loss of seagrass was then observed; that is, the area inhabited by seagrass in 2009 had halved by 2015. Slow recovery was tracked from 2017 and in 2020, seagrass habitat covered 54.7% of the estuary area or 1,386 hectares (ha) and had re-established in

the northernmost part of the estuary. One species (*Heterozostera*) has not been recorded in the system since the surveys between 1984 and 1993 and is likely locally extinct from the system.

- **Hardy Inlet** – the seagrass appears stable. *Ruppia megacarpa* is the dominant species, although small areas of *Zostera muelleri* have also been observed. Seagrass extent appears to have been stable during the past 20 years. We estimated the total area of seagrass habitat was about 501 ha in December 2018 and 617 ha in January 2020. The increased area of seagrass has coincided with an increase in its density. Environmental conditions (rainfall and temperature) were likely more favourable for seagrass growth in 2019–20 compared with 2018–19.
- **Wilson Inlet** – seagrass appears generally stable, with some evidence of loss around the townsite of Denmark in particular. *Ruppia megacarpa* is the only species recorded in the Wilson Inlet. We report a loss of seagrass given a survey in 2007 estimated 2,640 ha of seagrass coverage, compared with 1,852–2,059 ha for 2017–19. Conditions in 2019 (when the sandbar remained closed) appeared less favourable for seagrass in Wilson Inlet – with deeper, more tannin-stained water and a greater abundance of macroalgae resulting in lower seagrass density and little evidence of flowering. It seems likely that seagrass in the Wilson Inlet would be resilient to occasional years of non-bar opening, but that continued non-bar opening, or poorly timed bar openings, would negatively affect seagrass resilience.
- **Oyster Harbour** – seagrass has improved, with increased area and density. The slow-growing *Posidonia* species is most abundant in Oyster Harbour. The first surveys of seagrass in Oyster Harbour in the 1960s reported widespread seagrass meadows down to a water depth of 8 m. Significant losses were then reported in the 1980s with seagrass restricted to areas shallower than 2 m. Recovery (and a restoration program) followed from the 1990s onward. In 2006, seagrass was estimated to cover 560 ha of Oyster Harbour. Our most recent survey shows the area of seagrass has now expanded to 663 ha, with a generally higher density and the deepest observations of seagrass in water of 5.5 m. Given the slow growth of *Posidonia* species, it is likely this recovery reflects continued good water quality in the estuary.

Seagrass is an important component of a healthy estuary – as a primary producer and a valuable source of food and habitat. To ensure seagrass habitat continues to improve, it remains important for catchment management to support better water quality by reducing nutrient and sediment export to estuaries. We recommend that monitoring of seagrass continues in the coming years via these standardised methods, to allow ongoing assessment of our successes in improving water quality through catchment management and sustainable agricultural practices.

1 Introduction

1.1 What is seagrass?

Seagrasses are flowering plants (angiosperms) that have evolved from land plants and adapted to live underwater – generally in a marine environment. The seagrass families do not form a taxonomic group but rather an ecological group, and hence are not necessarily closely related (den Hartog & Kuo 2006). This is important for understanding their varied response to environmental conditions. At present, about 65 species of seagrass are recognised (Larkum et al. 2018), although this number has fluctuated during the past few decades with varying taxonomic or genetic classifications. It is suggested that Australia is home to about half of the known seagrasses, with the southern Australian bioregion home to many endemic species (Walker 1999).

Globally, with the exception of Antarctica, seagrasses are found in shallow coastal and estuarine environments. Focusing on Western Australia, the main habitats for seagrass are found within sheltered coastal embayments, protected bays, lagoons enclosed by fringing reefs and estuaries. The seagrass species observed within estuaries have very different life traits and characteristics compared with those that grow in the state's coastal waters. The seagrass functional form model[1] was first proposed by Walker et al. (1999), expanded by Carruthers et al. (2007) and more recently adapted to include life-history traits specifically related to resilience; that is, resistance and recovery (Kilminster et al. 2015). This model places large seagrass species, such as *Posidonia*, and small species, such as *Halophila* and *Zostera*, at opposite ends of the scale (Figure 1). These larger seagrass species are characterised by restricted but persistent distribution, and slow regeneration, turnover and ability to recover from perturbations. In contrast, the smaller seagrass species are typically more widely distributed, can reproduce quickly from stores of seeds in the sediment (termed seed banks), can be transitory or ephemeral with rapid turnover, and can respond rapidly to perturbation. Estuaries worldwide tend to be dominated by these smaller seagrass species, likely due to their ability to adapt to the dynamic conditions within an estuary, such as salinity variation over tidal and seasonal cycles.

Seagrasses grow in soft sediment, with their roots and rhizomes below the sediment surface. They are able to reproduce sexually and asexually. Asexual vegetative growth via rhizomes enables seagrasses to colonise large areas, which are termed seagrass meadows. Asexual reproduction can also occur by vegetative fragmentation where fragments of plants establish new meadows. Originally thought of as rare, fragmentation is now considered fairly important for maintaining seagrass populations (Di Carlo et al. 2005; Kendrick et al. 2005; Hall et al. 2006; Thomson et al. 2015).

[1] This is a conceptualisation of how the attributes or form that each seagrass species or genus possesses (e.g. body size, investment in rhizomes) influences the ecology of the seagrass meadow (i.e. its function).

Seagrasses can take up nutrients from both the water column and the sediment porewater. As such, seagrasses typically invest significantly in the below-ground parts of the plant. This below-ground biomass is described as both an asset and a burden (Hemminga 1998) – the burden being the high energy costs of growth and root and rhizome maintenance, making the plants vulnerable to unfavourable sediment conditions.

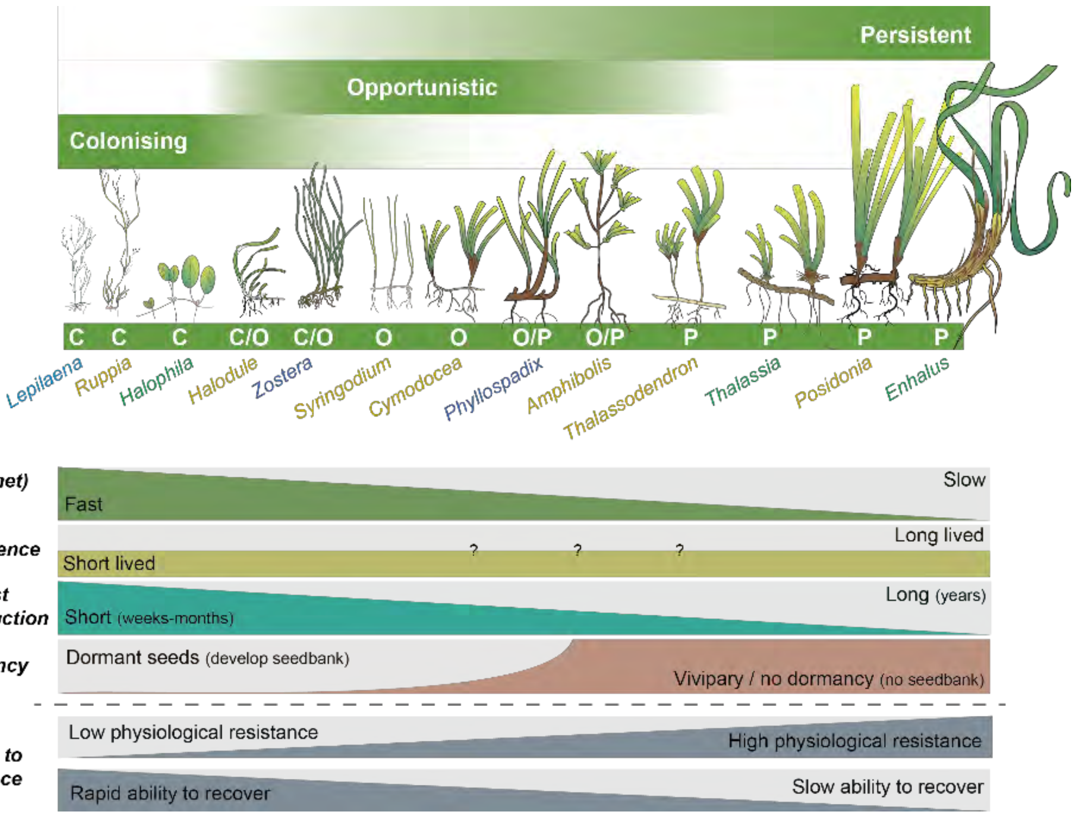


Figure 1 *Seagrass functional form model for seagrass resilience – from Kilminster et al. (2015)*

1.2 Seagrasses in south-western Australian estuaries

This report investigates four estuaries in the state's South West: Leschenault Estuary, Hardy Inlet, Wilson Inlet and Oyster Harbour. Each of these estuaries is a focus of the Regional Estuaries Initiative carried out by the Department of Water and Environmental Regulation[2]. The dominant species we have observed in these estuaries are *Halophila ovalis*, *Ruppia megacarpa* and *Posidonia australis*. In addition, we have observed *Zostera muelleri* and *Posidonia sinuosa* but to a lesser extent. Not all species occur in all estuaries. For the unique environmental and physiological traits of *H. ovalis, R. megacarpa* and *P. australis,* see Figure 2.

[2] Formerly the Department of Water

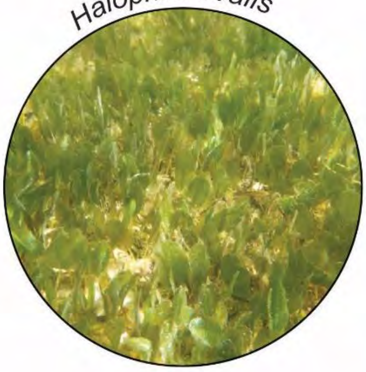
SEAGRASS SPECIES	ENVIRONMENTAL INFORMATION	PHYSIOLOGICAL TRAITS
Ruppia megacarpa 	Found in: permanently and intermittently open estuaries Requires moderate to high light conditions Brackish to saline waters Requires fresh water for germination	Male and female flower on the same plant Forms a seed bank Seeds are 1- 2 mm, shaped liked a beaked drupe Can grow high vertically
Halophila ovalis 	Found in: intertidal to deep waters, permanently open estuaries Requires moderate to high light conditions Low to hypersaline conditions	Male and female flower on separate plants Forms a seed bank Seeds are 0.5 mm and spherical Form leaf pairs on a petiole Forms a 'carpet' like meadow
Posidonia australis 	Found in: subtidal, sheltered environments, permanently open estuaries Requires high light conditions Marine salinity	Male and female flower on the same plants No seed bank Fruits float- oblong to ellipsoid 2-3 cm long Take ~10 years for seeds to form a mature plant Can grow high vertically

Figure 2 *Key environmental and physiological traits of the dominant seagrass species observed in our estuaries:* Ruppia megacarpa*,* Halophila ovalis *and* Posidonia australis

1.3 Ecosystem values of seagrass

Seagrasses provide a range of ecosystem services (Figure 3). They are a key element of estuaries and fulfil various important ecological functions. Seagrasses are primary producers – forming the base of complex food webs – and a food source (e.g. for black swans, *Cygnus atratus*). They provide habitat and shelter and represent a significant nutrient and carbon sink[3], while oxygenating and stabilising sediments. The benefit of seagrasses comes from their structure, which unlike macroalgae includes roots that anchor them to the seabed. This helps to stabilise sediments, which in turn reduces turbidity caused by sediment resuspension and also protects our shorelines (Koch et al. 2007). Seagrass meadows are commonly cited as nurseries for juvenile fish and support diverse and productive faunal assemblages compared with un-vegetated sediments (Orth et al. 1984; Valentine & Duffy 2006). Substantial seagrass coverage within an estuary indicates good sediment and water quality, although an absence or overabundance of certain seagrass species, or the presence of persistent nuisance algal blooms, may indicate excessive nutrients in the estuary.

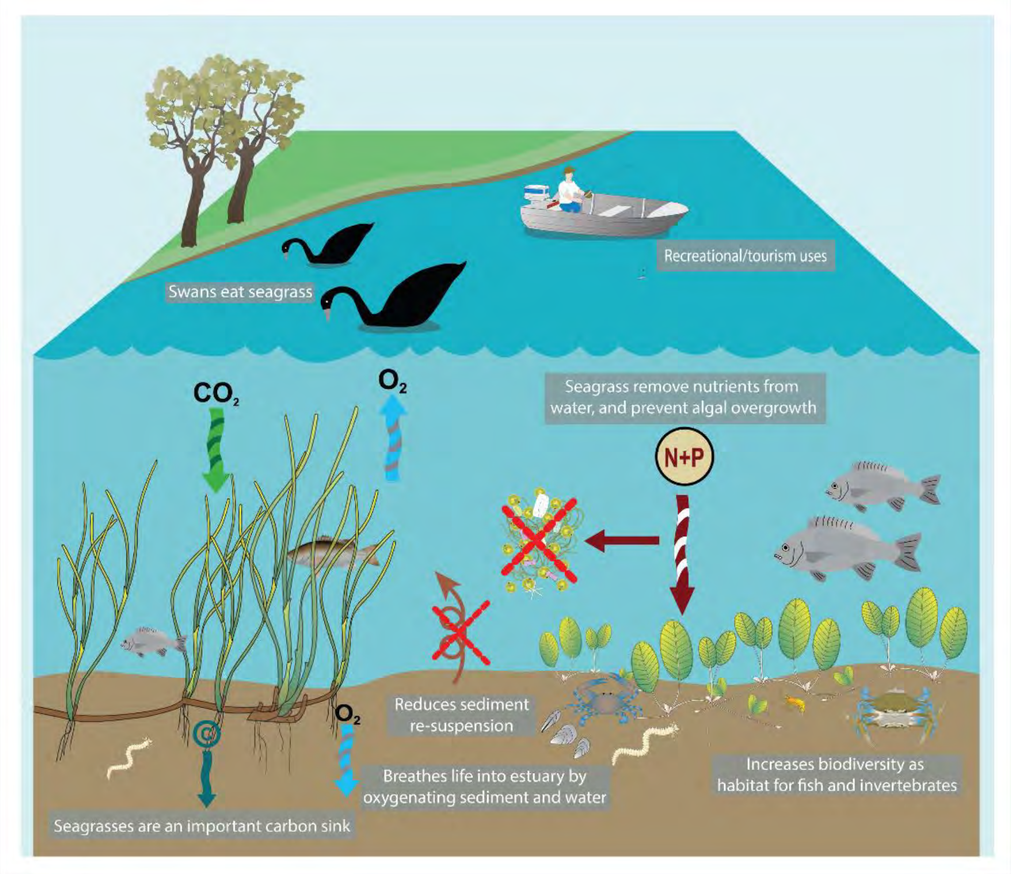


Figure 3 *Ecosystem services provided by seagrasses*

[3] The carbon captured in marine ecosystems, mostly via mangroves, tidal marshes and seagrass, is often termed 'blue carbon' and a number of Australian state and federal government strategies currently focus on protecting and/or restoring blue carbon stores to mitigate carbon emissions. An International Partnership for Blue Carbon has also been established – see https://bluecarbonpartnership.org/

1.4 Threats to seagrass

Most seagrass losses can be attributed to human activities in adjacent catchments that cause increased nutrient and sediment runoff (Walker & McComb 1992; Orth et al. 2006). Seagrass loss can result from direct and indirect causes (Figure 4). Direct causes tend to be localised and involve the physical removal of either the seagrass or the sediment in which it grows (trampling, dredging, storms, propeller or anchor scarring). Indirect loss of seagrass may often be more widespread and is often due to diffuse issues that can affect a large area of seagrass. Indirect loss of seagrass occurs when stressors (light, nutrients, salinity, temperature and toxicants) increase beyond that which the seagrass can tolerate. Ecosystems may be subjected to stark shifts in regime when the system reaches a tipping point, rather than going through a process of smooth gradual change (Folke et al. 2004). An example is a flip from a seagrass-dominated to algal-dominated state, which is considered undesirable for many estuarine ecosystems.

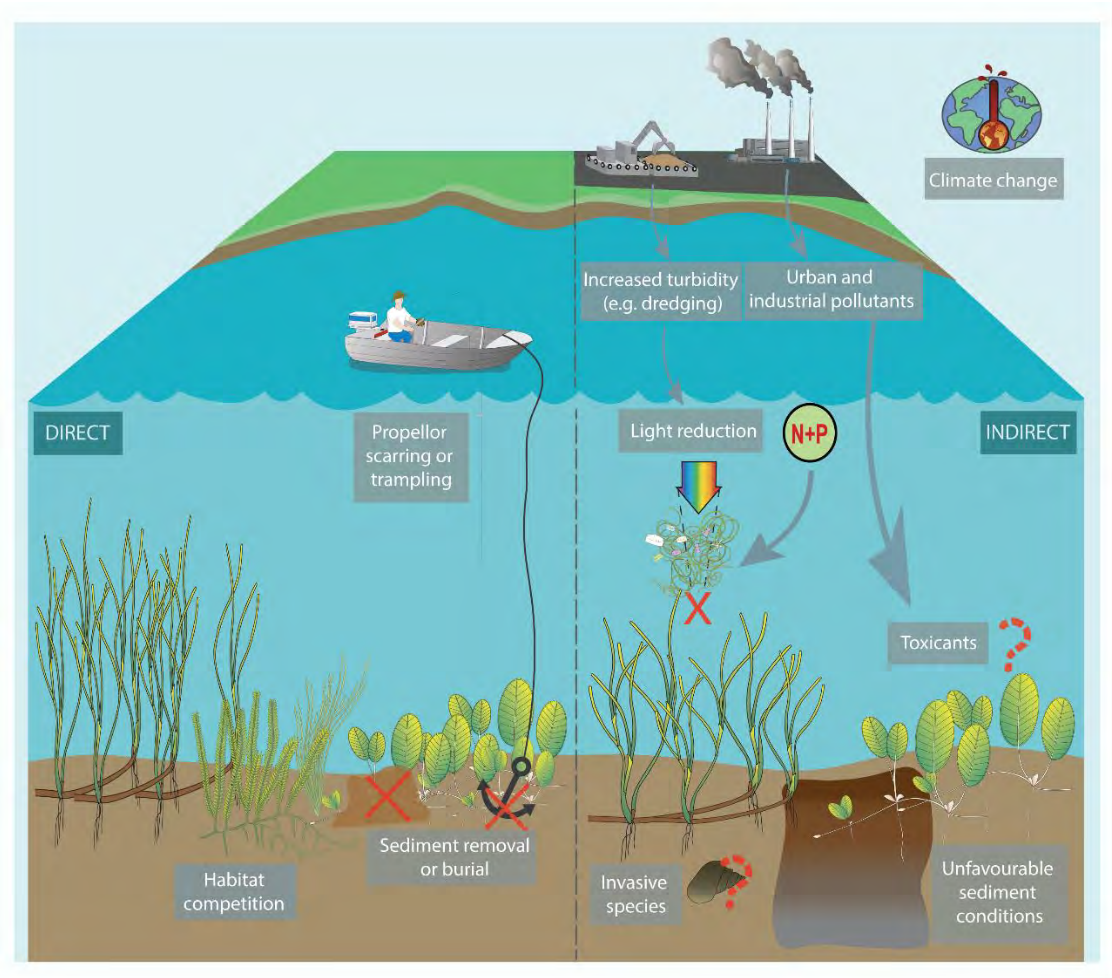


Figure 4 *Direct and indirect threats to seagrasses*

1.5 How and why do we monitor seagrass?

Seagrass has often been termed 'the canary of estuarine environments' as it requires adequate light and sediment quality to thrive. Seagrasses are significantly affected by the quality of the water delivered to them by river systems, streams and drains that receive runoff from agricultural, urban and industrial land uses. Regular monitoring of seagrass community attributes (such as distribution, percentage cover, composition, biomass and nutrient content) are essential to understand and manage this immensely valuable natural resource. An overabundance of nuisance algae (or sometimes certain seagrass species) can indicate that excessive nutrients are being washed in from the surrounding catchment. Generally, seagrass loss is cause for concern.

The current monitoring program is based on the hierarchical monitoring design proposed by Neckles et al. (2012), which uses information across multiple scales to understand ecosystem dynamics for management (Figure 5). Resilience, the capacity to resist and/or recover from a disturbance, is considered to be a cross-scale attribute (O'Brien et al. 2017), so collecting information at a number of scales provides the best evidence of the status and condition of seagrass within an estuary.

Broadscale monitoring looks at estuary-wide seagrass cover. This approach is useful to monitor seagrass extent and distribution over large areas and can detect long-term and broadscale changes in distribution, yet it does not inform on the ecological condition of seagrass and how it has changed due to local stressors. Fine-scale monitoring, at a few sites, allows for a rapid and consistent approach to understanding change in seagrass cover and distribution. Furthermore, it enables managers to implement remediation (if necessary) at a local scale and provides predictive knowledge to understand ecosystem function and response at a broader estuary-wide scale.

In this report we have also included our observations of macroalgae during the broadscale survey of seagrass (figures located in appendices). This is because of the potential link between macroalgal blooms and the health and abundance of seagrass. While a natural part of an estuarine ecosystem, macroalgae (or seaweeds) are known to respond to nutrient enrichment (Valiela et al. 1997). Nuisance algal blooms are typically the fast-growing green algae that can take advantage of excess supply of nitrogen or phosphorus. The proliferation of nuisance algal blooms is concerning for several reasons, including smothering – which leads to loss of seagrasses and uncoupling of sediment and water biogeochemical cycles, which in turn can change the function and structure of affected ecosystems (Valiela et al. 1997). Note, our annual surveys targeted the period of peak seagrass abundance but did not necessarily correspond with the period of highest macroalgal abundance linked to nuisance algal blooms.

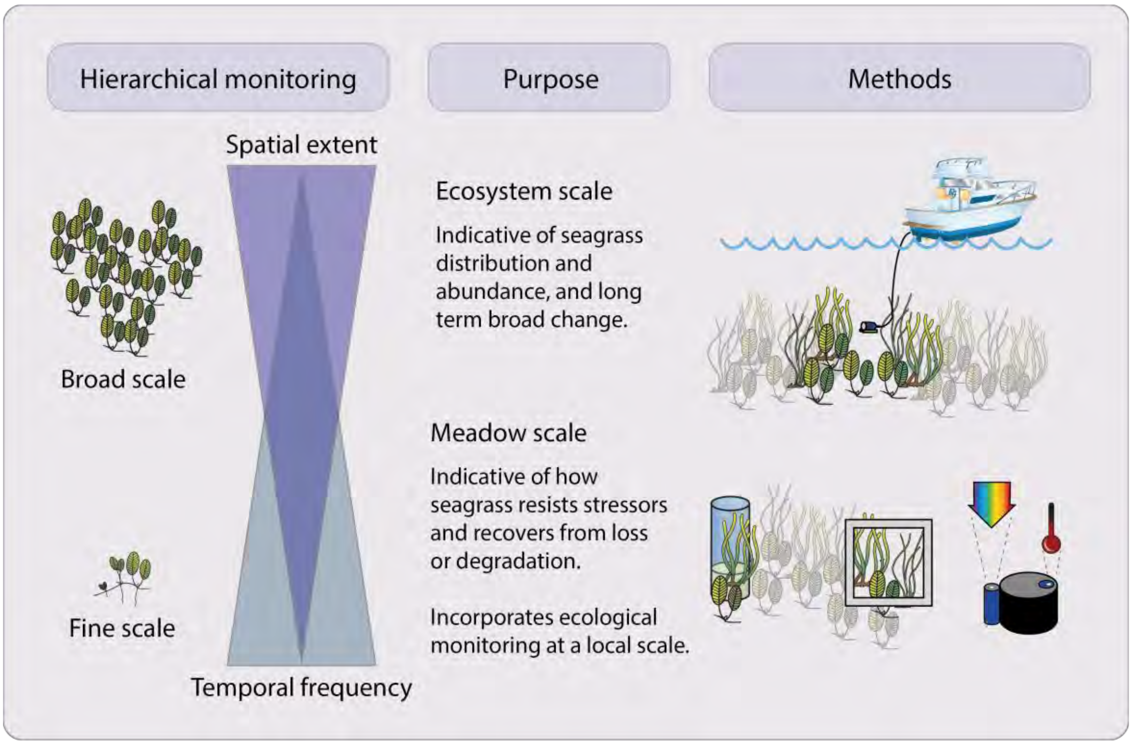


Figure 5 *An overview of monitoring at different scales using the Leschenault Estuary as an example*

1.6 About this report

This report focuses on broadscale seagrass distribution across four Western Australian estuaries; that is, the Leschenault Estuary, Hardy Inlet, Wilson Inlet and Oyster Harbour as assessed during the Regional Estuaries Initiative (2017–2020), compared with historical knowledge. While the principle design of the monitoring was maintained across all estuaries, the unique nature of each system (different seagrass species, area to cover, depth etc.) meant that specific aspects of the monitoring were tailored to each estuary. See Appendix A for details about our methods.

Unfortunately, many of the estuaries in south-west Western Australia are in poor or declining health. The primary cause is eutrophication, whereby an oversupply of nutrients results in the excessive growth of plants and algae, pushing the systems out of balance. The Regional Estuaries Initiative is a $20 million state government program aimed at improving the health of six at-risk estuaries in the south west: the Peel-Harvey, Leschenault, Vasse-Wonnerup, Hardy Inlet, Wilson Inlet and Oyster Harbour (Figure 6). As part of the Science for Management strategy, which aims to expand the monitoring and public reporting of estuary health, the department has been monitoring the condition and extent of seagrass. Note that seagrass coverage in the Peel-Harvey estuary has recently been reported (Krumholz 2019). For the Vasse-Wonnerup, the most up-to-date information is available on the Revitalising Geographe Waterways website: rgw.dwer.wa.gov.au.

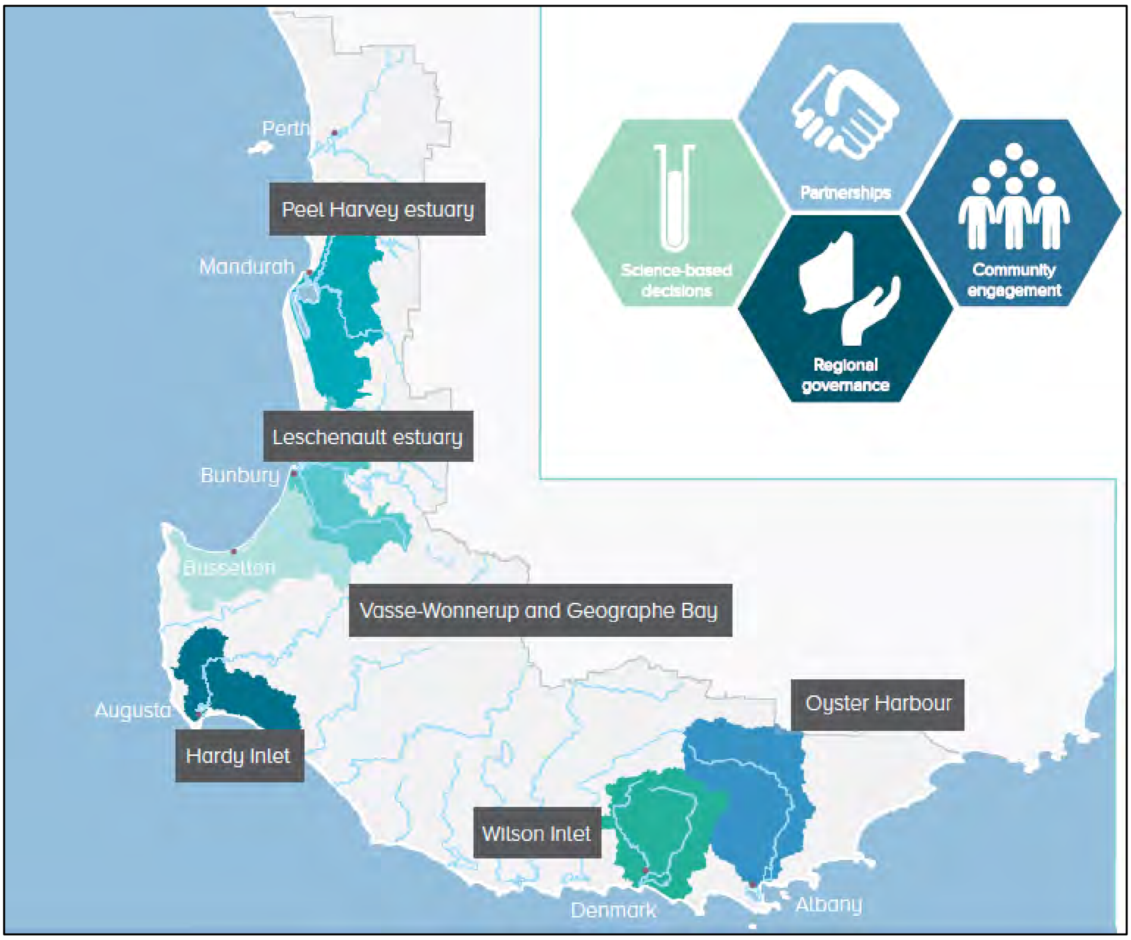


Figure 6 *Estuaries in the Regional Estuaries Initiative and their associated catchments*

Understanding the dynamic nature of estuaries is important to fully appreciate the information reported here about estuarine seagrasses. As partially enclosed waterbodies, estuaries form transition zones between freshwater and marine environments. Estuaries are influenced by the land and by the sea – with freshwater flow carrying sediments and nutrients from the surrounding catchments, and sea water coming into the estuary through tidal cycles. They are naturally dynamic environments with changing environmental conditions on daily and seasonal cycles.

An important feature of many of the estuaries in south-western Australia is the salt wedge. When salt water and fresh water meet, they can form layers, since salt water is denser than fresh water. This phenomenon is known as salinity stratification and may lead to deoxygenation of bottom waters. The position of the salt wedge can vary within an estuary due to the tide and fresh-water inflow influenced by storms and seasons. Some estuaries, particularly on the south coast of Western Australia, have intermittent sandbars at the estuary mouth that prevent marine water exchange. Overall, this dynamic nature results in a diversity of habitats within many of our estuaries and influences seagrass habitats.

2 Leschenault Estuary

2.1 Background

The Leschenault Estuary or *Derbal Elaap* as the Wadandi Noongar people know it, sits just north of Bunbury about 180 km south of Perth. It is a long, shallow (up to 2 m deep) coastal lagoon which is permanently connected to the ocean by an artificial channel called 'The Cut'. The estuary basin has an area of 27 km^2, with an approximate width of 2.5 km and length of 13.5 km. It is elongated in a north to south orientation and separated from the Indian Ocean by a sand dune peninsula (Figure 7).

Figure 7 *Key features of Leschenault Estuary*

The community highly values the estuary for its natural aesthetics, fishing, crabbing, boating and other recreational pursuits. The estuary is ecologically significant as a migratory route for many species of birds and home to a population of dolphins. There is a high level of biodiversity in the area with areas of fringing estuarine forest, saltmarsh, sandy rise vegetation, a wide variety of freshwater vegetation and mangroves (*Avicennia marina*, the

Leschenault region being the most southerly occurrence of this species). These habitats support a large number of faunal assemblages such as fish and crabs. Three seagrass species are reported to be present in the Leschenault Estuary: *Halophila ovalis, Ruppia megacarpa* and *Zostera muelleri*. These species tend to inhabit the eastern and to a lesser extent, the central and western shoreline.

The catchment has an area of 1,889 km^2, more than half of which has been cleared: 49% for agriculture and 3% for industry and urban development. Water from the surrounding catchment is discharged into the estuary by the Preston, Ferguson, Brunswick and Wellesley rivers, and by the Collie River below the Wellington Dam. Of all the catchments, the Collie, Preston and Wellesley catchments contribute the most nitrogen and phosphorus to the estuary. These nutrients can be linked back to beef and dairy farming (Hugues-dit-Ciles et al. 2012). The estuary also receives nutrient runoff from the Myalup Agricultural Precinct as well as from residential and industrial sources by way of Parkfield drain, which is located at the north of the estuary.

The estuary's hydrodynamics have been extensively modified by The Cut, the inner harbour and Leschenault Inlet. The inlet is a waterbody separate from the estuary and encompasses Point McLeod, the site of the original estuary opening. After The Cut was created in 1951, it transformed the estuary. The permanent opening of the estuary has seen its waters become predominantly marine in salinity, whereas before 1951 it was brackish in winter. There is now a marked salinity gradient, from south to north, with the northern end often hypersaline during summer, due to the limited tidal influence and the concentration of salt by evaporation. In general, the estuary basin is well mixed by wind and tidal movements. By contrast, the rivers delivering nutrients from the catchments tend to be highly stratified during low-flow seasons – leading to very low dissolved oxygen, algal blooms and sometimes fish kills.

Freshwater flow into the estuary has also changed. The construction of dams in the catchment has altered the natural flow of fresh water. Rainfall in the south-west has declined some 15–20% since the 1970s (Petrone et al. 2010), resulting in much greater reductions in freshwater flow – a situation forecast to continue (Bates et al. 2008; Silberstein et al. 2012). The limited freshwater flushing results in long residence times for water within the estuary, favouring nutrient, organic matter and pollutant accumulation. Widespread effects on estuarine habitats, flora and fauna are predicted to continue as a result of these altered climatic drivers (Hallett et al. 2018).

These issues, together with population growth and land clearing in the catchment, are a cause for concern for the health of the estuary. Increased urbanisation and agricultural activities result in high inputs of nutrients and other sources of pollution, the disturbance of habitat, more exotic species and increased pressure from boating and fishing. The system is already showing signs of stress and eutrophication, with reports of odours, nuisance and harmful algal blooms, low oxygen in the water column and the occasional deaths of fish, dolphins and black swans.

2.2 Historical surveys (1980s to 2016)

Seagrass was comprehensively monitored and studied for the Waterways Commission in the 1980s to mid-1990s by the Centre for Water Research, The University of Western Australia and the Marine and Freshwater Research Laboratory, Murdoch University (Lukatelich 1986; Hillman et al. 1995; Hillman et al. 2000). Seasonal surveys were carried out between November 1984 and November 1985, then again between October 1987 and May 1988. Biannual surveys (spring and autumn) were conducted between autumn 1988 and autumn 1992, with a final survey in autumn 1993.

All surveys reported *Halophila ovalis* as the dominant seagrass present in the estuary (Hillman et al. 2000). Semeniuk et al. (2000) reported the presence of *H. ovalis* throughout the estuary, except for a deeper channel in the mid-basin (see Figure 8 – left panel), based on data collected in November 1984 and April 1985 from Lukatelich (1986). Hillman et al. (2000) reported that *H. ovalis* was only absent from a small area in the centre of the inlet and inferred this was due to high turbidity driven by wind-induced resuspension of fine, muddy sediments in that area.

Based on surveys from 1984–93, Hillman et al. (2000) also reported *Ruppia megacarpa* and *Heterozostera tasmanica*[4] along the eastern shoreline, and *Zostera muelleri* near the marine end of the estuary, close to The Cut. The Department of Water (now Department of Water and Environmental Regulation) surveyed seagrass again in April 2009 and estimated that seagrass covered about 68.8% of the estuary area (Figure 8 – right panel; Table 1). *H. ovalis* again dominated seagrass observations, with *R. megacarpa* being found along the eastern shoreline and far north estuary. *Z. muelleri* was generally restricted to the most marine area of the estuary, and *H. tasmanica* was not observed.

Table 1 *Number of observations made in the Leschenault Estuary in 2009, 2015 and 2016, estimated seagrass area and percentage of estuary area covered with seagrass*

Year	Observations (boat)	Observations (kayak)	Estimated seagrass area	% estuary area[5]
2009	130	N/A	1,741 ha	68.8%
2015	114	N/A	905 ha	35.7%
2016	202	170	899 ha	35.5%

[4] It is probable that if the *Heterozostera* sp. was found in the Leschenault Estuary today, we would consider it to be *Heterozostera nigricaulis* or *H. polyclamys* based on Kuo J 2005, 'A revision of the genus Heterozostera (Zosteraceae)', *Aquatic Botany,* vol. 81, pp. 97–140. *Heterozostera tasmanica* is now considered to be confined to Victoria and north and eastern Tasmania, Australia.

[5] Note slight variation in these percentages to those previously reported (newsletters, local presentations and video) are the result of developing methods of interpolation and interpretation. We now consistently use IDW interpolation whereas in the past spline interpolation was used.

A substantial loss of seagrass was noted in the summer of 2013–14. The department resumed routine monitoring of seagrass, with estuary-wide surveys from summer 2015. In 2015 and 2016 seagrass had reduced to only about 36% of the estuary (Appendix B – Figure A 8). *H. ovalis* remained the most commonly observed seagrass, with distributions of the other species similar to patterns described in 2009 (Appendix B – Figure A 9 to Figure A 11). See Appendix B for a further discussion about this loss of seagrass.

H. tasmanica was not observed in surveys conducted after 1993–94, despite more than 6,000 observations made across the three sites monitored in detail from 2013–14 (data not shown).

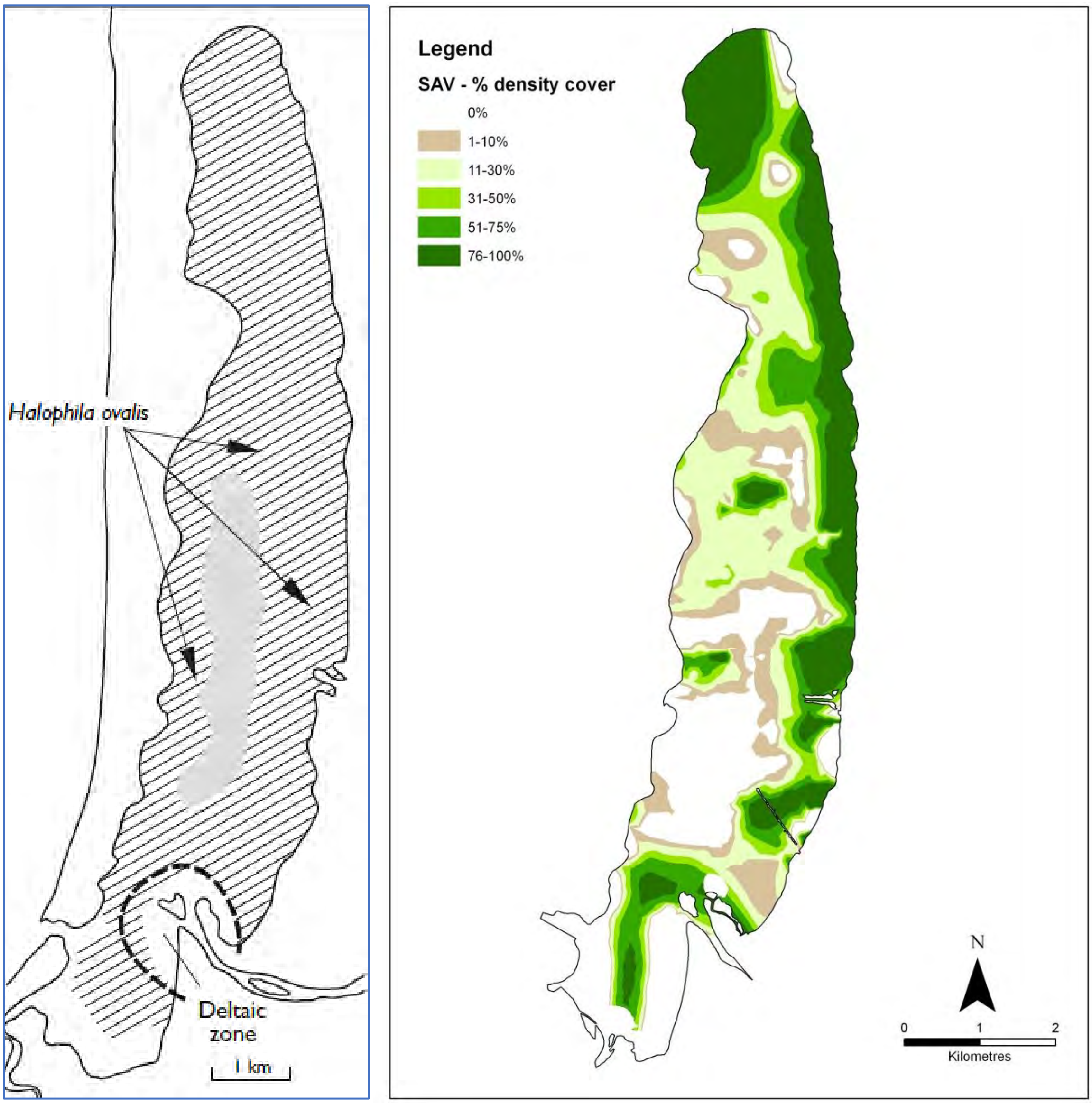


Figure 8 *Historical estimates of seagrass coverage in the Leschenault Estuary – left panel from Semeniuk et al. (2000) likely based on surveys in 1984–85; right panel from survey by the then Department of Water in April 2009 describing the submerged aquatic vegetation (predominantly seagrass)*

2.3 Current monitoring of seagrass in the Leschenault Estuary

Key findings

- Seagrass in the Leschenault Estuary appears to have stabilised and is showing improvement, after the major losses first monitored in 2015
- *Halophila ovalis* remains the most common seagrass species observed, with a slightly expanded distribution in the north of the estuary
- The distribution of *Ruppia megacarpa* has increased, re-establishing in the northern estuary in 2020

Seagrass distribution

We assessed seagrass distribution and cover for the Initiative in the Leschenault Estuary in February 2017, 2018, 2019 and 2020. We chose February as the survey month as it is the peak growing period of the dominant seagrass species *Halophila ovalis* and aligns with previous seagrass mapping the department conducted in 2009, 2015 and 2016 (see Appendix B).

We made more than 200 observations of seagrass each year to create seagrass distribution maps in the Leschenault Estuary and to estimate the area covered by seagrass habitat (Table 2). We surveyed the southern three-quarters of the estuary by boat each year. In alternate years we used kayaks to make observations in the far northern estuary, which is too shallow to access by boat. See Appendix A for a further description of our monitoring methods.

Seagrass was most commonly observed along the estuary's eastern shoreline, while it was consistently absent across years in the central area of its basin (Figure 9). The area of seagrass in the estuary showed a consistent trend of recovery from the lowest area of 751 ha in 2017 to a maximum area of 1,386 ha in 2020 (Table 2). The recovery of seagrass between 2019 and 2020 corresponded to a 12.9% increase in seagrass extent.

Across all years, the abundance of seagrass (described as percentage cover) was consistently highest close to The Cut and along the eastern shoreline north of the main urban footprint of Australind (Figure 10). The areas associated with each cover class are shown in Appendix B – Figure A 7, and generally show increasing seagrass densities over larger areas from 2017 to 2020.

Table 2 *Number of observations made in the Leschenault Estuary across years, estimated seagrass area and percentage of estuary area covered with seagrass*

Year	Observations (boat)	Observations (kayak)	Estimated seagrass area	% estuary area[6]
2017	229	N/A	751 ha	29.7%
2018	231	154	953 ha	37.7%
2019	231	N/A	1,059 ha	41.8%
2020	223	88	1,386 ha	54.7%

In all years we observed the majority of seagrass in less than 1.5 m of water. In 2020, for example, 94% of seagrass was observed in less than 1.5 m of water. Across all four years, we only observed seagrass in waters deeper than 1.5 m on 11 occasions. In all years, seagrass was noticeably absent in the central basin, likely due to sediment resuspension of fine particles making the light climate unsuitable for seagrass.

We recorded three species of seagrass in the estuary across the four years: *Halophila ovalis*, *Ruppia megacarpa* and *Zostera muelleri*. *H. ovalis* has been and remains the dominant seagrass species present in the estuary (Figure 11). *H. ovalis* slightly expanded its range into the northern estuary in 2020. *R. megacarpa* was more restricted to the eastern margins of the estuary, however we found its abundance had increased along the western margins and that it had re-established in the northern estuary in 2020 (Figure 12). The distribution of *Z. muelleri* appeared to be fairly restricted to the area around The Cut and along the western boundary, which maintains close-to-marine salinity all year round (Figure 13).

Given measurements of light[7] taken simultaneously during the survey, it is probable that the areas without seagrass are limited by water clarity. Euphotic depths[8] around 2 m (at the time of survey) were associated with low seagrass density, as was the case for average euphotic depth in the central basin of the estuary in both 2018 and 2020 (Appendix B – Figure A 12).

The proportion of observations in each percentage cover category for both seagrasses and macroalgae is shown in Appendix B – Figure A 5 and Figure A 6, for all survey years. Macroalgae cover increased during the more recent years of the survey, a further increase in cover may inhibit continued seagrass recovery.

[6] Using an area of 2,532 ha determined by GIS for the Leschenault Estuary

[7] Measured as photosynthetically active radiation with a Li-Cor instrument, and multiple readings throughout the water column used to determine the light extinction coefficients and euphotic depth at each site

[8] Depth receiving 10% of the surface irradiance, considered sufficient to sustain seagrass

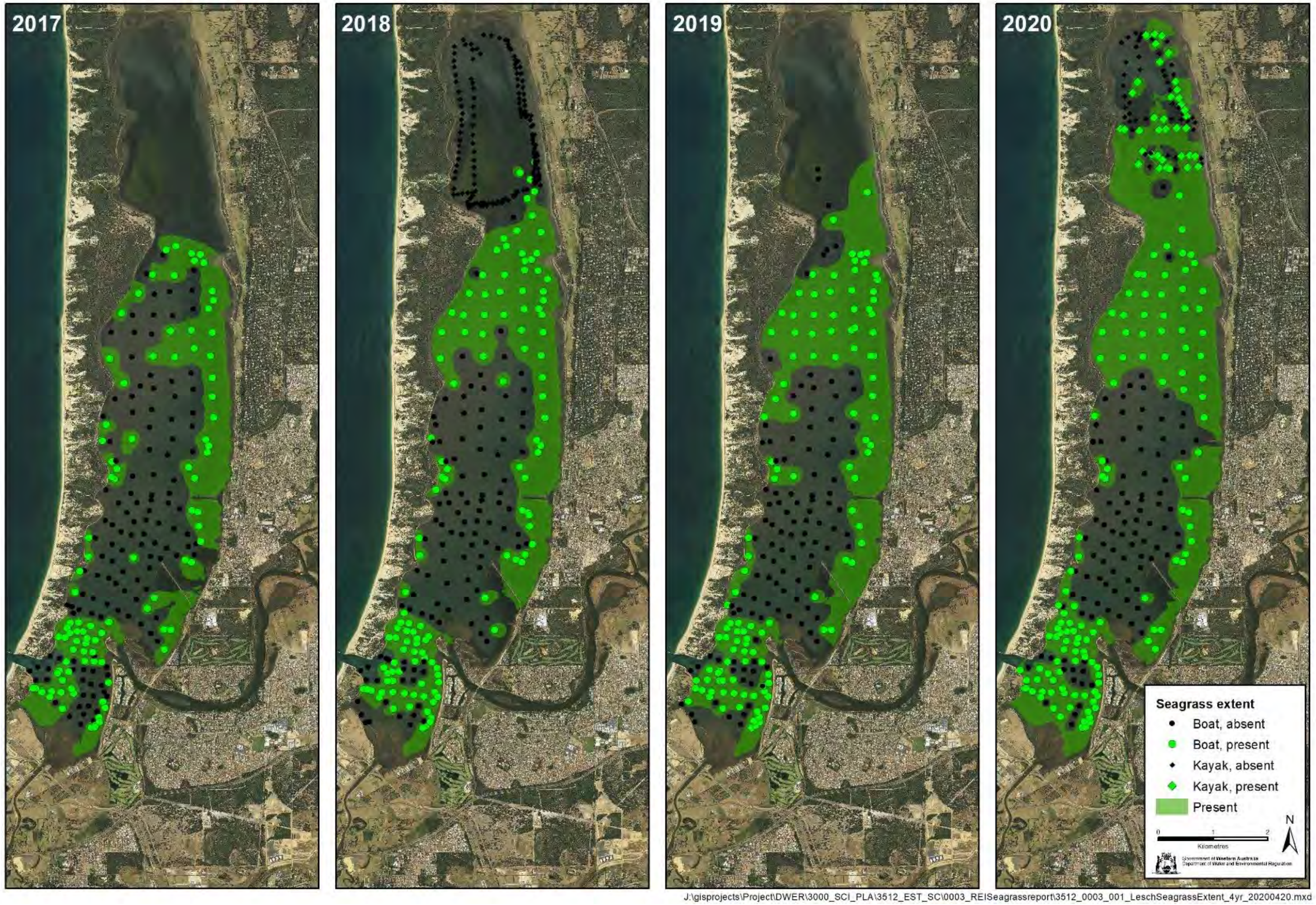


Figure 9 *Seagrass distribution in the Leschenault Estuary from 2017 to 2020*

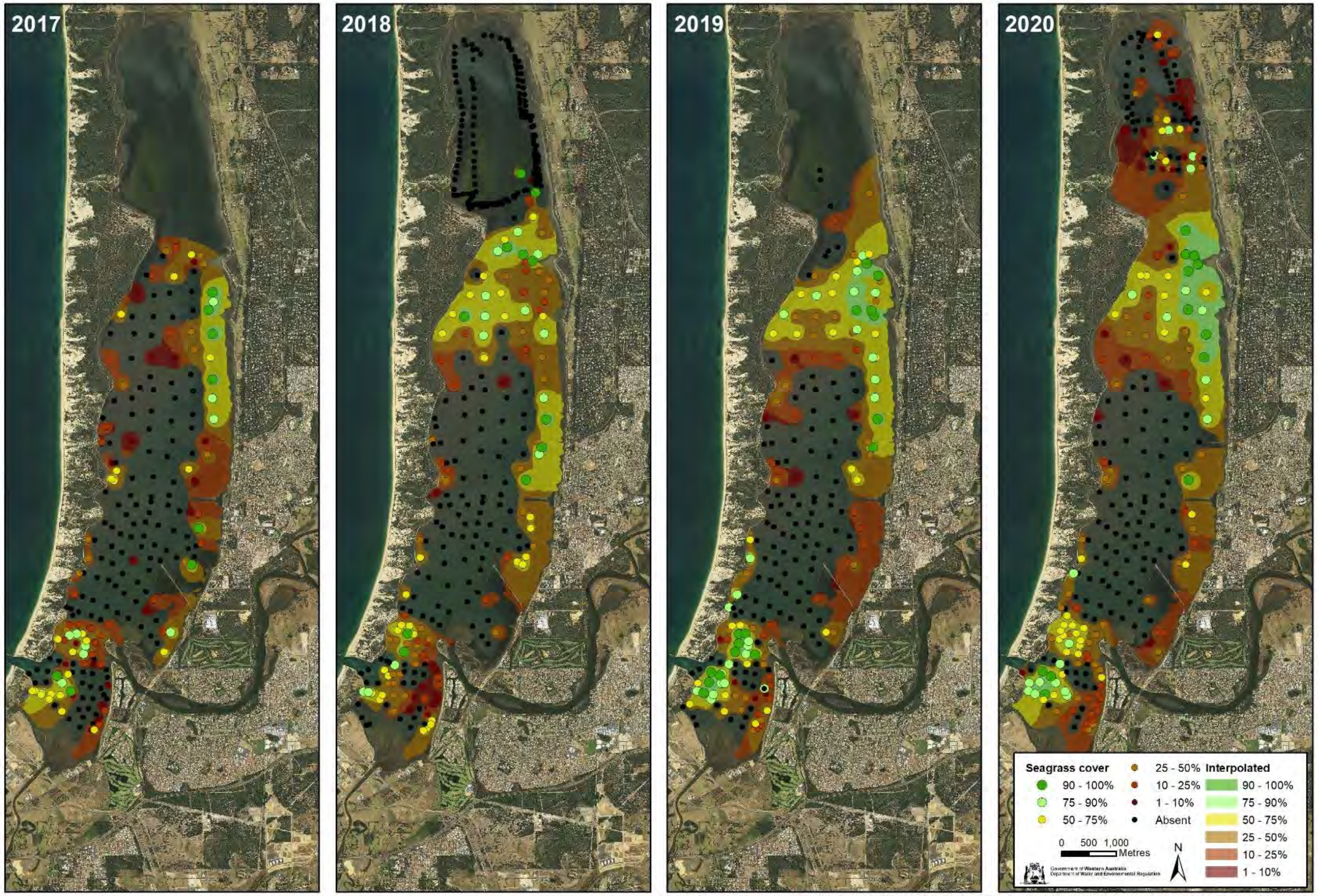


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Figure 10 *Seagrass percentage cover in the Leschenault Estuary from 2017 to 2020*

Figure 11 *Observations of* Halophila ovalis *in the Leschenault Estuary from 2017 to 2020*

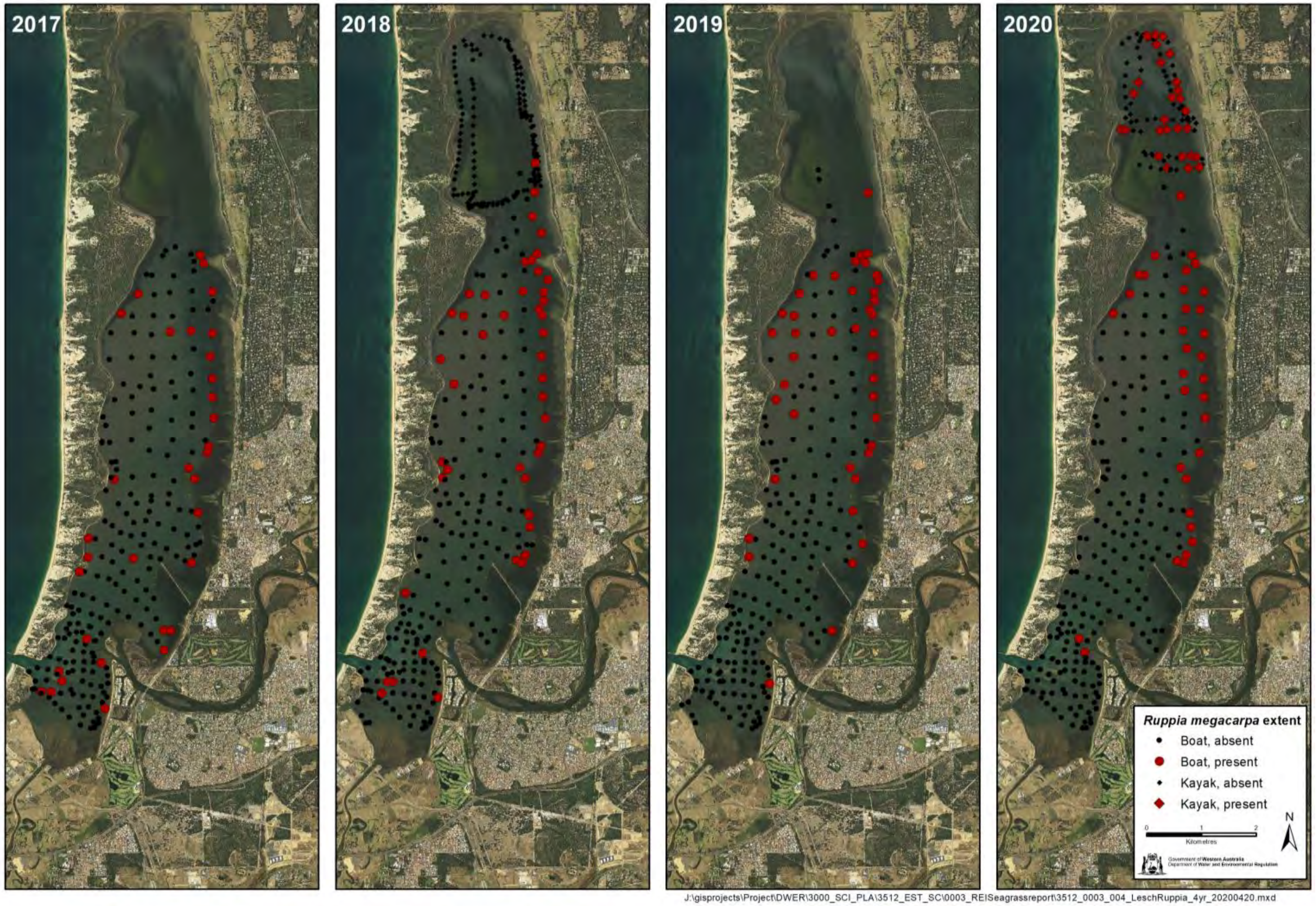

Figure 12 *Observations of* Ruppia megacarpa *in the Leschenault Estuary from 2017 to 2020*

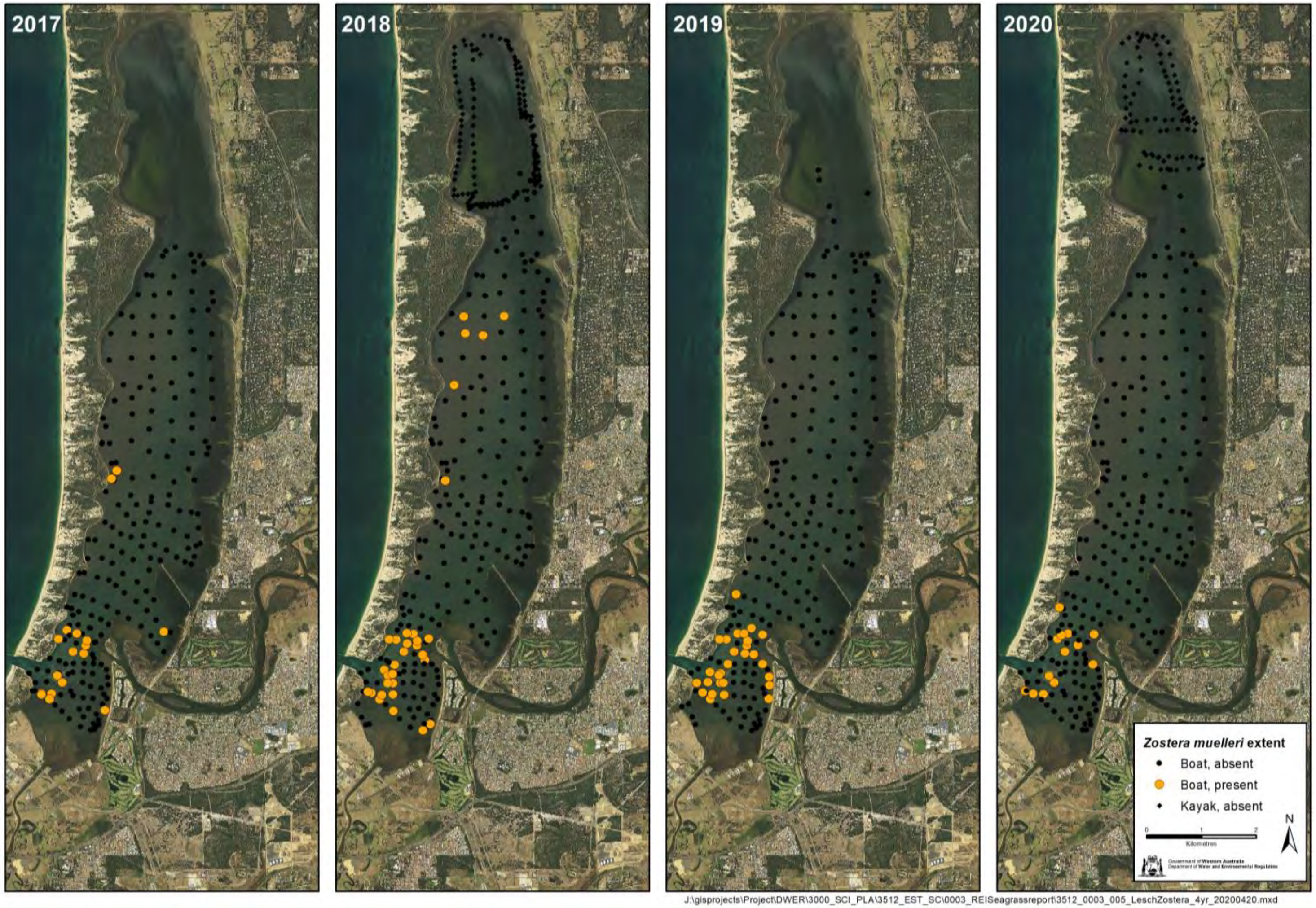

Figure 13 *Observations of* Zostera muelleri *in the Leschenault Estuary from 2017 to 2020*

3 Hardy Inlet

3.1 Background

The Hardy Inlet is a shallow estuarine system located adjacent to the town of Augusta, 320 km south of Perth. It is a relatively small estuary with an area of only 9 km^2, although it is part of a larger system (the Hardy–Blackwood) and at the seaward end of the 42 km-long Blackwood River estuary. *Goorbilyup* is the Wadandi Noongar name for the lower Blackwood River entering the estuary (*Goorbilya* means the large intestine of the stomach). The inlet is one of only two natural permanently open estuaries along the south coast of Western Australia. The mouth is naturally dynamic and its position has moved over the years, yet it has been artificially dredged in the past. Key features of the estuary include Molloy Island, which sits in the estuary's north-eastern area at the confluence of the Blackwood and Scott rivers (Figure 14). The island is partially developed for lifestyle housing but still retains a large proportion of its native vegetation. The smaller Thomas Island is situated in the centre of the widest part of the inlet. Between the two islands is a fluvial delta and the smaller Dick Island. The lower section of the estuary is typically shallow (<2 m).

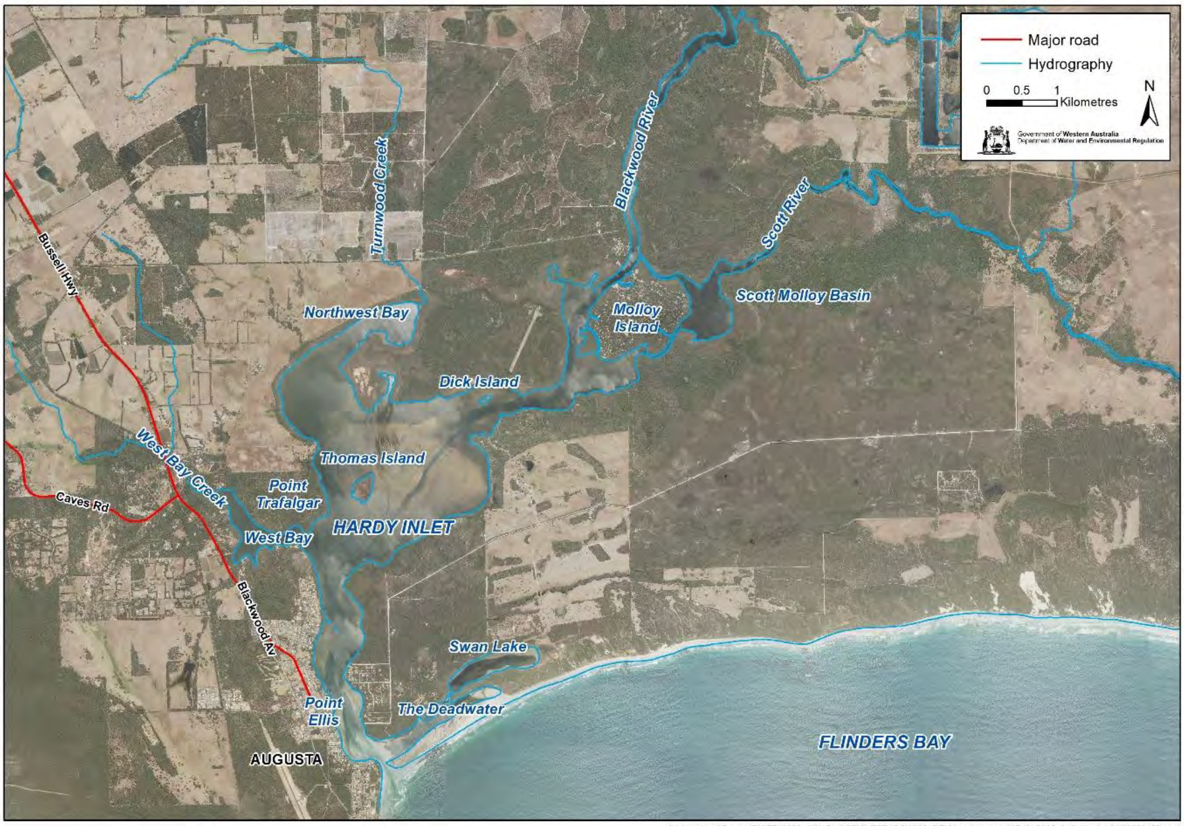

Figure 14 *Key features of the Hardy Inlet*

Hardy Inlet sustains a range of ecological, economic and social values. It has strong ecological values for resident and migratory waterbirds (e.g. black swans, avocets, terns and cormorants) and other aquatic flora and fauna. Waterbirds tend to favour different areas of the estuary depending on their food preferences. Tidal flats support migratory waders feeding on invertebrates in the shallow sediments. Black swans are known to feed on seagrass and cormorants on fish in the deeper and more open areas of the estuary. It is also a popular location for recreational activities such as fishing and boating and supports small-scale ecotourism activities.

The Hardy Inlet is fed by two main rivers, the Blackwood and Scott, and the smaller West Bay and Turnwood creeks, draining nearly 23,000 km^2 of land. The greater Blackwood catchment is the second-largest catchment in the state's south-west, only smaller than the Avon catchment. The catchment can be divided into the Blackwood River catchment (21,400 km^2) and the smaller Scott River catchment (670 km^2). While the Scott catchment is much smaller (only 3% of the greater catchment), it lies within an area of higher rainfall and hence contributes a disproportionally large amount of the flow for its small area.

Much of the Blackwood catchment has been extensively cleared for agricultural activities, yet most of this area is located within low rainfall zones, thus generating very little flow into the estuary. The downstream areas of the catchment receive a higher amount of rainfall, yet the land remains largely forested, which helps minimise the nutrients entering the estuary. Nevertheless total nitrogen loads into the estuary are still significant. Although the Scott catchment has been cleared less, fertiliser has been applied heavily on agricultural land. The region's sandy soils have a low ability to bind phosphorus, hence phosphorus from fertiliser is easily lost in surface water runoff. Hence, the Scott catchment accounts for 60% of the total phosphorus entering the estuary, despite its much smaller size compared with the Blackwood catchment.

The inlet's hydrology is driven by freshwater flow from the rivers, as well as tidal flow. The tidal influence extends about 40 km upstream in the Blackwood and 8 km upstream in the Scott. During winter, the input of fresh water often outweighs the influence of the tide, resulting in fresh water in the estuary for several weeks. This freshwater period is thought to be critical for the germination of *Ruppia* seeds. *Ruppia megacarpa* is known to germinate under freshwater conditions – see Brock (1982). When rainfall and flow decrease, the outgoing freshwater flow is not strong enough to exclude the marine water brought in by the tide. This results in a 'salt wedge', whereby the denser marine salty water sits beneath the less dense fresh water. During summer and autumn, salinity in the inlet is more marine because the river flow has little effect on the incoming tidal water.

Waters from the Scott and Blackwood rivers join the Hardy Inlet to the north of Molloy Island. The water from the Blackwood tends to mix and dilute its nutrient load more rapidly while water from the Scott is slowed by the narrow channel to the east of Molloy Island, restricting mixing and dilution.

Since the 2000s, the Hardy Inlet has started to show signs of nutrient enrichment associated with high-intensity land uses. Signs of stress include blooms of potentially toxic cyanobacteria (*Lyngbya*), fish kills from low oxygen levels in the water, declines in fish stocks and increased blooms of nuisance macroalgae (*Cladophora* and *Ulva/Enteromorpha*).

3.2 Historical surveys (1970s to 2008)

The Hardy Inlet was surveyed by Hodgkin in 1978 and then by Murdoch University's Marine and Freshwater Research Laboratory (MAFRL) in 2000 and 2008. In 1974 and 1975, the Department of Conservation and Environment conducted an extensive ecological survey across the Hardy Inlet in response to an application to establish a sand mine. Results from this survey can be found in *An environmental study of the Blackwood River estuary WA* (Hodgkin 1978). MAFRL conducted a sediment and aquatic flora survey for the Waters and Rivers Commission in 1999, focusing on the estuary's ecological health (see Hale et al. 2000). In 2008, MAFRL assessed the extent and distribution of seagrass and macroalgae in the Hardy Inlet (see Wilson & Paling 2008) for the Department of Water (Figure 15).

Different techniques were used for these surveys, hence some disparity in the results may be present. Hale et al. (2000) used stratified macrophyte sampling collecting cores from 35 sites within the estuary, while Wilson and Paling (2008) used manta-tows along transects.

All the surveys described *Ruppia*[9] as the dominant seagrass species in the Hardy Inlet, with it only being observed in the specific depth range of 0.5 to 1.5 m. Across all surveys *Ruppia* was absent in the inlet channel, likely due to the fast movement of tidal water. In the 1970s, it was observed growing along the shallow margins of the estuarine part of the Blackwood during summer and all-year-round in the inlet channel and the basin. In 2000, *Ruppia* extent was similar, but towards the lower inlet channel the seagrass was described as patchy, with high epiphyte growth. *Zostera mucronata*[10] was also observed in 2000, occupying a small patch to the north of Point Trafalgar and to the north-west of Thomas Island. *Z. mucronata* was also reported in the Congdon (1977) survey along the shoals south of Point Ellis, yet was described as patchy. *Halophila decipiens* was also observed in the lower estuary, along the inlet channel but was not seen in the 2000 or 2008 surveys (Kuo & Kirkman 1995). Seagrass distribution in 2008 was much the same, yet the total area of *Ruppia* had noticeably increased, specifically in the mid to upper reaches of the inlet channel (Figure 15).

The dominant factor for the presence or absence of *Ruppia* in the Hardy Inlet appears to be heavily regulated by depths or factors associated with it. Areas shallower than 0.5 m appear not to sustain the growth of the seagrass. Similarly, *Ruppia* does not appear to grow in areas deeper than 1.5 m, likely because its minimum light requirement cannot be met (Hale et al. 2000). Historically, seagrass does not grow in West Bay, likely due to the bay's turbid nature.

Ruppia is known to respond rapidly to changes within the physical environment. Its biomass has high annual variation relative to other species. In fact, for *Ruppia* in the Wilson Inlet, Carruthers et al. (1997) determined that about 40% of the variation in biomass and distribution could be explained by fluctuations in water turbidity, salinity and depth. The biomass of *Ruppia* and its function as a nutrient sink can vary greatly from year to year and month to month. Therefore, variations in its abundance may not necessarily reflect trends in long-term water quality.

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[9] Likely to be *Ruppia megacarpa*, however generally just referred to as *Ruppia* in historical reports, hence to align with language used in historical reports is just referred to as *Ruppia* within this report

[10] *Zostera mucronata* is not a currently accepted name. It is now known as *Zostera muelleri* subsp. *mucronata*

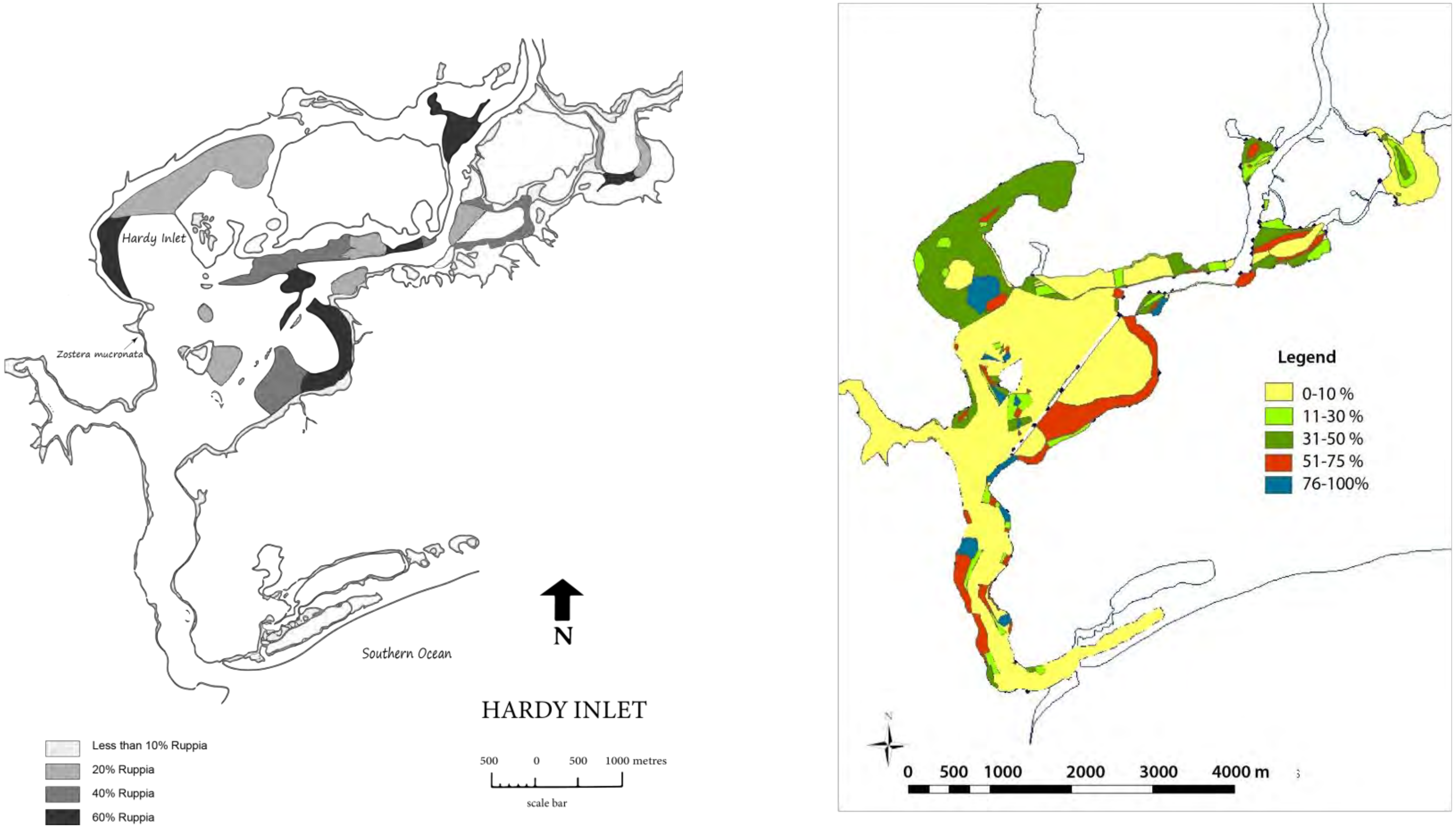

Figure 15 *Historical seagrass coverage in Hardy Inlet from 2000 (left) and 2008 (right) – reproduced from Hale et al. (2000) and Wilson and Paling (2008)*

3.3 Current monitoring of seagrass in the Hardy Inlet

Key findings

- Seagrass in the Hardy Inlet is predominantly *Ruppia megacarpa*
- The current distribution of seagrass seems similar to historical surveys
- Abundance of *Ruppia megacarpa* was much greater in 2020 than the previous year

Seagrass distribution

We assessed seagrass distribution and cover for the Initiative in the Hardy Inlet in the summers of 2018–19 and 2019–20. We made observations using an underwater drop camera, covering the area from the top of Molloy Island to the mouth of the inlet. Swan Lake was not included in the surveys. Additionally, for very shallow areas of the main estuary not accessible by boat, we used aerial imagery (2018–19) and targeted drone footage (2019–20) to infer seagrass cover. See Appendix A for more details.

In December 2018, we made 120 observations across the inlet, recording seagrass distribution and cover (as percentage cover classes) (Figure 16 and Figure 17). Due to extremely shallow conditions we could not use a boat to access the top end of North Bay, the fluvial delta between Thomas Island, Dick Island and Molloy Island, part of the Scott River basin and the eastern margins of the central basin. We inferred the presence or absence of seagrass in these areas using aerial imagery. We did not estimate cover class in these regions for this survey.

In January 2020, we made 109 observations by boat. We made an additional 42 observations of seagrass presence/absence and cover class using the targeted drone imagery we collected for the inaccessible shallow areas.

We estimated the total area of seagrass habitat to be 501 ha in December 2018 and 617 ha in January 2020. This equates to seagrass habitat in the main estuary body of 49.8% in December 2018 and 61.4% in January 2020[11].

[11] Using an area of 1,005 ha determined by GIS for the Hardy Inlet

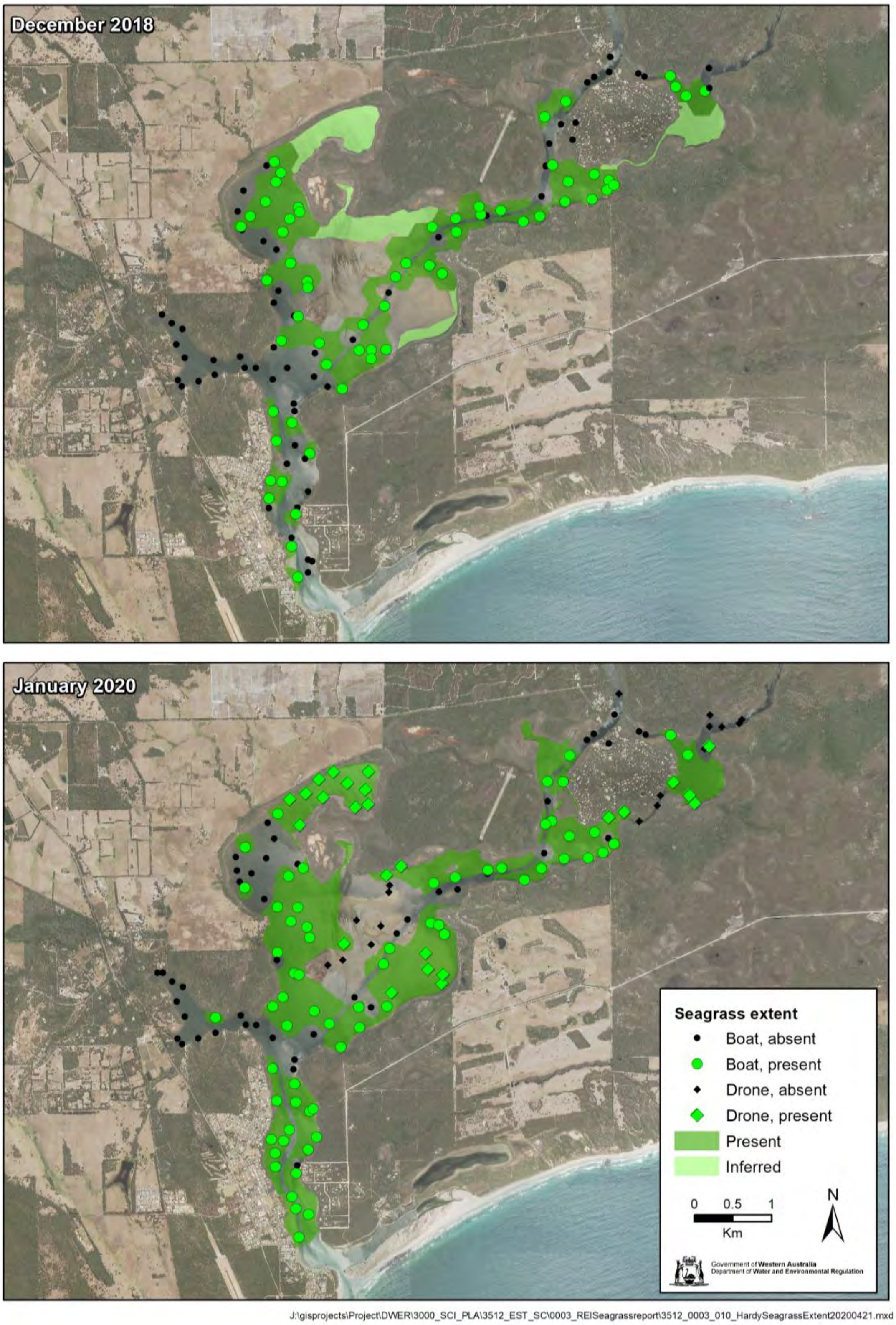

Figure 16 *Seagrass distribution in the Hardy Inlet in December 2018 (top) and January 2020 (bottom)*

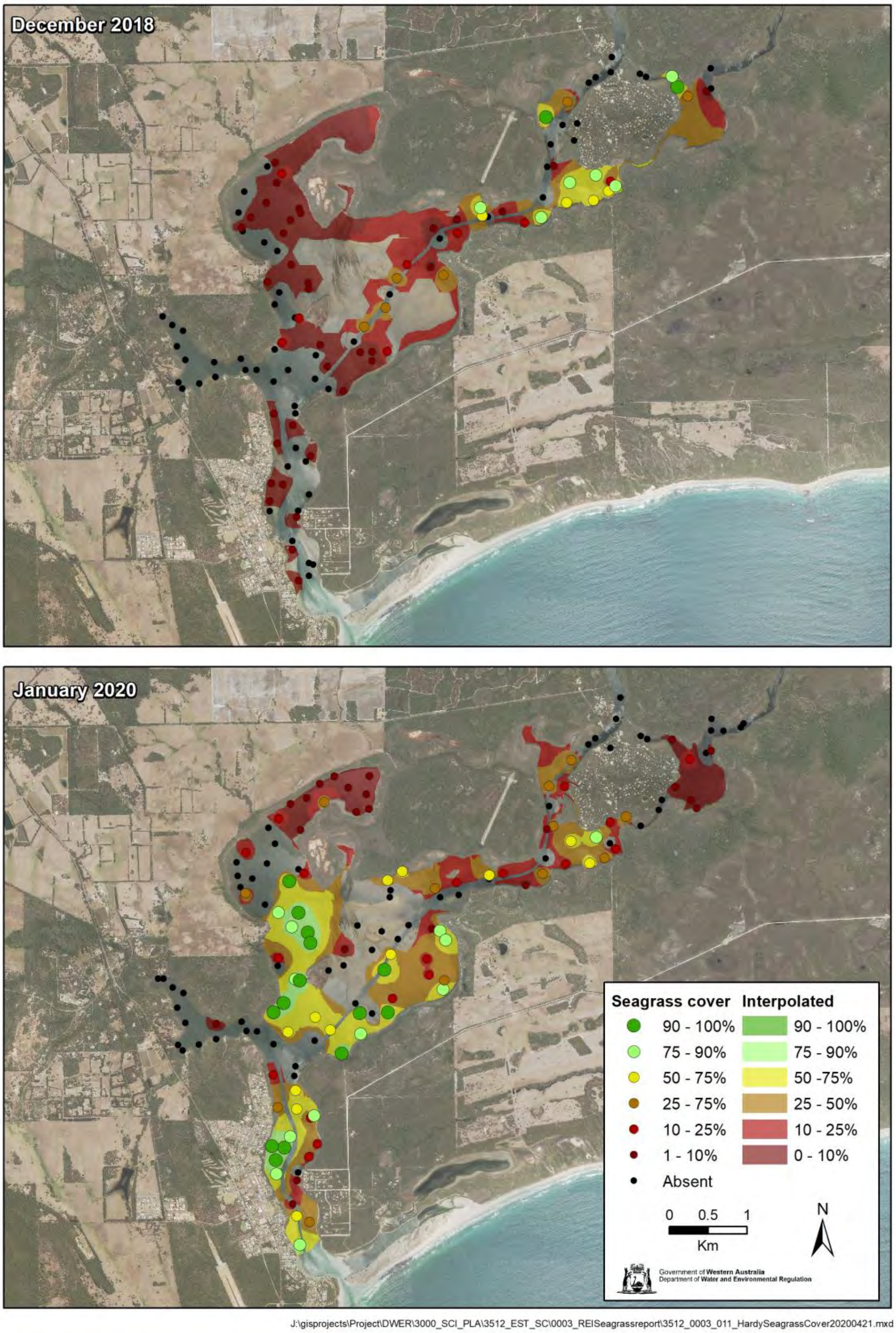

Figure 17 *Seagrass percentage cover in the Hardy Inlet in December 2018 (top) and January 2020 (bottom)*

Both of the department's recent surveys describe *Ruppia megacarpa* as the dominant seagrass species present in the Hardy Inlet. However, our methodology (using an underwater drop camera) may have missed minor amounts of other species present. For example, in 2018 *Zostera* was observed within a seagrass core sample collected at one of the fine-scale sites. Also, in January 2020 we made a speculative sighting with the underwater camera of what was likely *Halophila decipiens* in waters of 5 m depth in the more marine extent of the inlet. The presence of *H. decipiens* in the lower Hardy Inlet was confirmed in May 2020 (Appendix C – Figure A 16 and Figure A 17). Both species have previously been reported in the inlet (Kuo & Kirkman 1995; Hale et al. 2000). Minor amounts of *H. ovalis* were also observed within the meadows of *H. decipiens* in May 2020.

We believe the *Ruppia* species is *Ruppia megacarpa* due to several observations of distinctive flowering at the time of survey. Historically, however, it has been reported as *Ruppia maritima* (Congdon 1977) – perhaps unsurprising since the genus underwent revision in Australia in 1982 (Jacobs & Brock 1982). As with previous seagrass surveys, *R. megacarpa* was confined to a depth limit of between 0.5 m and 1.5 m, with the exception of three observations made at a greater depth in the 2020 survey.

Seagrass extent in both 2018 and 2020 appears largely similar to the last survey conducted in 2008. In 2020 the extent seems to have expanded, particularly in the inlet channel area between the townsite of Augusta and the eastern shoreline. Extent also appears to have increased between 2018 and 2020 along the eastern boundary of the central basin, however this may be due to the detailed aerial imagery from the drone enabling better data capture. Between 2008 and 2018, there appears to have been a slight reduction in seagrass cover in parts of North West Bay, followed by more loss between the 2018 and 2020 surveys.

In both surveys seagrass was noticeably absent in West Bay, which was described as extremely turbid and shallow. This bay is considered too turbid to support the growth and survival of seagrass. It has also been suggested that the sediment is too silty, affecting the ability of the roots to anchor the seagrass (Wilson & Paling 2008).

In 2018 seagrass cover across Hardy Inlet was fairly low, with the median percentage cover range being 1–10%, with some isolated areas of higher density such as south of Molloy Island (Figure 17). This seems to align with historical surveys where cover appears to be fairly low across the estuary, with areas of higher density along the mid to upper reaches of the inlet channel, around Molloy Island and on the eastern margin of the basin. In 2018 almost 50% of observations reported no seagrass present, with less than 2% of the observations being in the highest seagrass cover class of greater than 90% (Figure A 13).

By contrast, the 2020 survey reported that 40% of observations recorded no seagrass and almost 10% recorded cover of more than 90% (Figure 17 and Figure A 13). The median cover of seagrass (excluding observations made using drone imagery) increased to 10–25%.

Macroalgae was observed more often in December 2018 than in January 2020, and the abundance estimates by cover class are shown in Appendix C – Figure A 15.

4 Wilson Inlet

4.1 Background

Wilson Inlet, or *Nullaki* as the local Noongar people know it, is located on the south coast of Western Australia, adjacent to the town of Denmark. The inlet is 14 km long west to east and about 4 km wide, with a total area of 48 km^2. It is a seasonally closed estuary. Most of the estuary is a broad, shallow (average 1.8 m deep) flat-bottomed lagoon bordered by coastal dunes adjacent to a granite headland. Its maximum depth is 4 m. A sandbar isolates the estuary from the ocean, typically for several months of the year. The bar is artificially opened in winter most years, once the water level reaches about 0.7 m above mean sea level (MSL), to mitigate against flooding. The inlet has been opened every year since 1958 with four exceptions (2007, 2010, 2014 and 2019) due to low rainfall and low inflow volumes. The bar naturally closes each year when river flow ceases and ocean waves deposit sand, reforming the bar.

Different water conditions arise depending on whether the bar is open or closed. When the bar is closed, water tends to be saline to brackish, well mixed and oxygenated from surface to the bottom. Concentrations of nutrients and algae are typically low. These conditions indicate a 'healthy' estuary system. When the bar is open, stratification can lead to a saltwater layer underneath a fresh to brackish surface layer. Dissolved nutrient concentrations are slightly higher due to inflow of nutrient-rich water from the catchment, which together with higher temperatures, results in greater plant growth. During prolonged stratified conditions, low oxygen concentrations at the sediment can lead to the release of nutrients from the sediment.

The inlet is fed by two major tributaries, the Denmark and Hay rivers, as well as by three smaller rivers – the Sleeman River, Cuppup Creek and Little River – draining about 2,300 km^2 of land (Figure 18). The Denmark River accounts of 27% of the total catchment area and the Hay River 55%. About 55% of the Wilson Inlet catchment has been cleared of native vegetation to support livestock grazing, cereal cropping, plantations, horticulture and residential land use.

In the 1970s a large increase in the distribution and biomass of *Ruppia megacarpa* across the estuary was reported. This increase caused widespread concern within the community about changes in estuary function, restricted boat access, the effect on fisheries, and the increased occurrence of nuisance wrack on beaches.

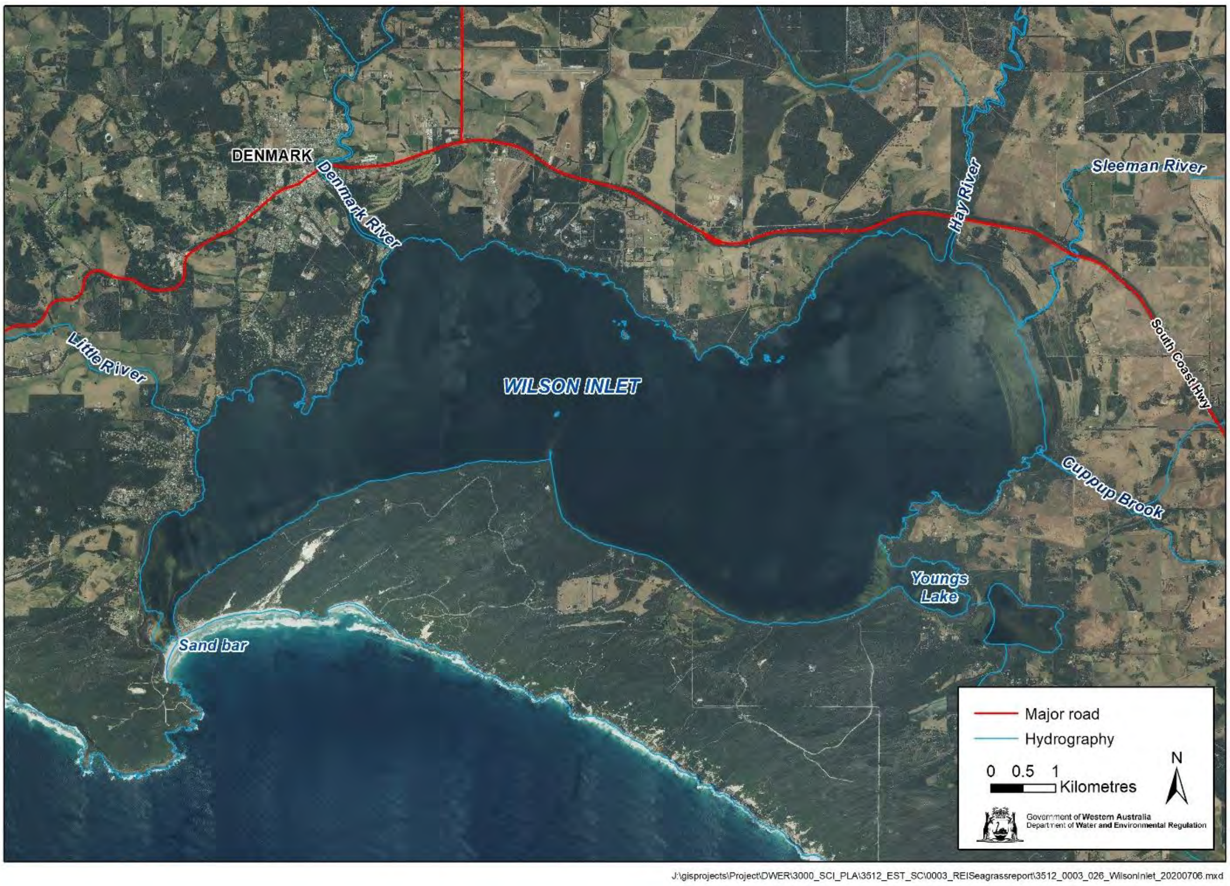

Figure 18 *Key features of Wilson Inlet*

4.2 Historical surveys (1980s to 2007)

Ruppia megacarpa has been observed in the Wilson Inlet for decades, particularly in the freshwater river mouths. Large increases in the distribution and biomass of *R. megacarpa* were reported in the 1920s and more recently in the 1970s. The increase in seagrass biomass to nuisance proportions caused concern within the community, as boat movement became restricted and large quantities of wrack rotted along the shoreline.

Surveys conducted in 1982, 1983 and 1994 describe the distribution of *R. megacarpa* as restricted to the shallow flats around the perimeter of the estuary. The central deeper basin did not appear to support the growth of seagrass. Bastyan et al. (1995) produced baseline maps of *R. megacarpa,* with the distribution being very similar to the previous observations.

Carruthers and Walker (1999) and Carruthers et al. (1999) conducted extensive surveys in the Wilson Inlet and investigated many physiological traits and responses of *R. megacarpa* to an array of varied environmental conditions. Broadscale observations of the estuary indicated that *R. megacarpa* was still the sole seagrass species in the Wilson Inlet and found no evidence of long-term increases or decreases in the abundance and distribution of the seagrass. Their experiments did, however, suggest that about 38% of the variation in the abundance of *R. megacarpa* could be explained by the physical characteristics of the water column (turbidity, salinity and depth). They also found that if conditions became favourable and a seed bank was present, *R. megacarpa* would be able to recover rapidly from a drastic reduction in distribution and cover.

The former Department of Water mapped the distribution of seagrass in the Wilson Inlet in 2007. *R. megacarpa* was observed throughout the estuary at depths less than 2 m, again dominating the outer perimeter, leaving the central basin area void of seagrass (Figure 19). Seagrass density was predominantly in the 11–30% cover range with some isolated areas of higher density. Seagrass density, as expected, decreased with increasing water depth. This study estimated the area covered by seagrass to be 2,640 ha and considered its extent was comparable to the previous survey in 1996.

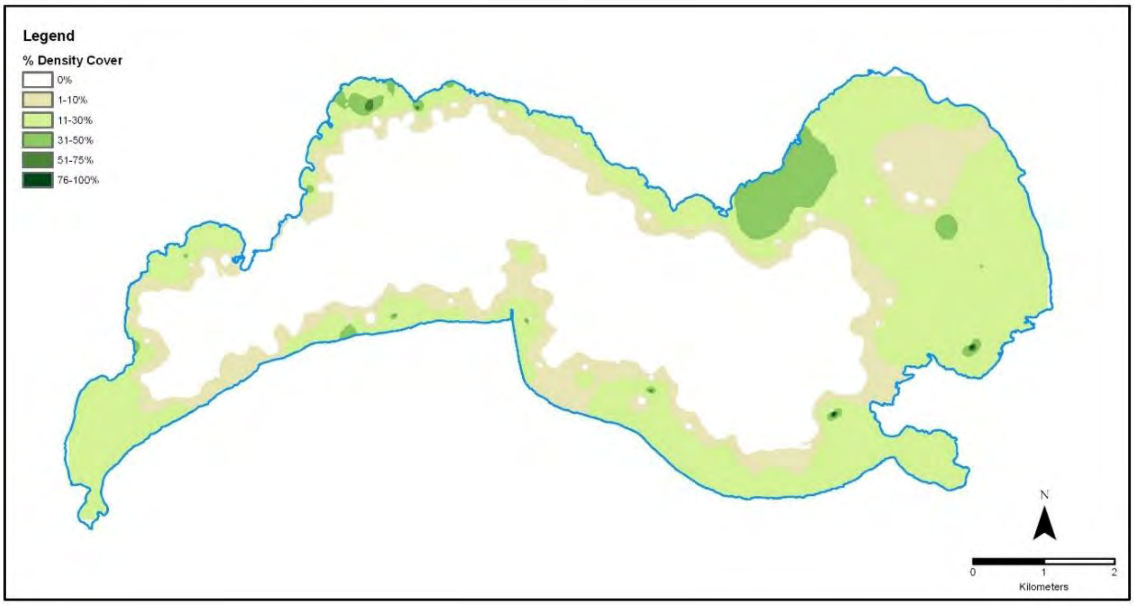

Figure 19 *Seagrass abundance in Wilson Inlet in 2007*

4.3 Current monitoring of seagrass in the Wilson Inlet

Key findings

- *Ruppia megacarpa* extent appears relatively stable in the Wilson Inlet
- Seagrass percent cover varied between the years sampled, potentially as a result of bar conditions. Seagrass was less dense in December 2019 given the bar had remained closed and the water was deeper and more tannin-stained, which would have reduced light reaching the seagrass.
- Macroalgae observed during these surveys were most abundant during December 2019, the year the sandbar was not open

Seagrass distribution

We surveyed Wilson Inlet in December 2017 and again in April 2018. (The sandbar at the mouth of the estuary was artificially opened 24 August 2017 and closed naturally on 25 March 2018.) We visited the estuary on these two occasions within the same 'summer season' as this was the likely time of greatest seagrass biomass, as reported in Carruthers et al. (1997). In April 2018, it was clear the seagrass had begun to seasonally senesce. We surveyed the seagrass again in December 2019 but this time the bar had not been opened because conditions for a successful opening had not been met. Table 3 describes the characteristics of each survey, including the number of observations we made on each occasion and the estimated area of seagrass.

The estimated areal extent of seagrass in both December 2017 and April 2018 were very similar, covering about 42% of the estuary (Table 3) – despite far fewer observations of seagrass in the April survey. This is most likely due to the shape of Wilson Inlet: it has few complex shoreline features and water depth is a strong factor determining where seagrass is found. Areal extent of seagrass was slightly reduced in the December 2019 survey to 38.4% of the estuary (Table 3). Seagrass appears to have declined in Wilson Inlet (about 580 ha) when compared with the survey from 2007. Seagrass was notably absent in the bay closest to the town site of Denmark and also in the deeper areas of the eastern part of Wilson Inlet.

All surveys described *Ruppia megacarpa* as the only seagrass species observed in Wilson Inlet. Species identification was confirmed in 2017 by numerous observations of the species' distinctive flowering across the inlet.

As with the 2007 survey, *R. megacarpa* was limited to the perimeter of the estuary and seagrass was absent from the deeper central basin area in all recent surveys (Figure 20 and Appendix D – Figure A 18). This is likely due to insufficient light reaching the seabed at these deeper locations, restricting seagrass growth.

Table 3 *Number of observations made in the Wilson Inlet across surveys, estimated seagrass area and percentage of estuary area with seagrass*

Year	Number of observations by boat	Bar status at survey time	Open or closed year	Estimated area of seagrass	% estuary[12]
2017–Dec	173	Open	Open	2,050 ha	42.4%
2018–Apr	70[13]	Closed	Open	2,059 ha	42.6%
2019–Dec	195	Closed	Closed	1,852 ha	38.4%

[12] Estuary area estimated by ArcGIS as 4,828 ha

[13] The 70 points observed in April 2018 were a randomly selected subset of those visited in December 2017, with the purpose to conduct a more rapid estuary-wide assessment to allow field time for fine-scale measurements (not reported here)

For the season when the bar was open (2017 and 2018 survey) very little difference in the distribution and cover of seagrass was apparent (Figure 20 and Appendix D – Figure A 18). The largest area of seagrass in these surveys had cover of 75–90%. For the summer season when the bar was not open (December 2019) the density of seagrass was lower, with 25–50% cover making up the largest area (Appendix D – Figure A 20) and only a few isolated areas of high density seagrass – see the maps of seagrass cover (Figure 21).

There were fewer observations of the densest seagrass class (90–100%) in 2019, compared with 2017–18. Also in 2019, more observations of no seagrass being present were made, compared with previous surveys (Figure A 19)

Between 70 and 80% of all observations where *R. megacarpa* was present occurred in the depth ranges between 0.5 and 2.0 m, with the median water depth observed across all surveys being 1.6 m. Only about 3% of all observations for each year were made at a water depth of greater than 3 m. Seagrass density also decreased as water depth increased (data not shown).

Canopy height was also estimated during the surveys, across all of which the median height was 0.4 m. Maximum canopy height was greater in the 2017 and 2018 surveys compared with 2019. Appendix D – Figure A 22 shows the canopy height estimations from December 2017 and December 2019.

Macroalgae was observed on 27% of occasions in April 2018 and December 2019, but only on about 5% of occasions in December 2017. Macroalgae was denser in 2018 and 2019 compared with that observed in December 2017 (Appendix D – Figure A 21).

Figure 20 *Seagrass distribution in the Wilson Inlet in December 2017 (top) and December 2019 (bottom) – see Appendix D, Figure A 18, for April 2018*

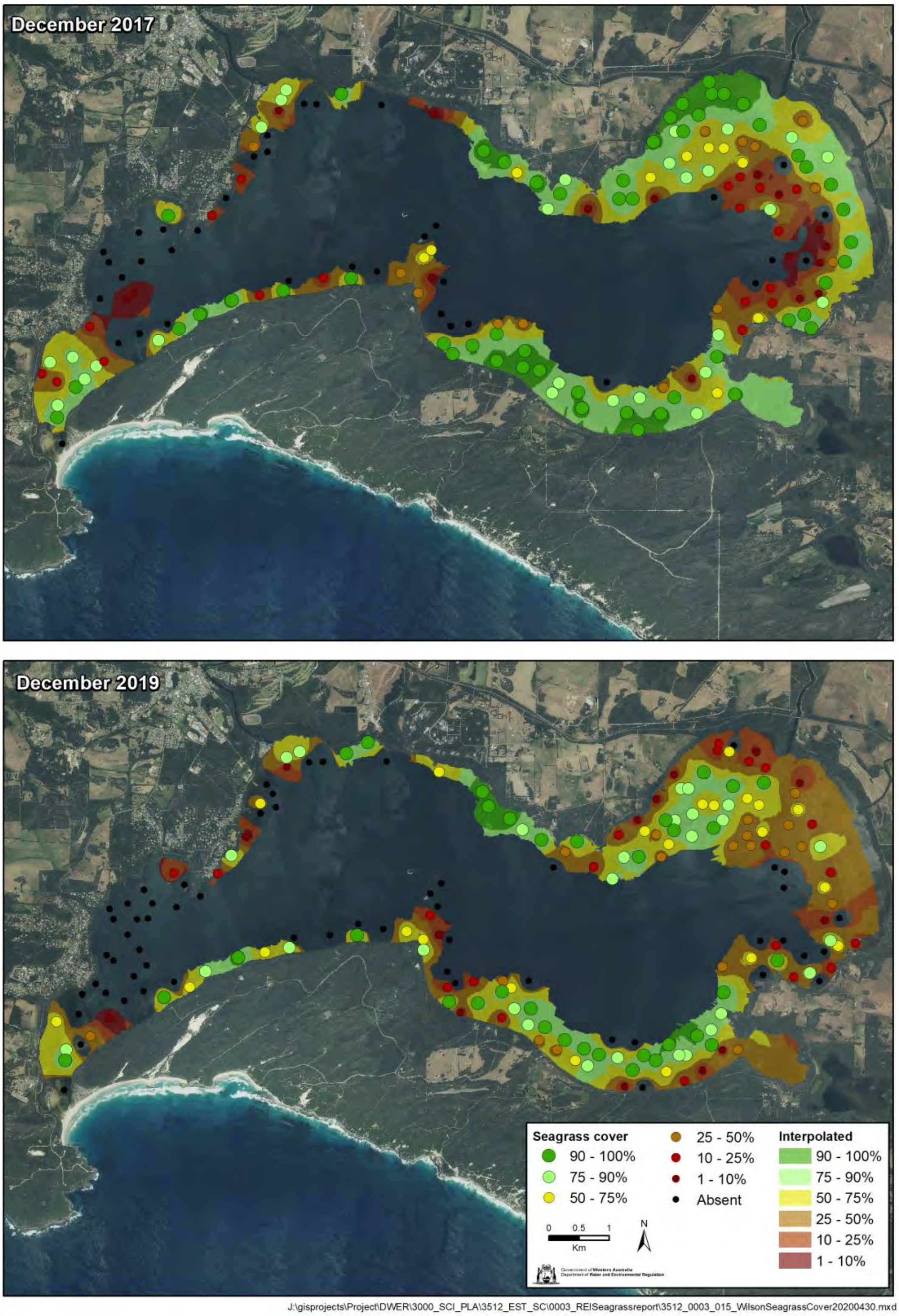

Figure 21 *Seagrass percent cover in the Wilson Inlet in December 2017 (top) and December 2019 (bottom) – see Appendix D, Figure A 18, for April 2018*

5 Oyster Harbour

5.1 Background

Oyster Harbour, or *Miaritch* as the Menang Noongar people know it, is located adjacent to the town of Albany, on the south coast of Western Australia. It occupies a relatively small area of only 15.9 km^2. The harbour is permanently open to King George Sound through a deep (5–6 m) channel near Emu Point (Figure 22). It is the only estuary on the south coast without a sandbar. It is relatively shallow, with an average depth of 2 m and a maximum depth of 10 m.

The surrounding catchment covers an area of about 3,000 km^2 extending northwards to Tenterden and including the Porongurup and Stirling Range national parks. The major inflows to Oyster Harbour are from the Kalgan and King rivers and the smaller Yakamia Creek, which meanders through the city of Albany before entering the harbour on the south-western side. The Kalgan River drains almost 2,500 km^2 of the larger catchment and extends roughly 75 km inland from the coast and is estuarine for about nine kilometres. The King River is only about 30 km in length, with the estuarine influence observed seven kilometres upstream. Both are characterised by strong winter/spring flows and moderate to negligible flows during summer/autumn.

About 65% of the catchment has been cleared for agriculture (cropping for wheat, canola, barley and beef and sheep farming). The only areas within the catchment that have retained a significant portion of native vegetation are those that overlap with the Stirling Range and Porongurup national parks. Large-scale application of fertiliser across the pastoral land has resulted in nitrogen and phosphate leaving the catchment and entering the harbour via the major rivers. Historically, the Kalgan River was found to be the major source of sediment input into the harbour (McKenzie 1962).

Oyster Harbour supports commercial and recreational fishing and oyster and mussel farming. Commercial fisheries target King George whiting, Australian herring and black bream. At present there are two oyster/mussel farm licences for the harbour. The native Angasi oyster (*Ostrea angasi*), the harbour's namesake, was reportedly abundant across the harbour in the late 1700s. However, by the late 1800s the oyster population had declined by 90%, likely due to over-harvesting by dredge fishing (Gillies et al. 2008). The loss of the natural oyster reefs reportedly saw further decline in water quality. The Nature Conservancy is currently working to restore the harbour's oyster reefs, and as of late 2019 had established 1600 m^2 of reef seeded with oyster spat from the Albany shellfish hatchery (Alex Hams, pers. comm.). The restoration of oyster reefs and a healthy seagrass community will help improve water quality and enhance fish abundance and productivity across the whole system.

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Figure 22 *Key features of Oyster Harbour*

5.2 Historical surveys (1960s to 2006)

Studies carried out by the Environmental Protection Authority (EPA) in the 1960s classified Oyster Harbour's ecosystem as 'healthy'. However EPA surveys conducted in the 1980s indicated the harbour had become increasingly eutrophic and that water quality had deteriorated, resulting in increased algal growth and an ecosystem collapse with significant loss of seagrass. The persistent seagrasses, *Posidonia australis* and *P. sinuosa* (family Posidoniaceae), are the dominant seagrasses within the harbour. *Amphibolis* and *Ruppia* species have been reported in the past. Several studies have investigated the ecological role of *Posidonia* sp. including aspects relating to its restoration and its carbon sink capacity in Oyster Harbour (Cambridge et al. 2002; Bastyan & Cambridge 2008; Rozaimi et al. 2016; Serrano et al. 2016). Periodic surveys of seagrass distribution and abundance within the harbour have also been conducted (Bastyan 1986; Bastyan et al. 1996).

The EPA's earliest surveys in 1962 described the seagrass meadows in Oyster Harbour as being healthy and dense. Seagrass, *Posidonia* sp. were observed along the gently sloping sand margins of the harbour up to a depth of 8 m. Since that time the distribution of seagrass in the harbour has gone through a period of extensive loss, with almost 50% being lost (1981 and 1984) due to deterioration in water quality and increased phosphorus causing algal blooms, which in turn suffocated the seagrass and limited light for photosynthesis (McKenzie 1962; Bastyan 1986; Kirkman 1987). Seagrasses were then reported to occur to a maximum water depth of between 1.5 and 2 m and were only observed at greater depths close to the permanent opening where marine water enters the channel.

Recovery of seagrass was reported in the 1990s (Bastyan 1986; Hillman et al. 1990; Hillman et al. 1991), although its density and distribution remained patchy. The last survey was conducted in April 2006, which found that seagrass density in Oyster Harbour was generally low (<15% coverage) (Figure 23). The highest density was observed south of the King River and along the harbour's southern shoreline between depths of 0.2 and 0.5 m. Seagrass was reported to cover a total area of 560 ha (Department of Water, unpublished). *P. australis* was the dominant species, with *P. sinuosa* being commonly observed in mixed meadows. Together these species accounted for 540 ha. *Ruppia* sp. was also observed in a much smaller area, covering about 20 ha. From 1996 to 2006, seagrass presence improved up to 9% but cover declined from 40% to 11.6%.

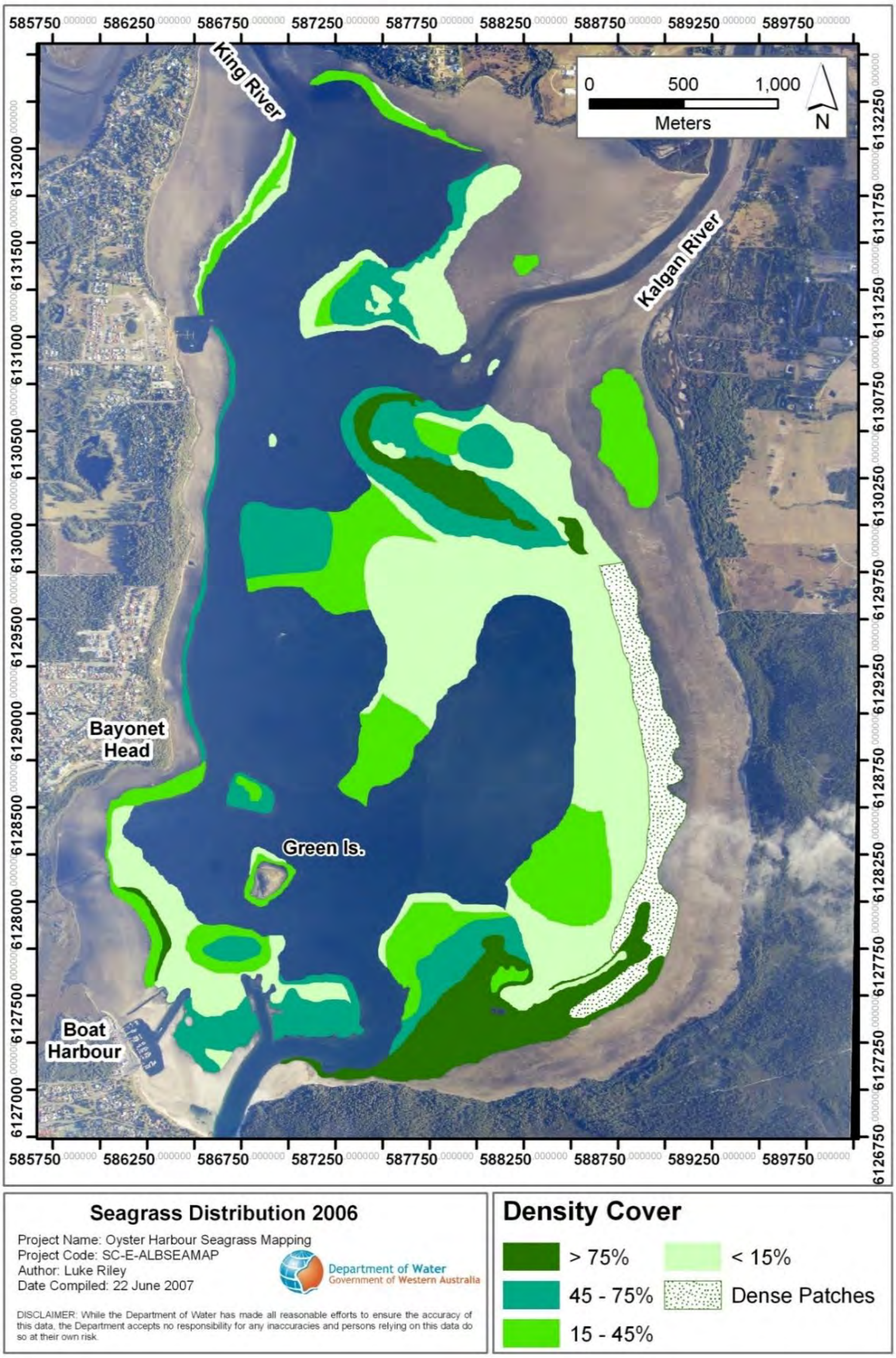

Figure 23 *Seagrass distribution in Oyster Harbour in 2006*

5.3 Current monitoring of seagrass in Oyster Harbour

Key findings

- Seagrass has likely extended its areal coverage by 18% since the 2006 survey
- *Posidonia australis* remains the dominant seagrass species within the harbour; *Posidonia sinuosa* is also present but to a lesser extent
- Seagrass appears healthy, with little macroalgae observed

Seagrass distribution

We surveyed seagrass in Oyster Harbour in March 2019 and made 216 observations using either an underwater camera or viewing cone across the harbour. Note the slight variation in methods compared with other surveys described in Appendix A, which enabled better alignment with historical datasets.

We estimated the areal extent of seagrass in Oyster Harbour to be 663 ha in March 2019, covering 41.6% of the estuary area (Figure 24). We excluded the 174 ha area of the harbour that belongs to aquaculture leases from the survey. Median seagrass cover was between 15 and 45%. Almost 35% of observations recorded cover greater than 75%. The seagrass with the highest density was usually found away from shorelines in the harbour (Figure 25). Seagrass in the category 45–75% cover made up the largest area of 306 ha (Appendix E – Figure A 23).

We observed two species of seagrass: *Posidonia australis* (dominant) and *P. sinuosa*. When we observed *P. sinuosa*, it was usually in mixed meadows and only occasionally on its own. Distribution of *P. sinuosa* appears to be confined to the southern part of the estuary, and close to the channel opening in particular, where marine exchange is higher (Figure 26).

We observed seagrass between 0.5 m and 5.5 m, with 60% of all observations occurring in water depth of 1 m or shallower. The median water depth where seagrass was observed was 0.7 m. Observations in water over 3 m in depth were predominantly of *Posidonia sinuosa*.

Estimated canopy height ranged from 30 cm to 1.2 m in length. On average if the water depth was less than 1 m, the canopy height was 50 cm or less. Once the water column was deeper than 1 m, median canopy height was about 1 m high (see Appendix E – Figure A 24 for canopy height spatial information).

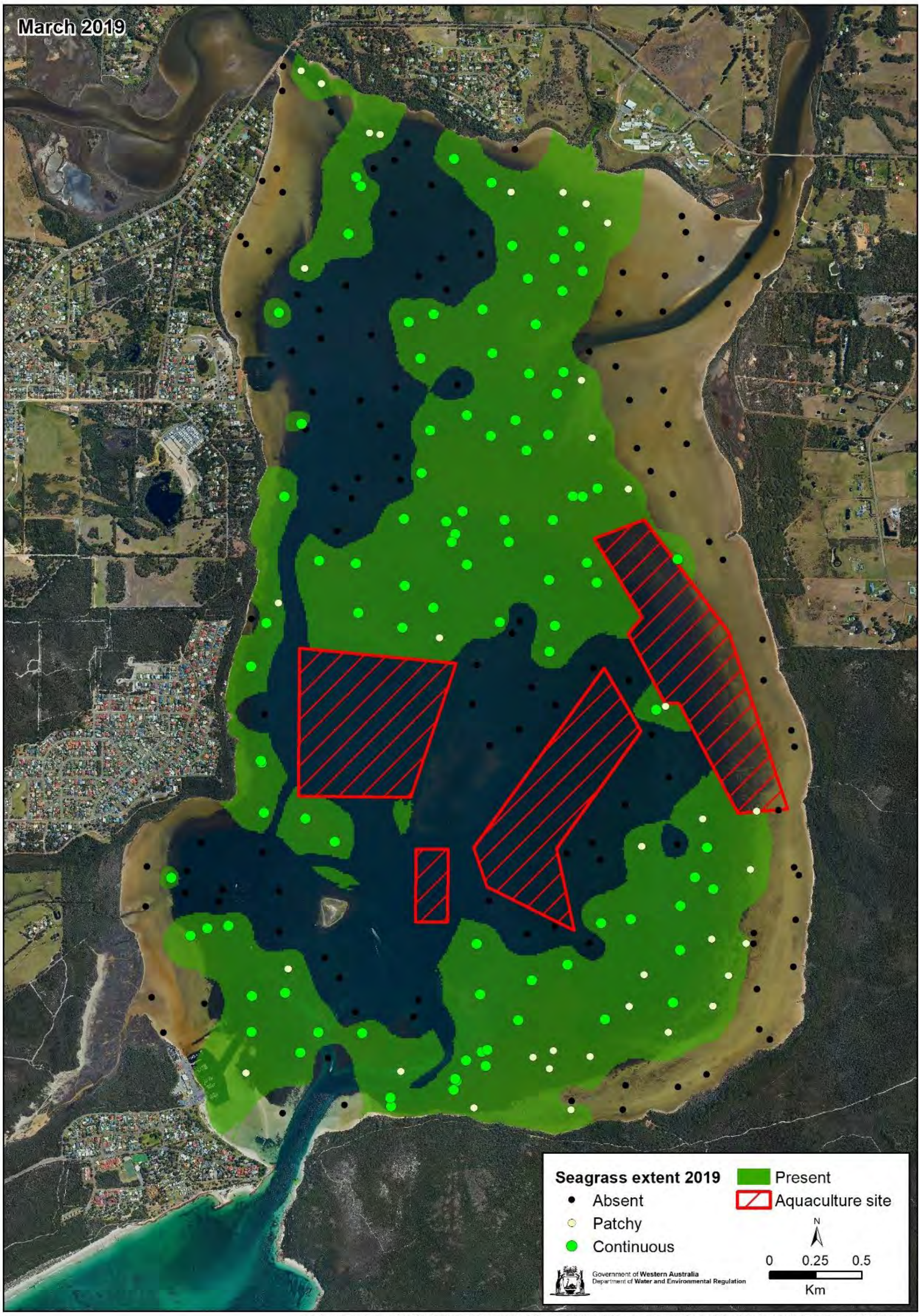

Figure 24 *Seagrass distribution of Oyster Harbour in March 2019*

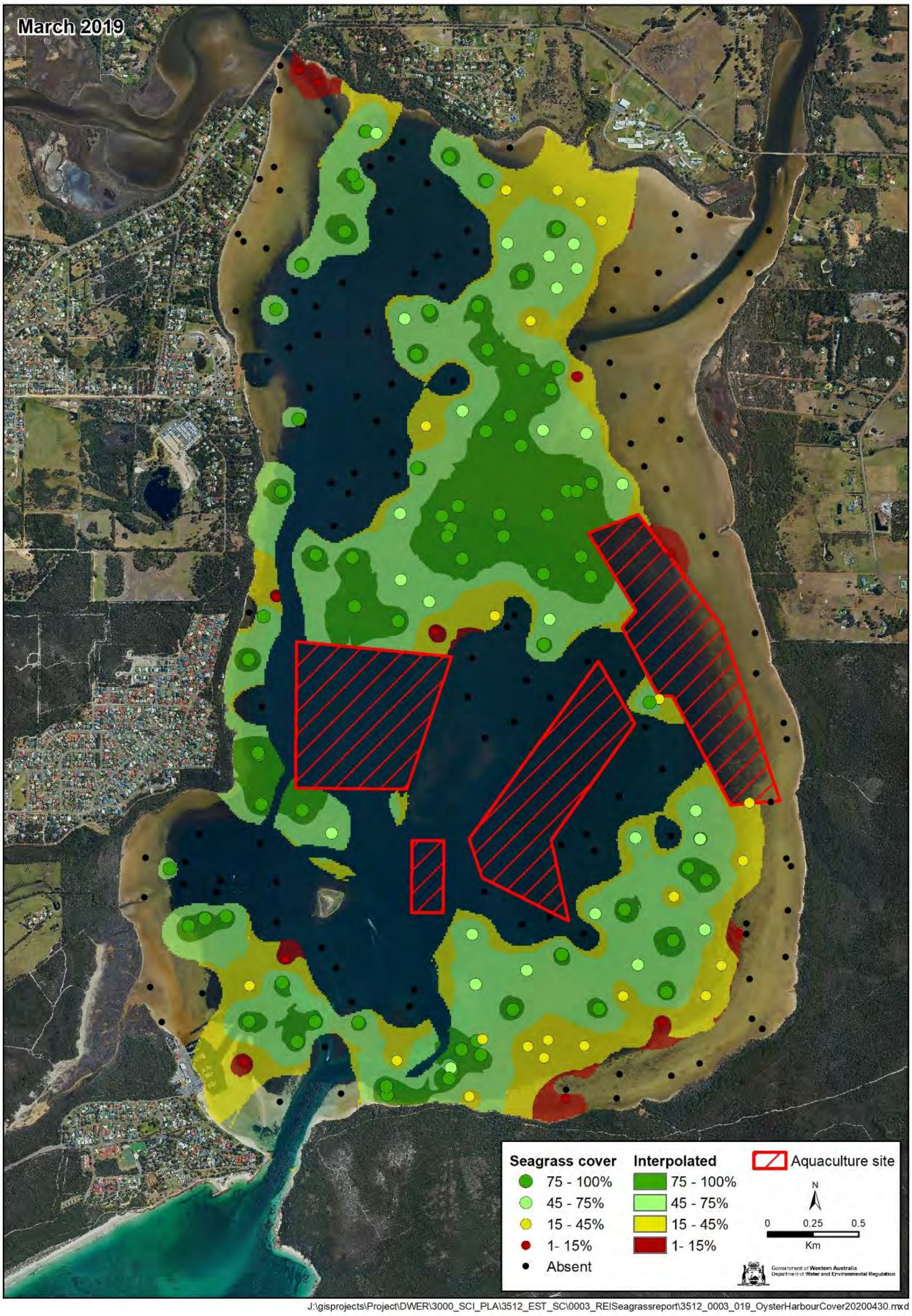

Figure 25 *Seagrass cover of Oyster Harbour in March 2019*

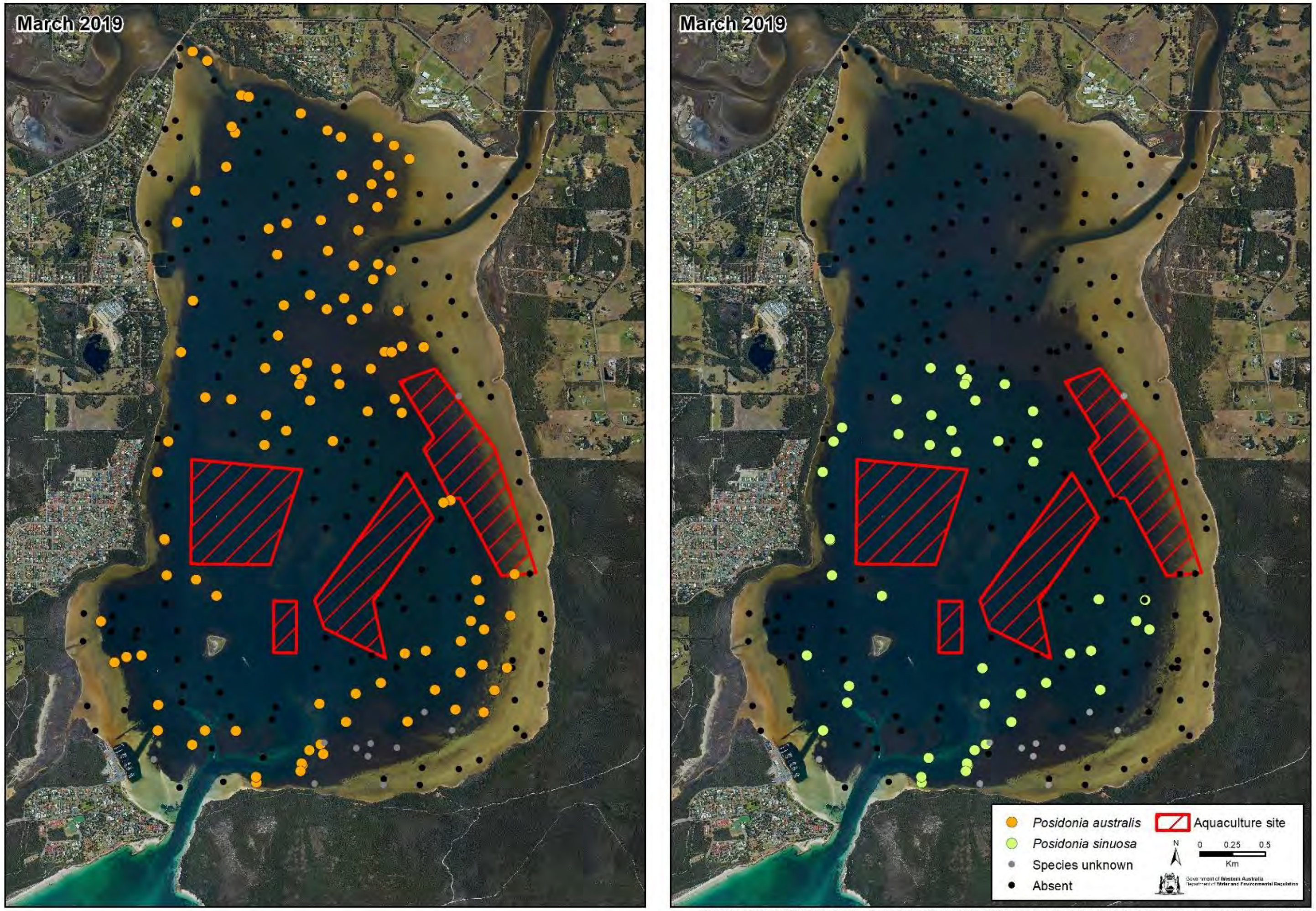

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Figure 26 *Observations of* Posidonia australis *(left) and* Posidonia sinuosa *(right) within Oyster Harbour in March 2019*

Any areas of seagrass with epiphyte cover greater than medium were typically located close to the aquaculture lots and near the entrances of both the King and Kalgan rivers. However, about 65% of the recorded epiphytes were categorised as ‘very low’ to ‘medium low’ abundances. The most dominant type of epiphyte observed was filamentous, occurring either on its own or co-occurring with encrusting or microalgal epiphytes.

The occurrence of macroalgae was very low – only 10 of 122 observations (data not shown). Species observed were limited to *Cysteroseria* sp. and *Hormosira banksia*. These sightings were restricted to the north-eastern area close to where the Kalgan River enters the estuary, and along the south-eastern corner close to the aquaculture lots. Cover of macroalgae was very low, being mostly observed in the 1–15% cover class.

6 Discussion

We assessed seagrasses in four south-western Australian estuaries during the period supported by the Regional Estuaries Initiative (2017–2020). This report provides the most up-to-date information about these important primary producers in our estuaries and compares their status to historical reports for each system. Reassuringly, seagrass condition is generally stable and/or recovering in each system.

Where possible, we standardised the assessment methodologies to understand the condition and extent of seagrass in south-western Australian estuaries. This included adoption of a hierarchical monitoring design that included broadscale and fine-scale measurements to understand both the current status of the system and the likely resilience and/or recovery of seagrasses. We will report the fine-scale site-based measurements at a later date, although we have drawn on some aspects of those investigations to aid interpretation of the estuary-wide seagrass status. Where we deviated from the standardised methodology, this was usually to allow better alignment with historical data to assess change over time.

Seagrasses in south-west estuaries inhabit both ends of the life-history scale – *sensu* Kilminster et al. (2015), with *Halophila* and *Ruppia* species being fast growing and reliant on the establishment of seed banks to recover from disturbances. Conversely, *Posidonia* is much more slow-growing and relies on a resistance strategy in the face of disturbance. Consideration of these life-history traits supported our choice to assess seed banks as part of the fine-scale monitoring of *Ruppia megacarpa* we conducted in association with the estuary-wide surveys reported here. *Ruppia* has been found to be particularly variable in terms of its biomass and quick to respond to favourable environmental conditions, so its biomass is thought to be somewhat limited to describe long-term water quality trends (Carruthers et al. 1997). These life-history traits must also inform our interpretation of the seagrass status for each system.

The status of seagrass in each of the systems we studied can be summarised as:

- **Leschenault Estuary** – the seagrass is on a recovery trajectory. Seagrass distribution within the estuary had declined when survey results from 2009 were compared with surveys in the 1980s and early 1990s. A further major loss of seagrass was then observed; that is, the area inhabited by seagrass in 2009 had halved by 2015. Our fine-scale site-based measurements (data not reported here) suggest the estuary was on a recovery trajectory two years before the estuary-wide surveys reflected this. In 2020 a recent maximum was reached: seagrass habitat was recorded in 54.7% of the estuary area (1,386 ha of seagrass) and had re-established in the northernmost part of the estuary. Improvements in water quality and reduction in fine sediments reaching the estuary will likely support continued recovery of seagrasses in this system. One species (*Heterozostera tasmanica*) has not been recorded in the system since the surveys between 1984 and 1993 and is likely locally extinct from the system.
- **Hardy Inlet –** the seagrass appears stable. *Ruppia megacarpa* is the dominant seagrass species in the Hardy Inlet, although small areas of *Zostera muelleri* have

also been observed. Seagrass extent appears to have been stable across all the survey periods (2000, 2008, December 2018 and January 2020). We estimated the total area of seagrass habitat was about 501 ha in December 2018 and 617 ha in January 2020. The increased area of seagrass has coincided with an increase in its density. Lower spring and summer rainfall and more sunny and warm days[14] likely created a more favourable growth season in 2019–20 compared with 2018–19[15].

- **Wilson Inlet** – seagrass appears generally stable, with some evidence of loss around the town site of Denmark in particular. *Ruppia megacarpa* is the only seagrass species recorded in the Wilson Inlet, with surveys in 2017–2019 showing stability in seagrass extent. Our fine-scale measurements have found the presence of a seed bank with viable seeds, with field observations of prolific flowering in many parts of the estuary. However, our data shows a loss of seagrass given a survey in 2007 estimated 2,640 ha of seagrass coverage, compared with 1,852–2,059 ha for 2017–19. Seagrass loss is evident in the bay closest to the Denmark town site and also in the deeper edge along the eastern part of the inlet. In addition, bar-closed conditions appeared less favourable for seagrasses in the inlet – with deeper, more tannin-stained water, lower seagrass density, little evidence of flowering and a greater abundance of macroalgae. It seems likely that seagrass in the Wilson Inlet would be resilient to occasional years of non-bar opening, but that continued non-bar opening or a poorly timed bar opening would negatively affect seagrass resilience.
- **Oyster Harbour** – seagrass has improved, with increased area and density. The slow-growing *Posidonia* species is most abundant in Oyster Harbour. The first surveys of seagrass in the harbour in the 1960s reported widespread seagrass down to a water depth of 8 m. Significant losses were then reported in the 1980s with seagrass restricted to areas shallower than 2 m. Recovery (and a restoration program) followed from the 1990s onward. In 2006, seagrass was estimated to cover 560 ha of Oyster Harbour. Our most recent survey shows the area of seagrass has expanded to 663 ha, with a generally higher density and the deepest observation at a water depth of 5.5 m. Given the slow growth of *Posidonia* species, it is likely this recovery reflects continued good water quality in the estuary.

Although the monitoring of seagrasses in south-west estuaries has been intermittent during the past few decades, the data collected has nevertheless supported this current assessment of the status of seagrass in these systems. Our standardised methods and multi-scale approach enable a strong understanding of seagrass condition, tailored to the

[14] Bureau of Meteorology data from station 009518 Cape Leeuwin was used to assess the climate of each season. Rainfall in spring and summer combined was more than twice as high in 2018–19 (198.4 mm) compared with 2019–20 (94.8 mm). Temperature (both minimum and maximum) was higher in spring 2019 (13.8 and 19.4°C) and summer 2019–20 (17.7 and 24.3 °C) compared with the same seasons in the previous year (spring 2018: 13.2 and 18.3 °C; summer 2018–19: 16.5 and 22.2 °C). Solar exposure in spring 2019 was higher than either summer (24.1 MJ/m^2 compared with 20.9 and 20.7 MJ/m^2 respectively for summers 2018–19 and 2019–20).

[15] Note – although sampled in December 2018 and January 2020, sampling actually occurred only about two weeks later in 2019–20 compared with 2018–19.

particular estuary and seagrass type dominant within it. Generally, seagrass is considered to be stable and/or increasing, although in some areas loss has occurred. There are localised areas of concern, such as near the town site in Wilson Inlet, which may be associated with nutrient enrichment which would contribute to an over-abundance of nuisance macroalgae. A long-term decline in seagrass in the Leschenault Estuary has been associated with water quality issues, and a widespread loss potentially associated with climate change (marine heat wave and/or hypersalinity), but the seagrass is now recovering.

Seagrass is an important component of a healthy estuary – as a primary producer and a valuable source of food and habitat. To ensure seagrass habitat continues to improve, it remains important for catchment management to support better water quality by reducing nutrient and sediment export to estuaries. We recommend that monitoring of seagrass continues in the coming years via these standardised methods, to allow ongoing assessment of our successes in improving water quality through catchment management and sustainable agricultural practices.

Appendices

Appendix A — Detailed methods

Broadscale survey - sampling grid design

The broadscale or estuary-wide seagrass mapping surveys relied on the use of boats and underwater camera observations, using either a Splashcam Deep Blue Pro underwater camera (Ocean Systems Inc) or a viewer cone if the water was shallow enough. For each estuarine system, we used ESRI ArcGIS software and bathymetry data to create a hexagonal grid to cover the area within the estuary where seagrass was likely to occur, typically aiming for around 200 points within each estuary. Information that informed our sampling grid design for each estuary included historical surveys, as well as species-specific traits. For example, the depth cut-off was different for each species (e.g. 3 m AHD for *Ruppia megacarpa* in the Wilson Inlet). We placed a random point within each hexagonal grid and extracted the GPS coordinate. For the Wilson Inlet, where a number of recent surveys had been completed, if the randomly generated sampling point was within 100 m of a previously sampled location, then the historically sampled location replaced the randomly assigned point. This resulted in 46 randomly selected locations being replaced with a previously sampled point. For the Hardy Inlet, we clipped the hexagons at the estuary boundary before randomly allocating sampling points to the grid, to maximise the likelihood of the sampling points being closer to shorelines (this was necessary due to the more complex shape of Hardy Inlet compared with Wilson Inlet). See the hexagonal sampling grids developed for the Wilson Inlet (Figure A 1) and Hardy Inlet (Figure A 2). For Oyster Harbour, we excluded regions with depth greater than 6 m and aquaculture leases from the sampling domain where the hexagonal grid was applied and randomly assigned 250 potential sampling locations (Figure A 3).

We did not determine the Leschenault Estuary sample points using the hexagon grid methodology adopted in 2017. Instead we used the original sample points from the 2009 survey and expanded them to give a more comprehensive coverage of the estuary. From 2017 to 2020 we sampled a consistent 230 locations. These sample points are located in an approximate square grid pattern, aligned diagonally to the main estuary body (see Figure A 4). Note that the northern part of the Leschenault Estuary is not accessible by boat due to shallow waters, so we undertook observations by kayak in alternate years.

Broadscale survey - field

In the field, we recorded the actual GPS locations and used these to generate seagrass distributional maps (not the planned sampling location) for each survey. We lowered a Splashcam Deep Blue Pro underwater camera set-up (Ocean Systems Inc) or a viewer cone – if the water was shallow enough – over the boat to make observations. At each point seagrass and macroalgae species composition and density (as percentage cover classes) were recorded *in situ.* Despite the large number of observations carried out in each estuary, it is likely our method of using the underwater drop camera caused us to miss species present in very minor amounts. We estimated seagrass densities from the field of view of the camera and categorised these into predetermined cover classes (Table A 1 and Table A 2).

We recorded additional information including water depth and the presence/absence of epiphytes. For *Ruppia* and *Posidonia* species we estimated the canopy height to 10 cm interval classes. In addition, we collected water quality information (e.g. YSI, PAR, Secchi) at a subset of sites in each survey (data not reported in full here).

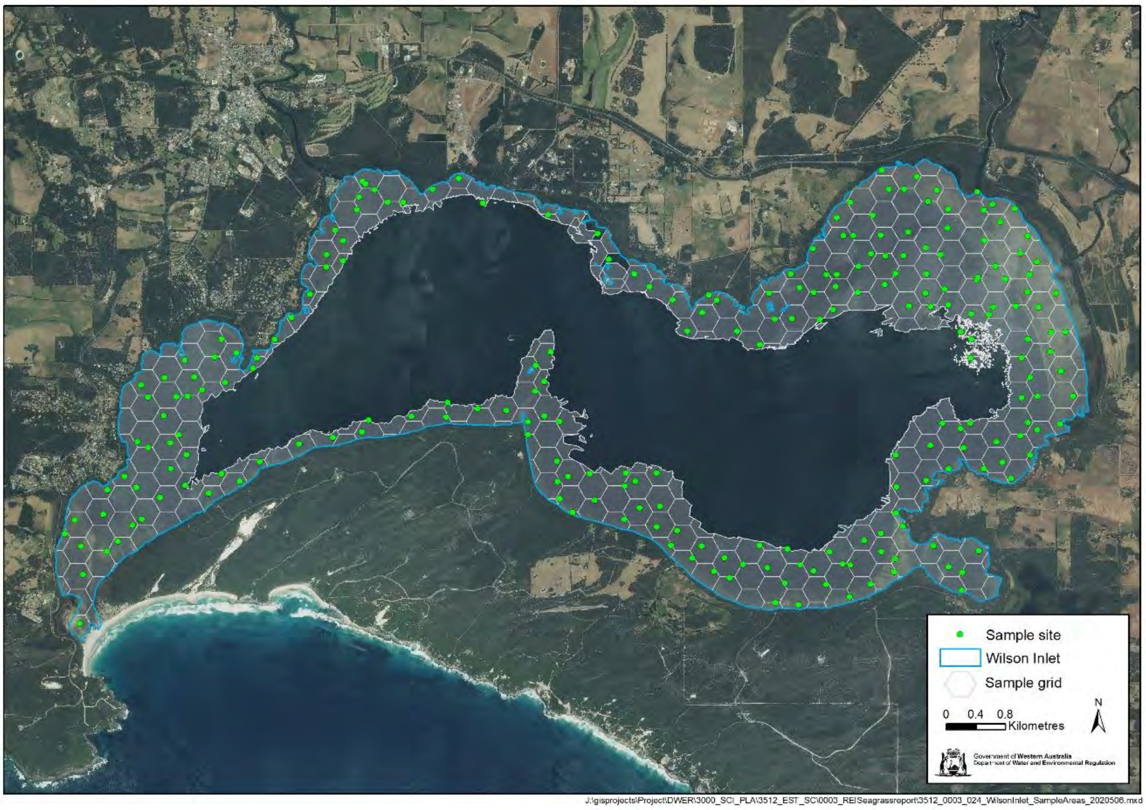

Figure A 1 *Sampling design grid for Wilson Inlet*

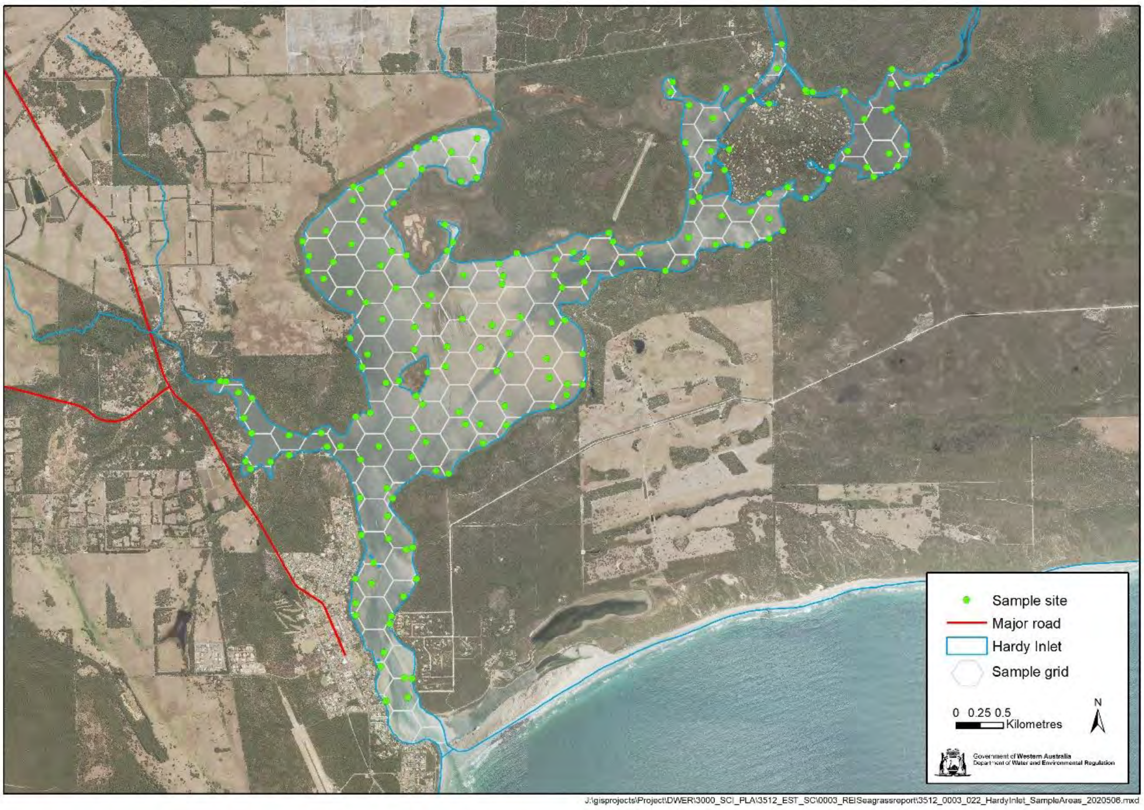

Figure A 2 *Sampling design grid for Hardy Inlet*

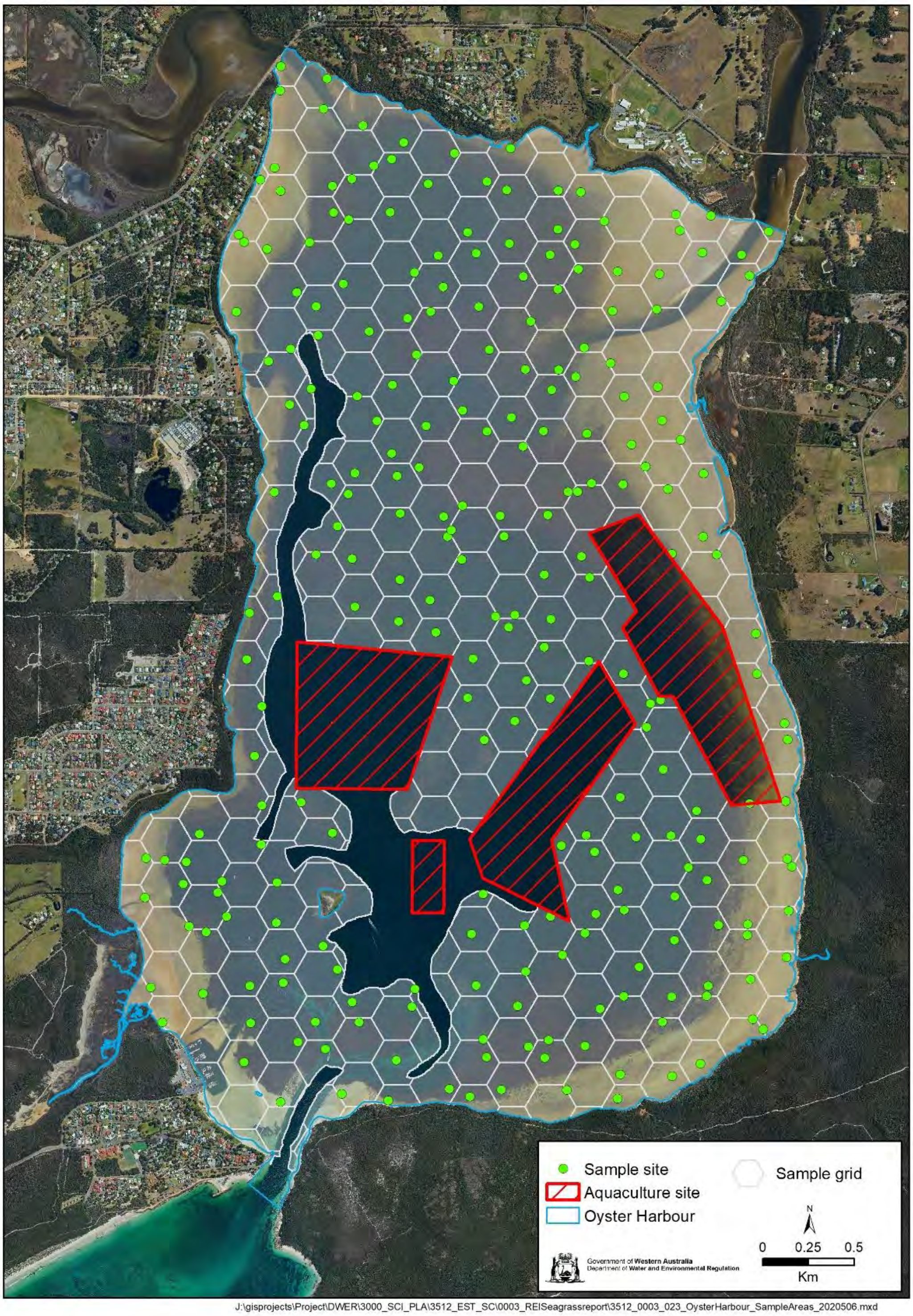

Figure A 3 *Sampling design grid for Oyster Harbour*

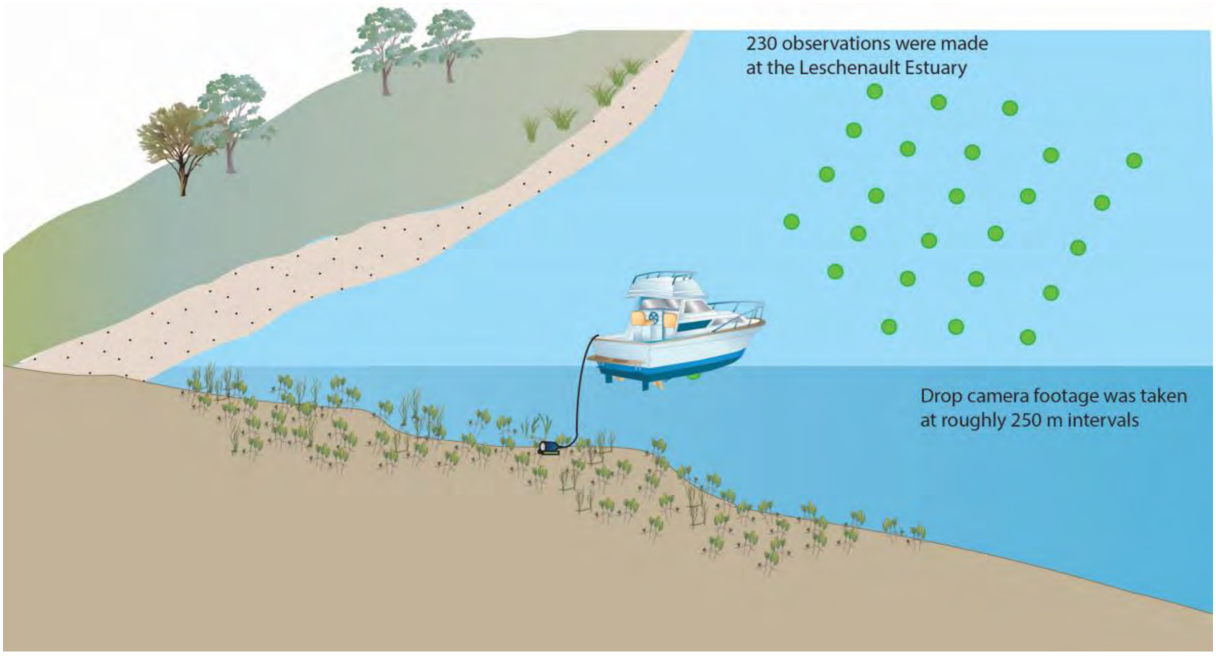

Figure A 4 *Leschenault survey grid demonstrating underwater drop camera method*

Table A 1 *Seagrass cover classes with respective percentage cover range and the midpoint percentage used for statistical analyses for the Leschenault Estuary, Hardy Inlet and Wilson Inlet*

Cover class	Percentage range %	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	95

Table A 2 *Seagrass cover classes with respective percentage cover range and the midpoint percentage used for Oyster Harbour*[16]

Cover class	Percentage range	Midpoint (%)
0	0	0
1	<15%	8
2	15–45%	30
3	45–75%	60
4	>75%	87.5

[16] The deviation away from the standard cover classes used by the department's seagrass monitoring programs was to allow comparison with historical maps of Oyster Harbour seagrass cover.

Broadscale survey - seagrass map generation

We used ArcGIS software to create maps of seagrass cover and density, and calculate the extent of covered areas. We trialled different interpolation techniques, most notably spline and inverse distance weighting (IDW) to create the most plausible maps of seagrass distribution. We used IDW for all maps presented in this report.

For seagrass extent maps, IDW was carried out with the following processing extents:

- Leschenault: we edited the polygon with aerial imagery to remove bare areas.
- Hardy Inlet: we manually edited the interpolation output to remove the deep channel (as the bathymetry is unreliable/being updated) from the polygon. We manually added the inferred areas.
- Wilson Inlet: we clipped the polygon to 3.5 m bathymetry.
- Oyster Harbour – we clipped the polygon to 6 m and removed the aquaculture areas.

We assigned 1 to sample sites with seagrass/species present and 0 to seagrass/species absent. The interpolation output was classified by assigning the values 0–0.5 as 'absent' and the values >0.5 as 'present'.

For seagrass cover maps, the IDW was carried out on cover category midpoints and the processing extent was the seagrass-present area generated for the extent maps. We applied the seagrass cover ranges to classify the output into cover ranges.

Data sources used:

Aquaculture areas – DPIRD 2019

Estuary polygons – Landgate 2012

Hydrography – DWER 2007

Main roads – Landgate 2020

Bathymetry – DWER 2016

Aerial imagery

Hardy Inlet – Landgate 2017

Leschenault – Landgate 2012

Oyster Harbour – Landgate 2017

Wilson Inlet – Landgate 2014

Appendix B — Additional information from the Leschenault 2009, 2015-20 surveys

The department generated seagrass distribution maps in 2009, 2015 and 2016 following the methods described in Appendix A (Figure A 8 to Figure A 11).

Additional Figure A 5, Figure A 6 and Figure A 7 show proportion of seagrass and macroalgae observations made at each cover class across all years, and Figure A 12 links euphotic depth and seagrass cover for 2018 and 2020.

Seagrass covered 68.8% of the Leschenault Estuary in 2009 (Table 1). Surveys were not conducted again until 2015. Seagrass cover drastically declined over this period to about 36% of the estuary in 2015 and 2016. We can only speculate as to the likely cause of seagrass decline since no detailed monitoring was undertaken during this period. Yet the most likely explanation, given the pattern of seagrass loss was predominantly in the northern extent, is of the physiological tolerance of seagrass being exceeded. *Halophila ovalis* is close to the salinity threshold in the northern Leschenault Estuary in most years with the typical hypersalinity observed. The lowest rainfall on record in 2010 may have exacerbated the hypersalinity in this region. Additionally, eutrophication may have played a role in the loss of seagrass. Extensive macroalgal blooms were reported in the local newspapers between 2009 and 2015, including one in 2013–14 which lasted about 12 weeks. Indeed, the water entering the estuary from the north at Parkfield drain has consistently shown very high nutrient concentrations in recent years.

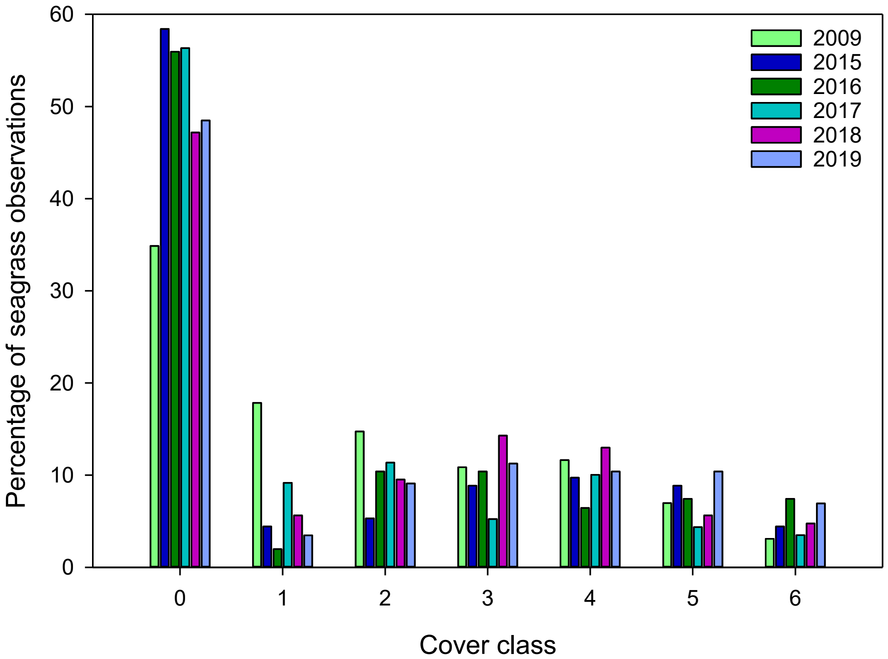

Figure A 5 *Percentage of seagrass observations in each cover class for the Leschenault Estuary in each year of survey, where 0 = none, 1= less than 10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent cover*

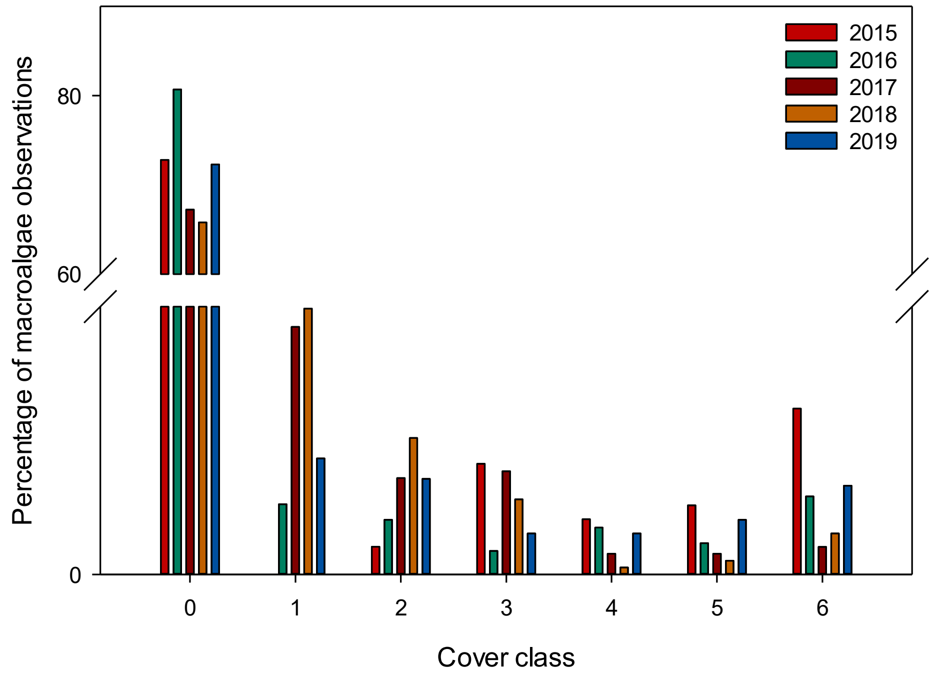

Figure A 6 *Percentage of macroalgae observations in each cover class for the Leschenault Estuary in each year of survey, where 0 = none, 1= less than 10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = ured in 2009*

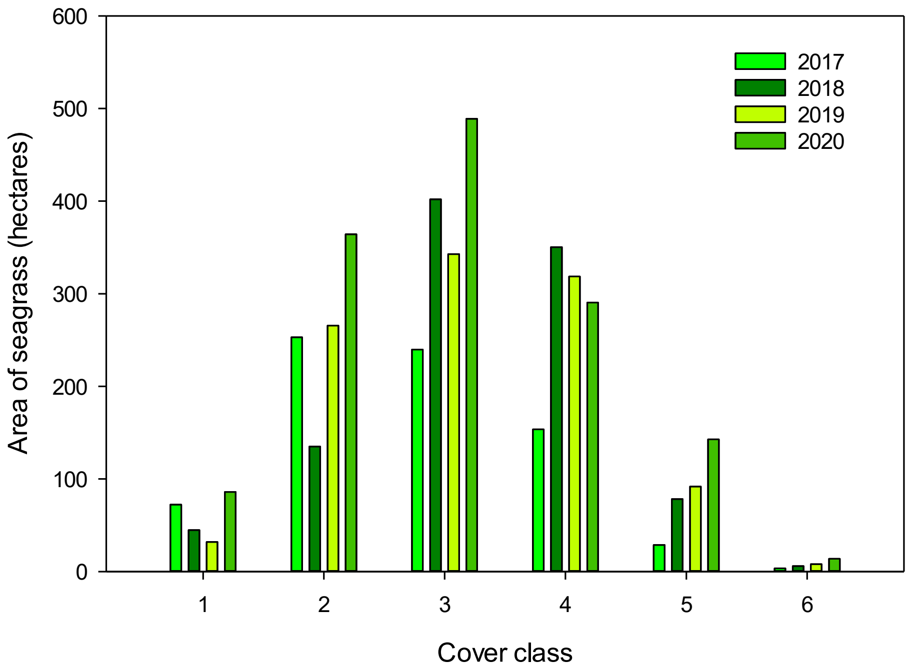

Figure A 7 *Areas of seagrass estimated in Figure 10 (Leschenault 2017–20) for each cover class where 1= less than 10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent cover*

Figure A 8 *Seagrass extent in the Leschenault Estuary in 2009, 2015–19*

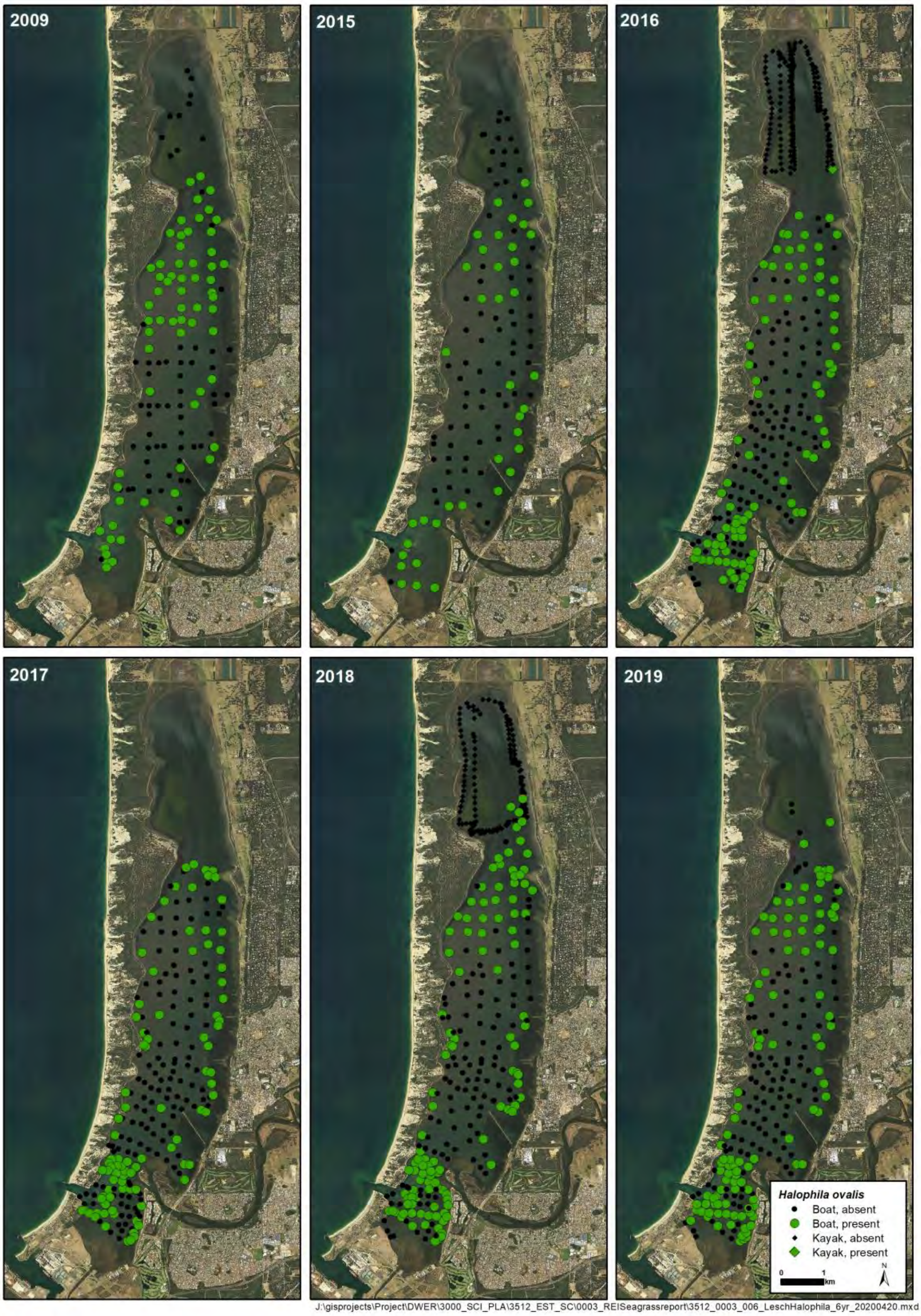

Figure A 9 *Observations of* Halophila ovalis *in the Leschenault Estuary over six years (2009, 2015–19)*

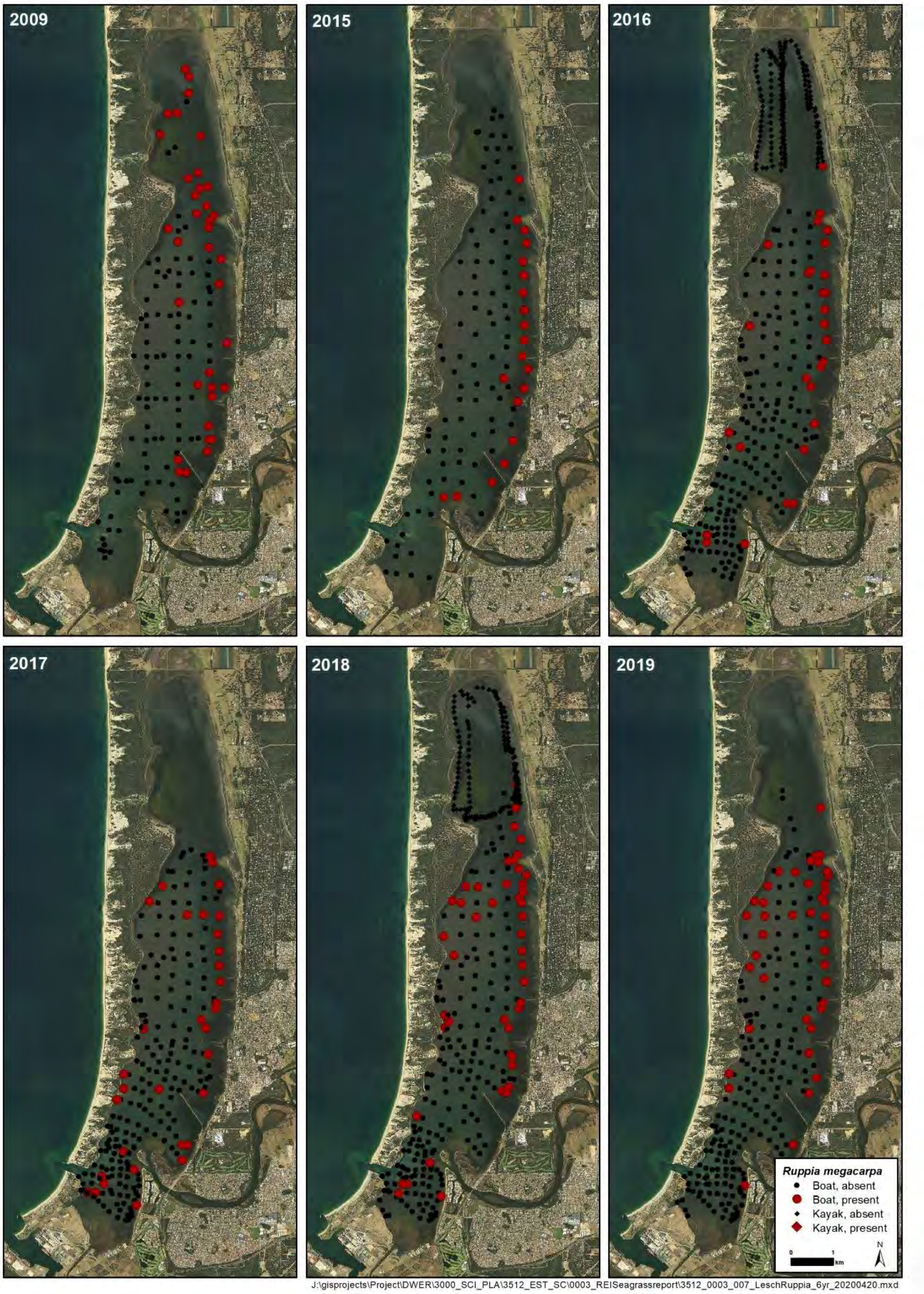

Figure A 10 *Observations of* Ruppia megacarpa *in the Leschenault Estuary over six years (2009, 2015–19)*

Figure A 11 *Observations of* Zostera muelleri *in the Leschenault Estuary over six years (2009, 2015–19)*

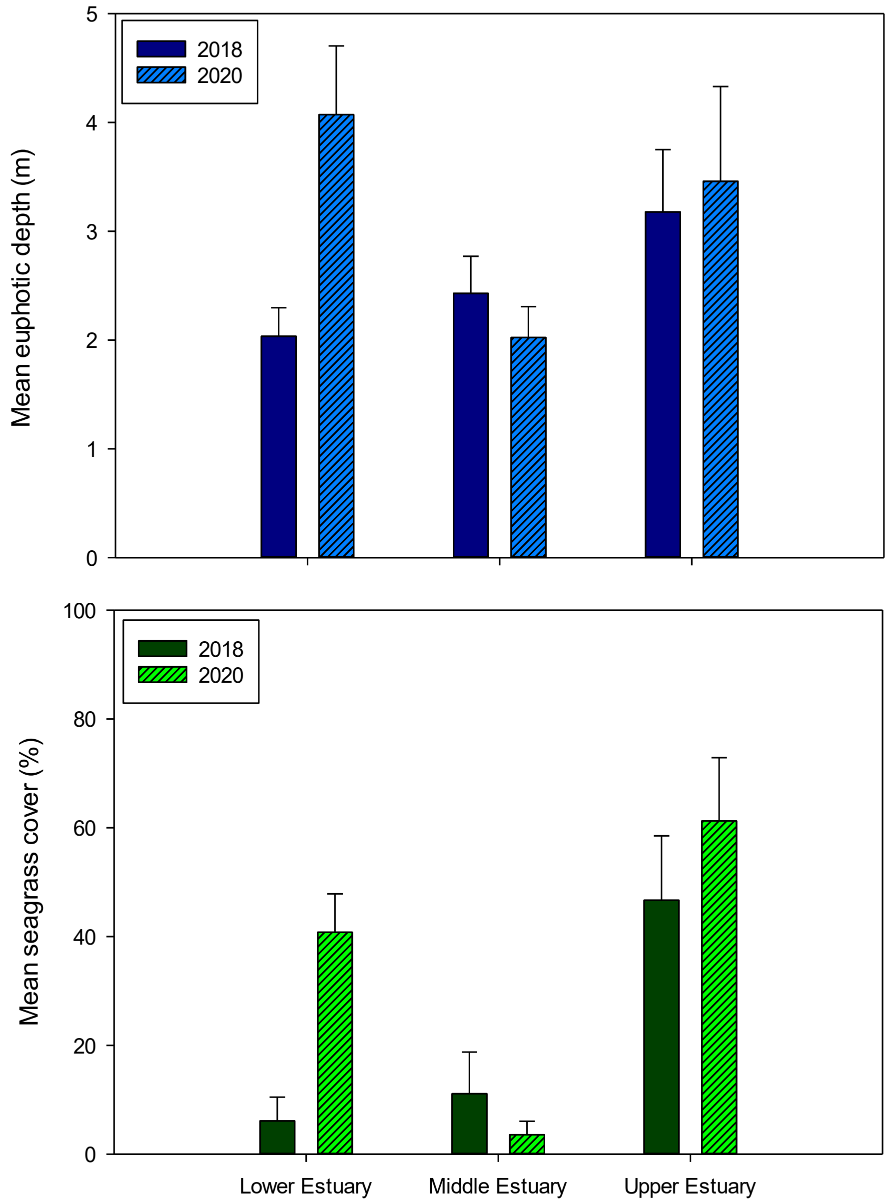

Figure A 12 *Average euphotic depth (10%) and seagrass cover for different regions in the Leschenault Estuary (mean ±SE)*

Appendix C — Additional information from the Hardy Inlet surveys

Figure A 13 and Figure A 15 show the proportion of observations of seagrass and macroalgae made in each cover class. Figure A 14, shows the area occupied by seagrass within each of these cover classes.

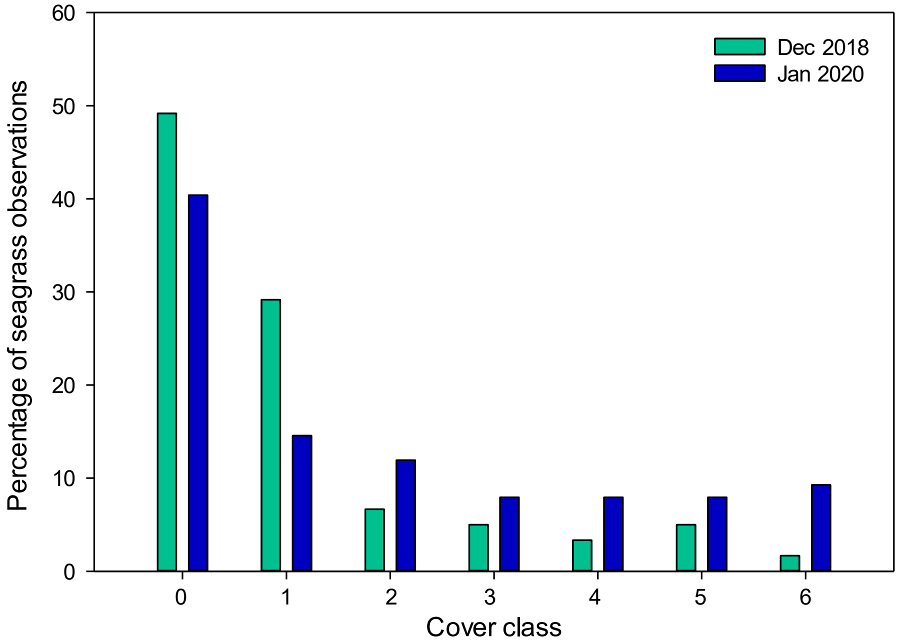

Figure A 13 *Percentage of seagrass observations made in each cover class, for Hardy Inlet for each survey, where 0 = none, 1= less than 10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent cover*

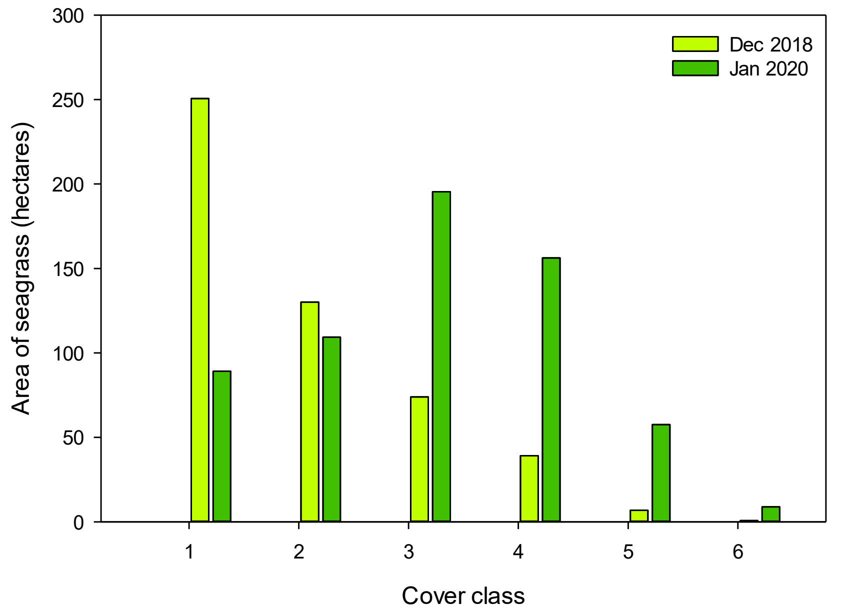

Figure A 14 *Areas of seagrass estimated in Figure 17 (Hardy Inlet survey December 2018 and January 2020) for each cover class where 1= less than 10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent cover*

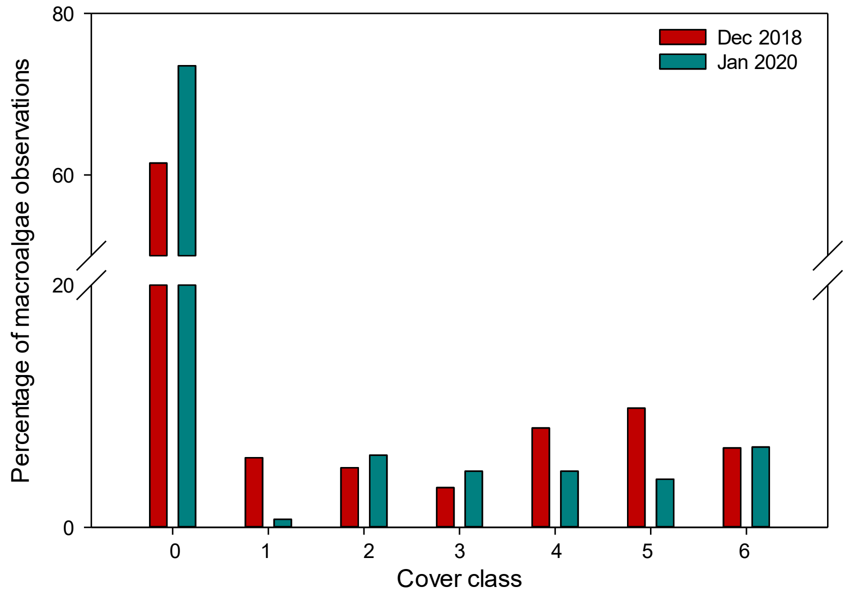

Figure A 15 *Macroalgal abundance estimated during seagrass surveys of the Hardy Inlet in December 2018 and January 2020, where 0 = no macroalgae, 1 = 0 to <10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent cover*

Figure A 16 *Photograph of* Halophila decipiens *meadow confirmed in the Hardy Inlet, 14 May 2020 at 34°18' 95S, 115°09'853E (photo: J. Browne)*

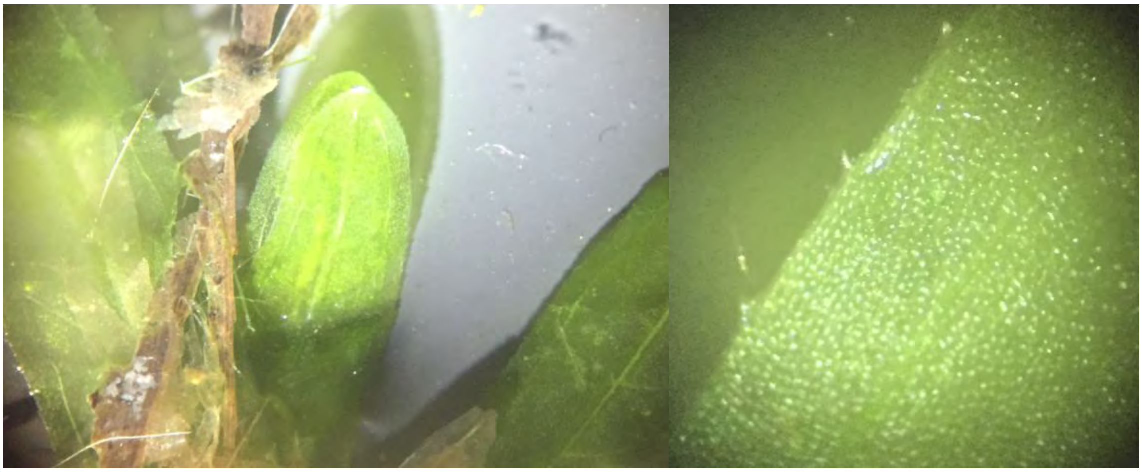

Figure A 17 *Microscope view of the serrated leaf blade of* Halophila decipiens *(photo: J. Browne)*

Appendix D — Additional information from the Wilson Inlet surveys

Figure A 18 below show the seagrass distribution and percentage cover maps generated by the department in April 2018. Figure A 19 and Figure A 21 show the proportion of seagrass and macroalgae observations made within each cover class across the three surveys periods, while Figure A 20 shows the area in hectares occupied by seagrass for each cover category during the period of the Regional Estuaries Initiative study. Additionally, canopy height estimates made in December 2017 and 2019 are compared in Figure A 22.

Figure A 18 *Seagrass distribution (top) and percentage cover (bottom) for Wilson Inlet April 2018*

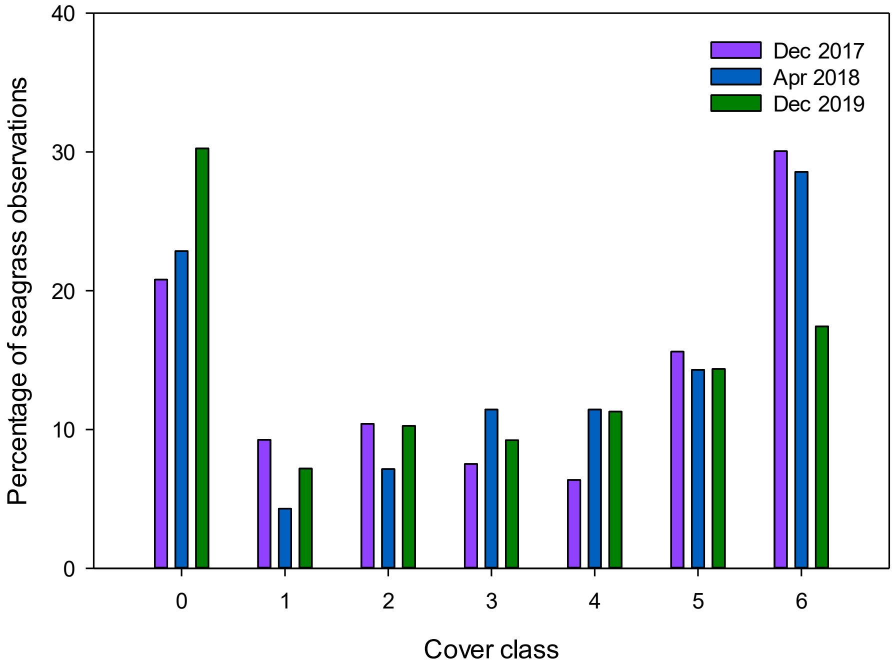

Figure A 19 *Percentage of seagrass observations made in each cover class, for Wilson Inlet for each survey where 0 = none, 1= less than 10%, 2 = 10 to <25%, 3 = [illegible] grass percent cover*

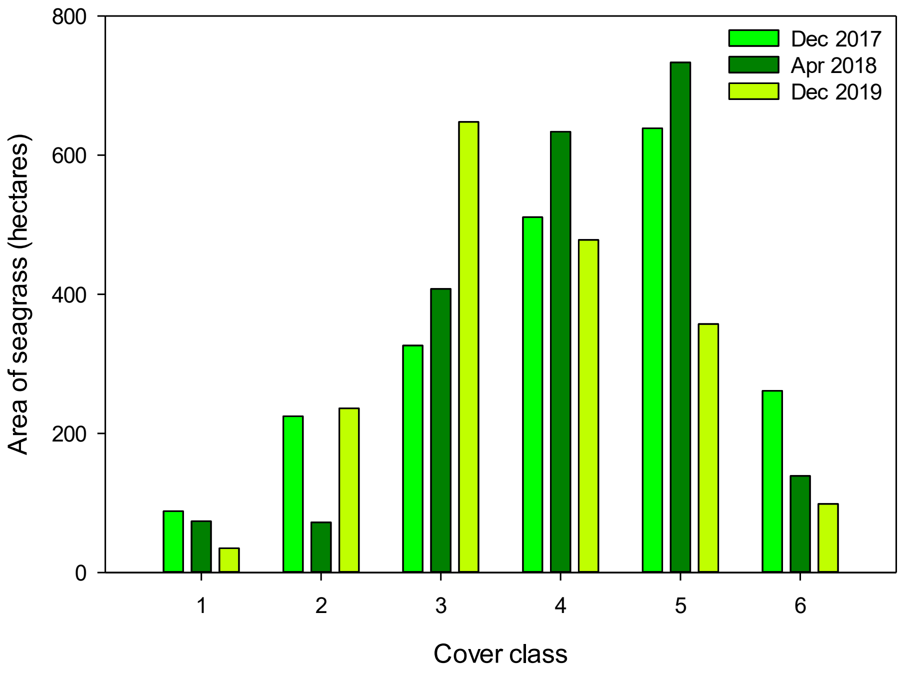

Figure A 20 *Areas of seagrass estimated in Wilson Inlet surveys in December 2017, April 2018 and December 2020 for each cover class where 1= less than 10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent cover*

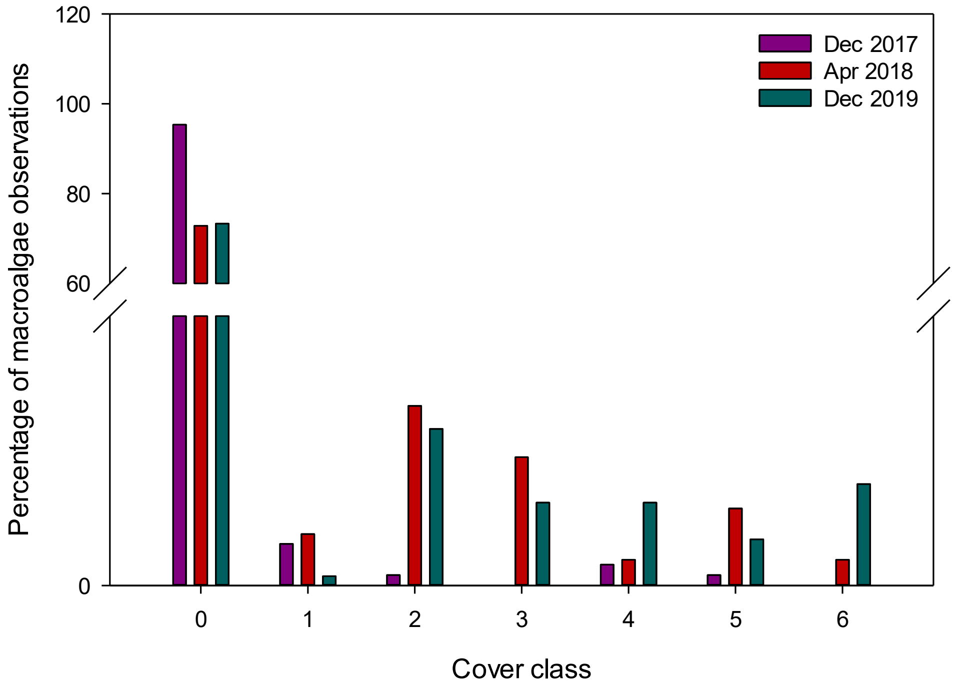

Figure A 21 *Macroalgal abundance estimated during seagrass surveys of the Wilson Inlet in December 2017, April 2018 and December 2019 where 0 = no macroalgae, 1 = 0 to <10%, 2 = 10 to <25%, 3 = 25 to <50%, 4 = 50 to <75%, 5 = 75 to 90%, 6 = >90% seagrass percent. Note, in April 2018, macroalgae was only observed about 5% of the time, compared with about 27% for the other two periods*

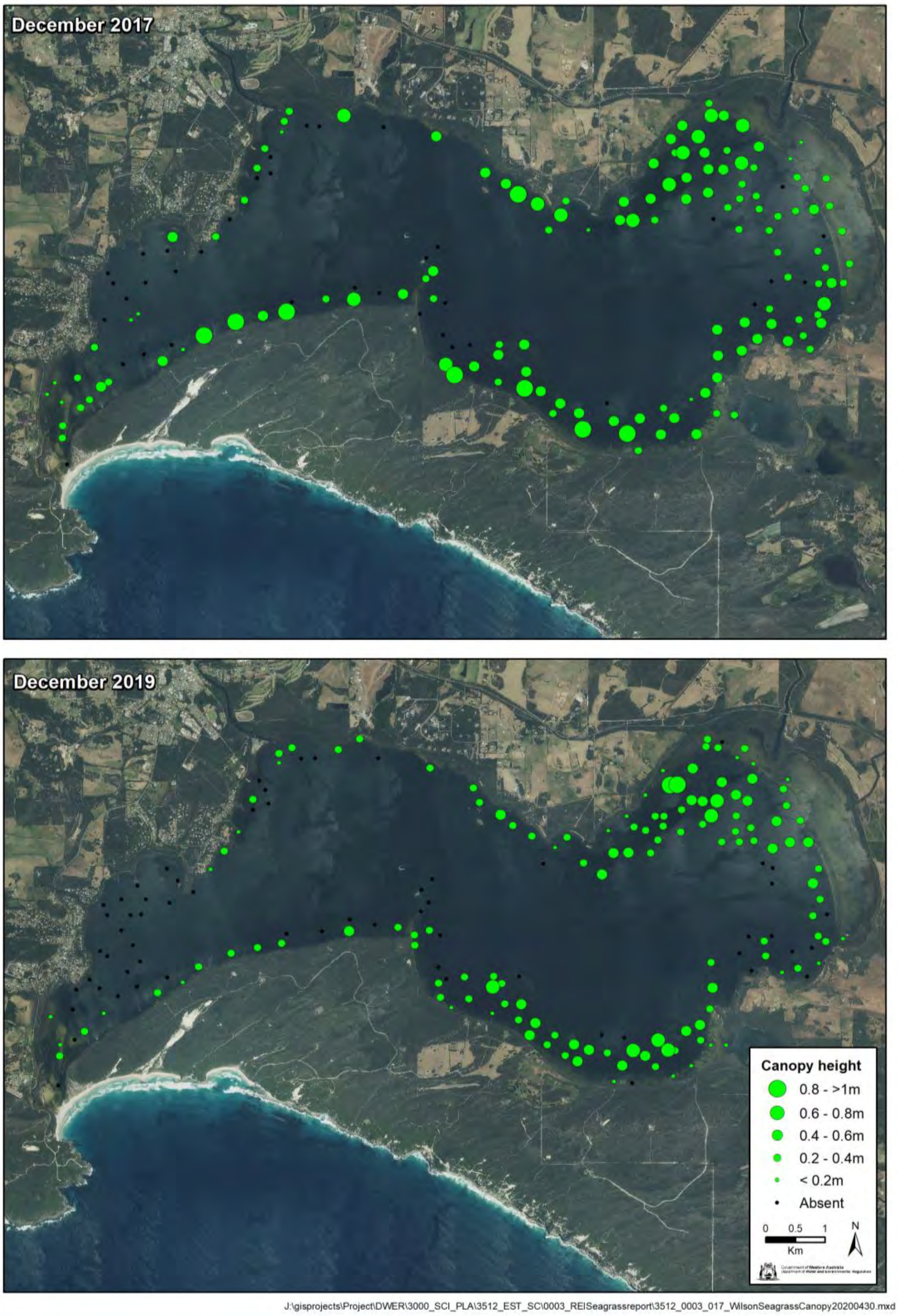

Figure A 22 *Canopy height (m) estimated at each site in December 2017 and December 2019*

Appendix E – Additional information from the Oyster Harbour survey

Figure A 23 shows the area of seagrass occupied within each cover class and Figure A 24 shows the range of canopy heights estimated from seagrass observations in March 2019. Note macroalgae not shown due to only 10 observations made during the estuary wide survey.

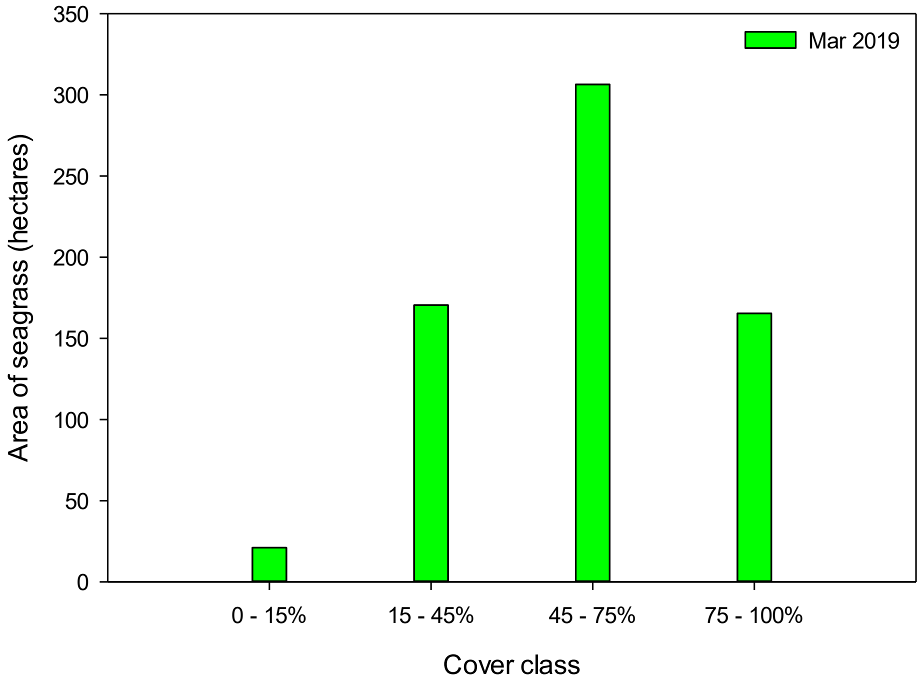

Figure A 23 *Areas of seagrass estimated in the Oyster Harbour survey March 2019 for each cover class*

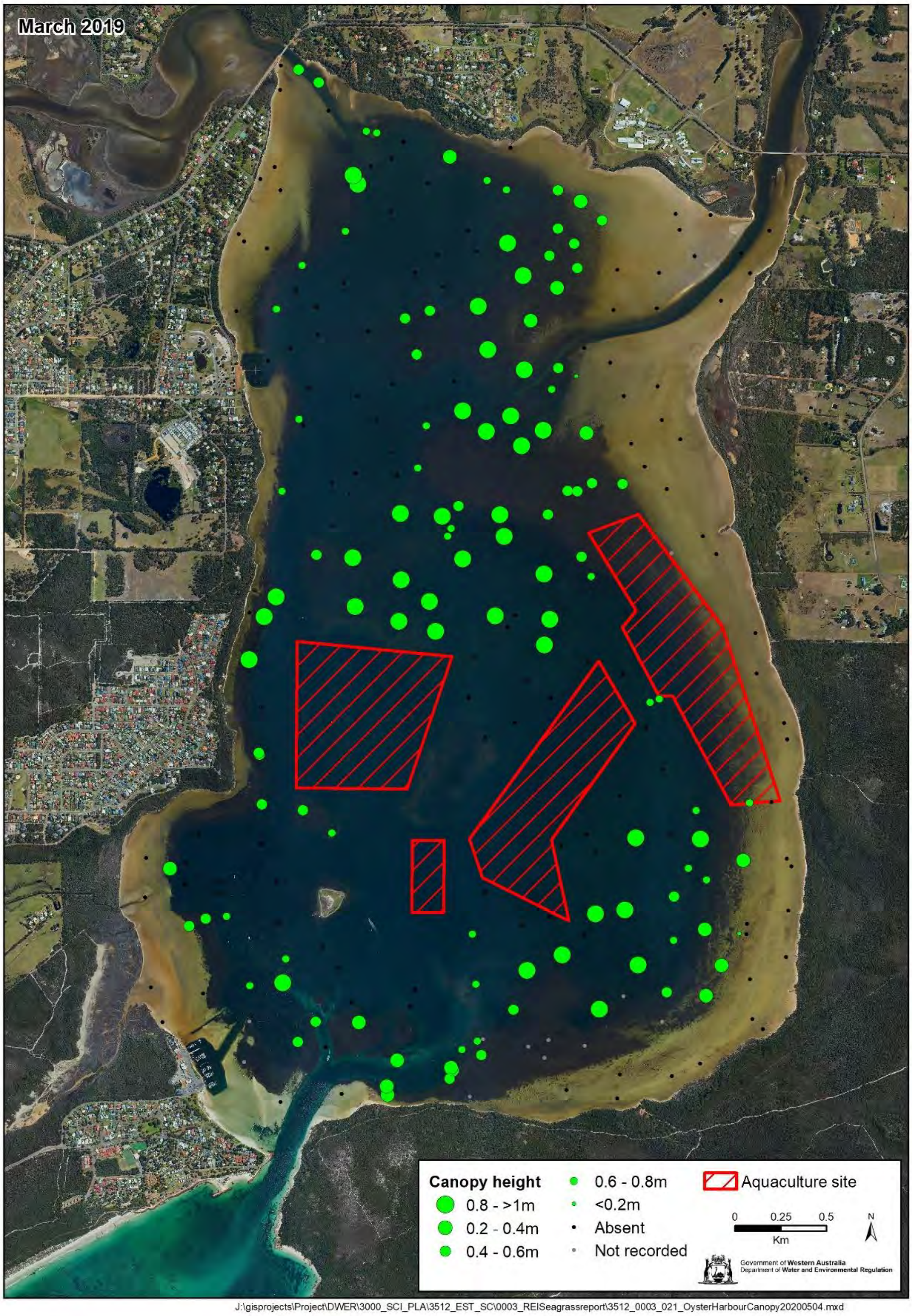

Figure A 24 *Canopy height (m) estimated at each site in March 2019 for Oyster Harbour*

Shortened forms

AHD	Australian height datum – referring to the official national vertical datum for Australia
DPIRD	Department of Primary Industries and Regional Development
DWER	Department of Water and Environmental Regulation
EPA	Environmental Protection Authority
GPS	global positioning system
IDW	inverse distance weighting
MAFRL	Marine and Freshwater Research Laboratory
MSL	mean sea level
PAR	photosynthetically active radiation – referring to the amount of light available for photosynthesis
SAV	submerged aquatic vegetation
YSI	Yellow Springs Instruments – referring to multiparameter sondes used in assessing various water quality parameters (e.g. salinity, temperature, turbidity etc.)

Glossary

abundance	The quantity of individuals in a given area
angiosperm	Flowering plants
anthropogenic	Of, relating to, or resulting from human activity
assemblage	A collection of organisms belonging to a number of different species that co-occur in the same area, and may interact through trophic and spatial relationships
bar-closed	A condition in which a sandbar builds or is maintained at the mouth of an inlet and/or estuary
bar-open	A condition in which the sandbar at the mouth of the inlet and/or estuary allows connection to the ocean
benthic	The collection of organisms living on or in the bottom of a waterbody
biodiversity	Collective term for all the taxa of plants, animals and micro-organisms in a given area
biomass	The quantity of living matter, usually expressed as weight per unit area
bioregion	A region defined by characteristics of the natural environmental rather than by human-made divisions (e.g. state and/or country borders)
brackish	Water having more salinity than fresh water but less than sea water
canary	An advanced warning of some danger; a metaphor originating from the times when miners used to carry caged canaries while at work, to forewarn of dangerous conditions
composition	The identity of all the different organisms and/or species that make up a community (e.g. species of seagrass in a meadow)
cover	The area of ground surface covered by a species, often expressed as a percent (%)
density	The number of individuals within a given area or volume
distribution	The geographical area where individuals of a species occur
endemic	Native to and restricted to a certain place
ephemeral	Short-lived or transitory
epiphyte	An organism that grows on the surface of a plant and derives its moisture and nutrients from the water in aquatic environments
estuarine	Of, relating to, or found in an estuary
eutrophication	A natural process of the accumulation of nutrients leading to increased aquatic plant growth. Human activities that contribute fertilisers and other high-nutrient wastes can speed up the process, leading to algal blooms and deterioration in water quality.

fluvial	Produced by the action of a river or stream
foundation species	A species which has a strong role in structuring an ecological community
hectare	10,000 square metres or 2.47 acres
hydrodynamics	The dynamics of fluids in motion
hypersaline	Of or belonging to the geological saline concentration above that of sea water (i.e. > 35 parts per thousand)
keystone	A species whose presence and role within an ecosystem has a disproportionate effect on other organisms within a system
macroalgae	A macroscopic algae – collective term used for sea 'weeds' and other algae that are visible to the naked eye
macrophyte	A macroscopic plant (i.e. seagrass and/or algae)
manta-tow	A survey technique in which a snorkel diver is towed behind a small boat making direct observations in a broadscale
nitrogen	In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrite (NO_2^-), nitrate (NO_3^-), and as ammonia/ammonium (NH_3/ NH_4^+) and molecular nitrogen (N_2). It can also occur bound to organic compounds.
nutrients	Minerals dissolved in water, particularly inorganic compounds of nitrogen and phosphorus, which provide nutrition (food) for plant growth
perturbation	A change in an environmental parameter, which can last for short or long periods of time
phosphate	Phosphorus occurs in numerous compound forms in the environment, including phosphate which is a dissolved form comprising of phosphorus and oxygen (PO_4^{3-})
photosynthesis	A biological process in which plants use sunlight to synthesise carbohydrates and oxygen from carbon dioxide and water
physiological	Relating to the physiology or normal functioning of an organism
population	The number of organisms of the same species that live in a particular geographic area at the same time
porewater	Water contained in pores or gaps within soil and/or sediment
quadrat	A square plot used for the study of plants and/or animals in ecology
resilience	The ability of an individual, species, or ecological community to resist the impacts of disturbance and/or recover following degradation
salinity	The measure of total soluble or dissolved salt (i.e. mineral constituents in water)

salinity gradient	Spatial pattern in the mixture of water from two distinctly different sources, often fresh and salt water (sea water and fresh water from land runoff, or sea water and hypersaline water resulting from low runoff and evaporation)
sediment	Particulate matter that can be transported by liquid flow, which is eventually deposited as a layer of solid particles on the bed or bottom of a body of water (e.g. sand or mud)
seed bank	Natural storage of seeds (often dormant) within the soil and/or sediment of natural ecosystems
tannin	A naturally occurring organic compound found in plant material that is often yellow or brown in colour when suspended in water
transect	Used in ecology to define a line or narrow section of the environment where observations and/or measurements are made
turbidity	Having sediment or particles suspended or stirred up in the water column
turnover	The movement of something into, through and out of a place, and the rate at which a thing is depleted and replaced (e.g. seagrass presence)
water quality	A general term describing the suitability of water for a given use

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