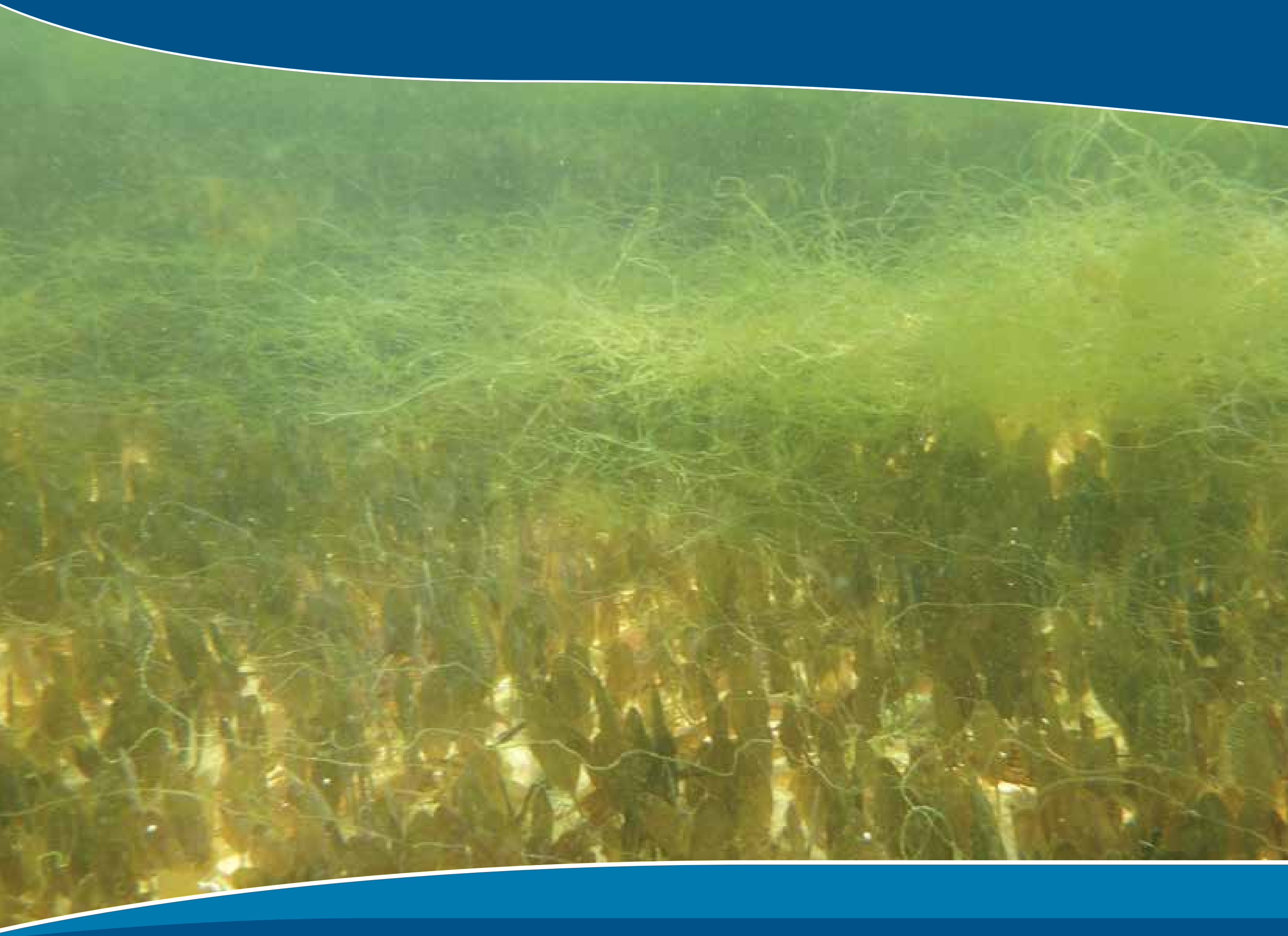
Government of Western Australia
Department of Water

Monitoring seagrass extent and distribution in the Swan-Canning estuary



Water Science technical series

Report no. WST 70
January 2014

Government of **Western Australia**
Department of **Water**

Monitoring seagrass extent and distribution in the Swan-Canning estuary

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January 2014

ISSN 1836-2869 (print)
ISSN 1836-2877 (online)

ISBN 978-1-922248-23-7 (print)
ISBN 978-1-922248-22-0 (online)

Acknowledgements

The Department of Water would like to thank the following for their contribution to this publication:

- Vanessa Forbes and Kieryn Kilminster for study design and report writing
- Ben Marillier, Kelli O'Neil, Frances Miller, Mark Shackleton, Frances D'Souza, Lillian Robb, Georgina Evans, Karl Hennig, Dominic Heald, and Jeff Cosgrove for help in the field
- Lisa Dinnis for assistance with data analysis
- Malcolm Robb for supporting this project with staff time.
- Symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols).

This project was funded by the Government of Western Australia through the Swan River Trust and Department of Water.

Reference details

The recommended citation for this publication is: Forbes & Kilminster 2014, *Monitoring seagrass extent and distribution in the Swan-Canning estuary,* Water Science Technical Series, report no. 70, Department of Water, Western Australia.

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Cover photograph: *Halophila ovalis* overlain by the nuisance green alga *Chaetamorpha linum* within shallow water of the Swan-Canning estuary.

Disclaimer

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Summary

Seagrass habitat in the Swan-Canning estuary appears to have reduced by almost one-third since the early 1980s, when total area estimated in the estuary was nearly 600 ha. The dominant seagrass in the Swan-Canning estuary is *Halophila ovalis* (common name paddleweed). This seagrass species is fast growing and often ephemeral – both aspects that create challenges for understanding seagrass distribution and extent with any certainty. Historically, efforts to map seagrass distribution in the Swan-Canning estuary have been at an estuary-wide scale using a variety of survey methods, making comparisons difficult. Studies to understand aspects of seagrass ecology have also been sporadic.

The purpose of this study was to develop a robust and easily repeatable method of surveying seagrass at the meadow scale. These methods provide high-resolution data on species composition and percentage coverage at a limited number of representative sites. Repetition of this survey on an annual basis will inform on changes in seagrass distribution and extent within the Swan-Canning estuary. It is designed as part of a simple program for reporting scientific data to a broad audience in a repeatable and consistent format and will be supported by the measurement of ecological indicator data collected at the same scale as described in Kilminster and Forbes (2014).

The study involved snorkeller observations along 10 transects at each of the six sites, complemented at the deeper meadow edge by drop-video camera observations. Overall more than 5500 observations of seagrass were made in each year (2012 and 2013).

Seagrass was more frequently observed and had higher percentage cover in 2013 compared with 2012. Seagrass was observed growing deeper in 2013 compared with 2012 at four of the six sites investigated, further supporting the observation that conditions within the estuary were more favourable for seagrass in 2013 than in 2012. Across the whole estuary, seagrass was observed 13% more often in 2013 than in 2012. If this is typical of the magnitude of inter-annual variability for seagrass in the Swan-Canning, it would suggest a genuine loss in habitat has occurred since the 1980s.

Climatic conditions are likely to be the overriding factor causing the differences observed in seagrass abundance between these study years. The summer of 2011–12 was unseasonably wet, which is likely to have reduced the light available for seagrass photosynthesis – both through turbidity associated with rainfall and lower light due to cloud cover. Supporting this observation, the Bureau of Meteorology reported a greater number of hours of sunshine in 2013 compared with 2012 (December to March at Perth Airport).

Seagrass extent and distribution are useful tools to describe the performance of seagrass in the estuary. The methods employed in this study were shown to be adequate to capture inter-annual changes in seagrass distribution and extent, with some ability to describe where these changes occur. There remains the challenge of explaining why those changes have occurred.

Seagrass distribution should not be a standalone measure. We expect to see natural fluctuations in seagrass distribution, especially for the estuarine seagrass species that are well adapted to fluctuating environmental conditions. Seagrass loss can also be due to human-induced stresses (such as dredging or eutrophication), which are potentially

manageable. Without assessing the physiological indicators, which inform on individual stressors – as was carried out by Kilminster and Forbes (2014) – we cannot inform on why seagrass changes have occurred. For this reason, the Department of Water and Swan River Trust intend to undertake both surveys and physiological monitoring of the seagrass in the estuary in 2014.

1 Introduction and background

Seagrasses, dominated by the species *Halophila ovalis* (paddleweed), are a vital component of the shallow-water environment of the Swan-Canning estuary. As a keystone element of the estuary, seagrasses have several important ecological functions. They are a primary producer, food source (e.g. black swans), habitat, nutrient and carbon sink, and sediment oxygenator and stabiliser (Figure 1). Each of these functions is critical to the condition of the estuary.

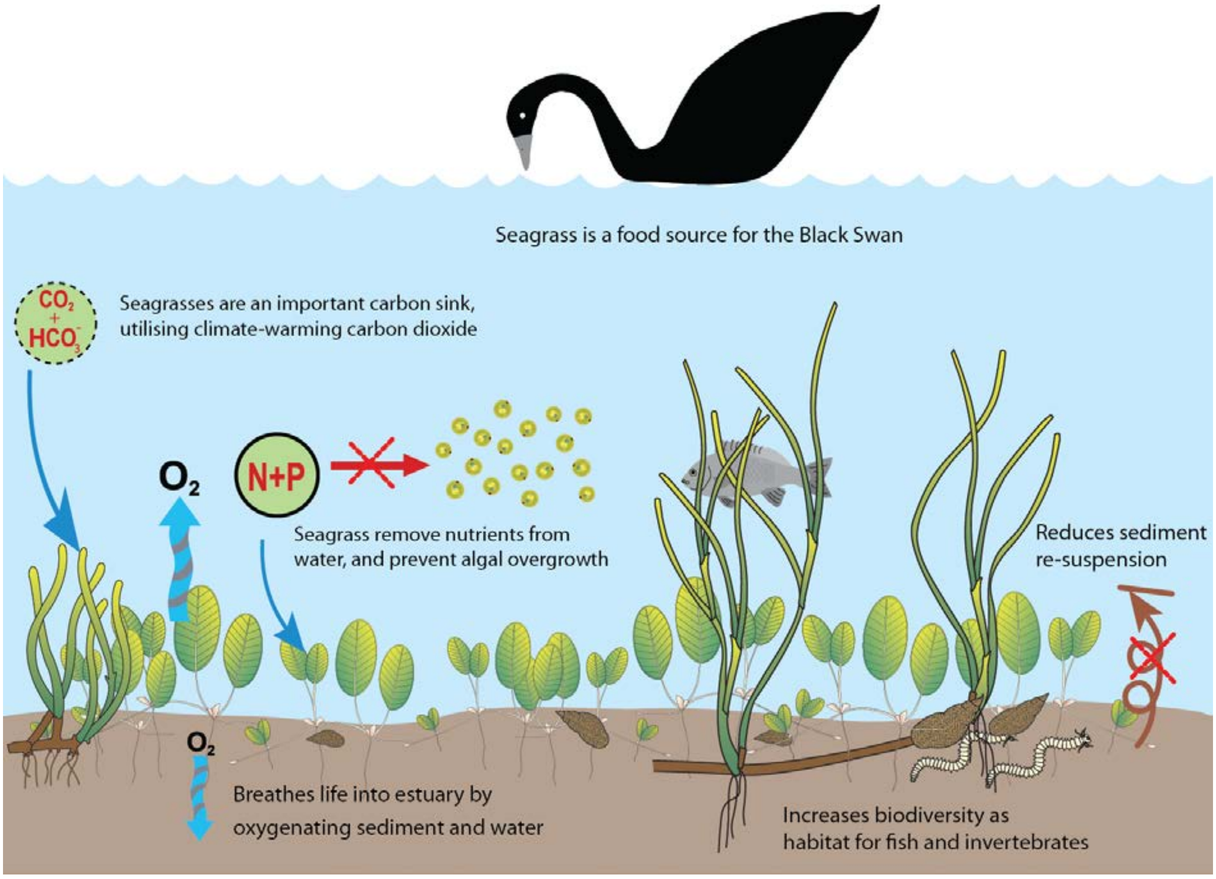


Figure 1 *Ecosystem value of seagrass in the Swan-Canning estuary*

Seagrass beds are significantly affected by the quality of the water delivered to them by river systems, streams and drains receiving runoff from agricultural, urban and industrial land uses. The threats to seagrass include nutrient over-enrichment, light reduction, sediment changes, physical disturbance, invasive species and toxicants. These threats relating to the Swan-Canning estuary are discussed in further detail in Kilminster and Forbes (2014).

Increasingly, managers have been looking at the status of seagrass communities as measures of estuarine condition. Seagrasses are biological components that assimilate conditions within the estuary as a whole. Regular monitoring of seagrass community attributes – such as distribution, percentage cover, composition and biomass – are essential to understand and manage this resource.

1.1 Seagrass in the Swan-Canning estuary

There are four species of seagrass within the Swan-Canning estuary (Figure 2): *Halophila ovalis, Halophila decipiens, Ruppia megacarpa* and *Zostera muelleri.*

Halophila ovalis, or paddleweed, is the dominant seagrass in the Swan-Canning estuary and has generally been the focus of distribution studies therein. It is a small, fragile, perennial species that is easily detached or fragmented by wave action and is often the first seagrass to establish on newly available substrata (den Hartog 1970; Kirkman 1985). In sheltered environments it is capable of forming dense stands, as seen in the estuary. *Halophila decipiens* has been observed to occur in deeper waters and intermixed within *H. ovalis* meadows (K. McMahon 2012, pers comm.) but was not explicitly noted during this study.

Ruppia megacarpa is also a perennial species. It is only found in sheltered environments and its tolerance for a range of salinities – from brackish to hypersaline (Brock 1982) – makes it well suited to estuarine conditions. In the Swan-Canning estuary it is found mixed in with *Halophila ovalis* in the main basin of the estuary, Melville Water and Freshwater Bay. Some small monospecific stands of *R. megacarpa* also can be found; for example, adjacent to Thomsons Park along the Applecross shoreline.

Zostera muelleri is typically a marine intertidal species, but is mainly subtidal in the Swan-Canning estuary. It can tolerate short periods of exposure and temperatures up to 40°C. It is also reasonably salinity tolerant, favouring salinities closer to that of seawater (36 PSU), although it can grow in salinities as low as 9 PSU or 25% that of seawater (Kerr & Strother 1985). *Z. muelleri* is generally found in the lower estuary channel where conditions are more influenced by marine exchange. Occasional ramets of *Z. muelleri* can also be found among the *Halophila* beds in Freshwater Bay and Lucky Bay.

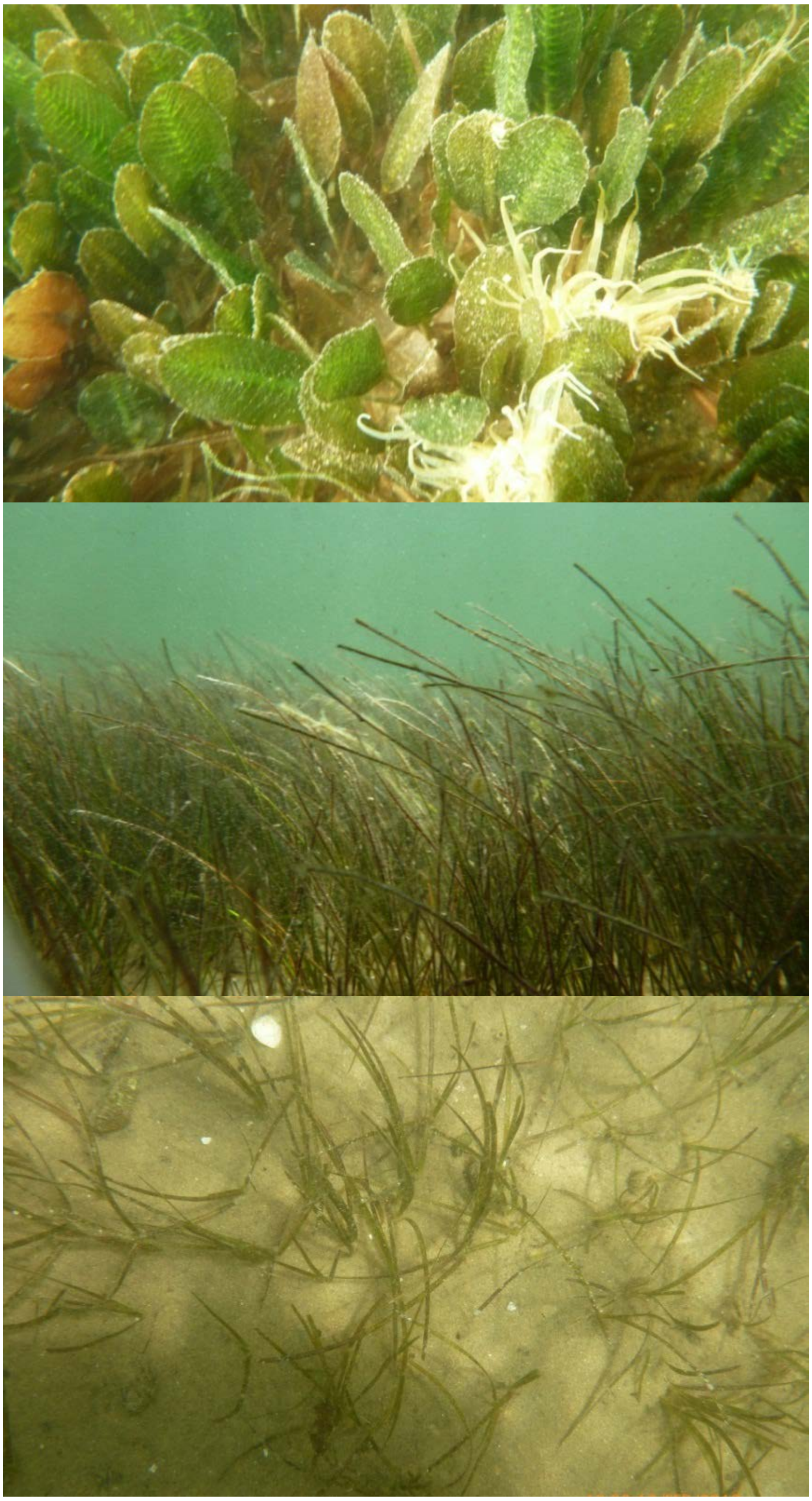


Figure 2 *From top to bottom:* Halophila ovalis *(paddleweed) with a sea anemone in Whalen Bay at site HTH;* Ruppia megacarpa *in Freshwater Bay at the DLK site; and* Zostera muelleri *in Freshwater Bay at the DLK site*

1.2 Causes of seagrass habitat loss

Seagrass loss may result from direct or indirect causes (Figure 3). Direct causes are typically localised and involve the physical removal of the seagrass or the sediment in which it grows. Examples of direct causes of seagrass loss include physical disturbance by trampling, removal due to excavation or storms, and propeller scarring from boats. Seagrass loss via indirect causes may often be more widespread than direct causes, as these are often due to diffuse issues that can affect a large area of seagrass. Indirect loss of seagrass occurs when stressors on seagrass are increased beyond that which the seagrass can tolerate. Stressors that affect seagrass include light, nutrients, salinity, temperature and toxicants. Some of these stressors respond to natural variation in climate, resulting in annual variation in seagrass productivity and distribution. However, anthropogenic pressures such as agriculture, urbanisation and industry can also result in loss of seagrass habitat.

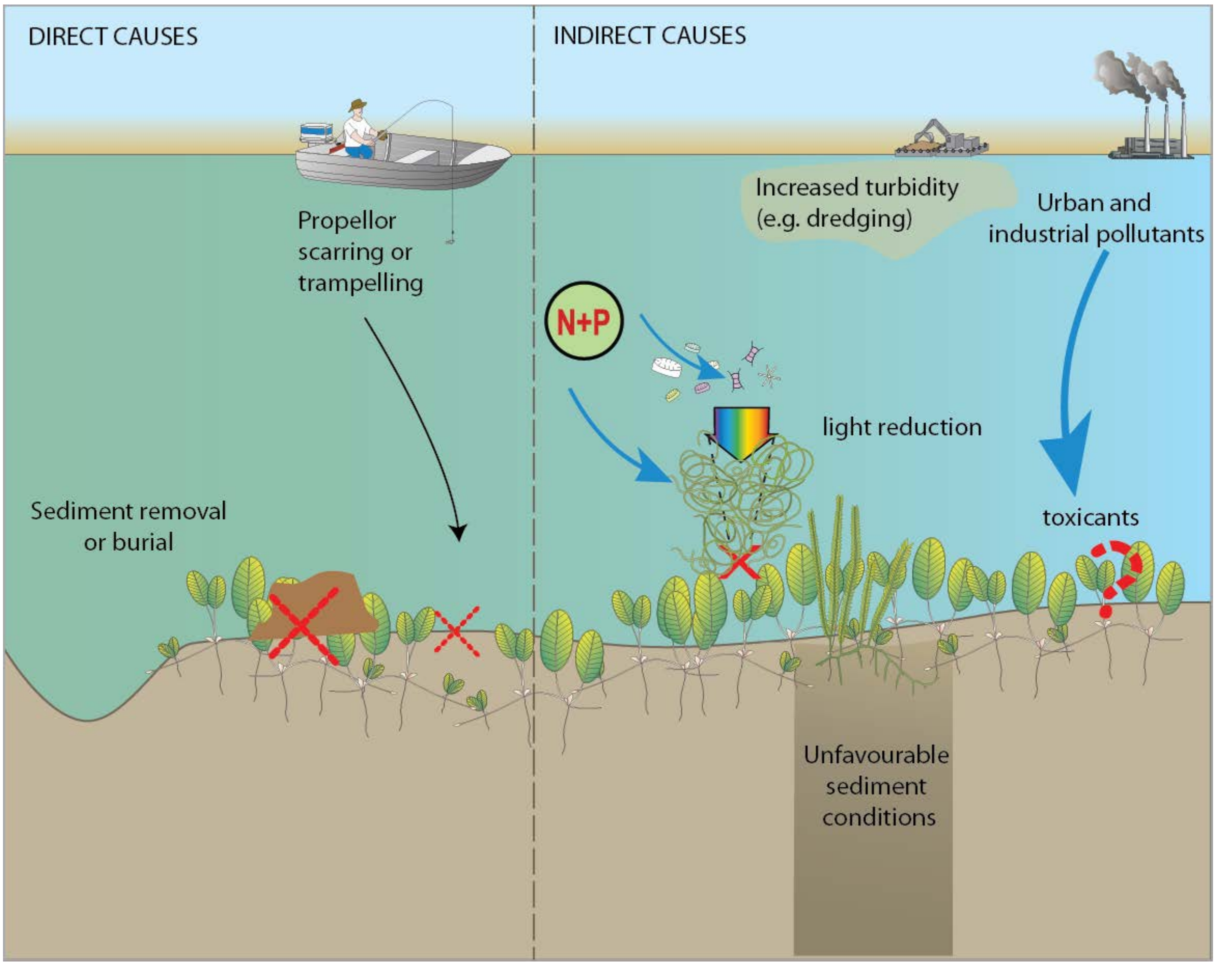


Figure 3 *A conceptual diagram of direct and indirect threats to seagrasses*

1.3 Background to seagrass monitoring in the estuary

To manage seagrass resources effectively, approaches at different scales are required (Virnstein 2000; Neckles et al. 2012). Large-scale monitoring (whole estuary) addresses the question of estuary-wide seagrass coverage, whereby procedures to obtain whole-of-estuary coverage may include imagery (satellite and digital photography), ground-truthing and photo-interpretation to create polygons to produce seagrass maps. To date, this has been the focus of seagrass monitoring in the Swan-Canning estuary (Table 1).

Estimates of the area covered by seagrass in the Swan-Canning estuary indicate that *Halophila ovalis* has gradually reduced by about 30% during the past 30 years: from 600 to 400 ha (Table 1), with patterns of distribution appearing to have remained quite similar (Figure 4). While these reports likely reflect a real decline in seagrass cover in the estuary, differences in how and when these survey data were collected make it difficult to be confident about the magnitude of the changes reported.

Table 1 *Estimates of* Halophila ovalis *cover (ha) within the Swan-Canning estuary 1976–2012*

Source	Year	Timing	Methods	Cover (ha)
Hillman et al. (1995)	1976	March 1976	Drawn from aerial photography (1:5000), ground-truthed using distribution patterns described by Allender (1970)	568
	1982	March 1982	Drawn from aerial photography (1:10 000).	598
Phillips and Wilshaw (1996)	1995	December	Drawn from aerial photography (1:10 000) taken in December 1995. Ground-truthed by boat using a glass viewer, and by snorkel and Scuba.	461
Department of Water (Appendix A)	2011	February 2011	Underwater video, point data along estuary-wide transects. Used to validate polygons drawn from 2008 Landgate satellite image (most recent image available).	403

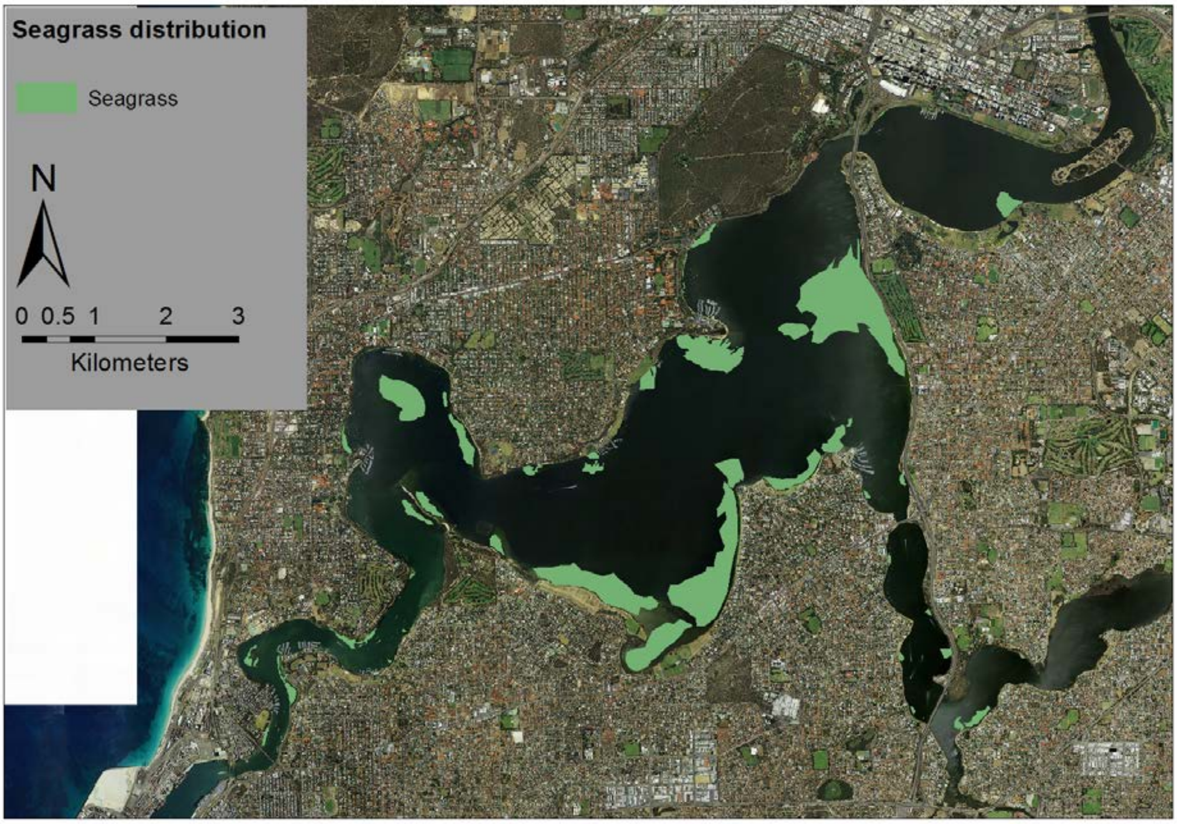


Figure 4 *The distribution of seagrass in the Swan-Canning estuary 2011–12*

Monitoring at this large scale is useful to monitor seagrass extent and distribution over large areas (Neckles et al. 2012) and, with improvements and greater consistency, can also detect long-term and broadscale changes in seagrass distribution. However this scale of monitoring can be costly, time consuming and fails to inform on the ecological condition of seagrasses in relation to local stresses (Neckles et al. 2012). It does not provide managers with any preventative or predictive ability.

Monitoring at a smaller scale, at a select number of sites of interest (as undertaken in the current study) allows for a rapid, economical and consistent approach to monitor change in seagrass cover and distribution. Data can be statistically compared from year to year, and delivered more quickly to management. Most importantly, nested within this approach lies the intensive ecological monitoring proposed by Kilminster and Forbes (2014) for providing the causal links to any significant change in seagrass habitat. The benefits include enabling management to implement remediation (if necessary) at a local scale, as well as providing predictive knowledge to understand ecosystem function and response at a broader estuary-wide scale.

2 Project overview

In 2012 the Water Science Branch of the Western Australian Department of Water developed a program to monitor seagrasses at a habitat or meadow scale in the Swan-Canning estuary. Measures included observations of seagrass composition, distribution (presence/absence), cover and depth range along transects at six representative sites in the estuary. In 2013, a partnership was formed between the Department of Water and Swan River Trust to repeat this program and develop it into a tool for reporting changes in seagrass habitats to managers and the broader community. The monitoring program itself aims to be more affordable, repeatable and consistent than historic assessments of seagrass cover. The program is presented as an addition to the biophysical dataset and indicators developed by Kilminster and Forbes (2014), and for this reason have been implemented at the same representative sites.

The specific objectives of this project were to:

- repeat the exact sampling program (same sites, same transects, similar time of the year)
- compare data of seagrass composition, distribution, cover and depth range between sampling years (2012 and 2013)
- develop quantitative performance measures of seagrasses at a habitat or meadow scale in the Swan-Canning estuary.

The underlying hypotheses for the study being that:

- seagrass community structure at a habitat or meadow scale including composition, distribution, cover and depth range will change depending on interrelated environmental and anthropogenic pressures as outlined in the previous section.

3 Sampling program

3.1 Site locations

To complement the study to develop physiological indicators by Kilminster and Forbes (2014), the same six locations were used in this study. The location of these sites covers the range of physical conditions in the estuary and, according to historical reports and observations, have regular seagrass populations present (Figure 5).

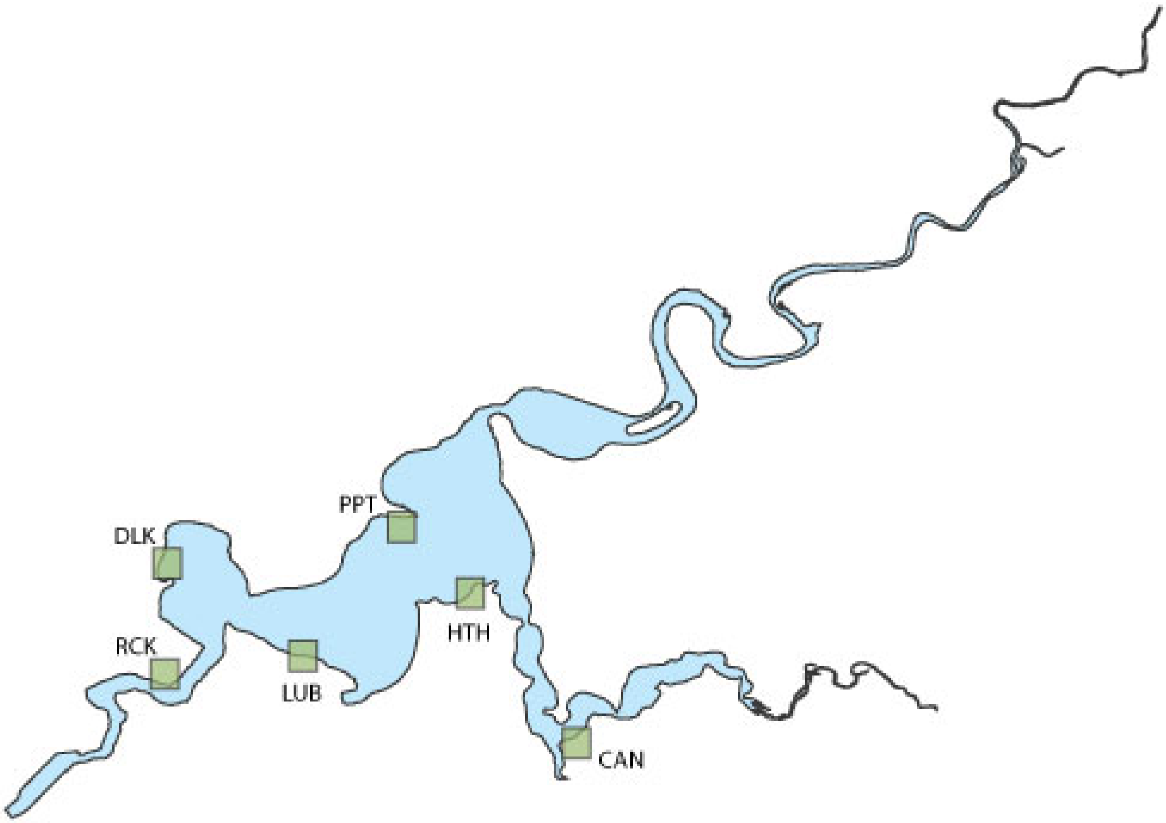


Figure 5 *The six site locations of fixed transects in the estuary (CAN = Canning River estuary, HTH = Heathcote, LUB = Lucky Bay, RCK = Rocky Bay, DLK = Freshwater Bay, PPT = Pelican Point)*

Pelican Point (PPT – Melville Water)

Transects at PPT were located perpendicular to the Pelican Point shoreline from west to east between the coordinates 388635E 6460394N and 389261E 6460410N (grid zone 50) and included a section of the Pelican Point Marine Park (Figure 5). The site was generally shallow with very little gradient (-0.2 to -1 mAHD). Water depths at the time of sampling ranged between 0.2 and 0.8 m. A boat and underwater camera setup were used to survey the site's deeper margin which extended well beyond the length of the individual transects.

Kite and wind surfers use the area just beyond the marine park (marked by yellow buoys) extensively – however the area is relatively free from human disturbance. Seagrass wrack sometimes lines the shoreline, blown onshore by prevailing south-westerly winds (Figure 6). At the time of sampling algae was prevalent in the shallows, which made assessments more difficult. Algal accumulations can be prevalent along the site's shallow margin at certain times of the year.

Figure 6 *Seagrass wrack lining the shoreline at the Pelican Point site (PPT)*

Freshwater Bay (DLK – Freshwater Bay)

Transects at DLK were located perpendicular to the Peppermint Grove shoreline (within Freshwater Bay), north of the Royal Freshwater Bay Yacht Club (between 384073E 6458725N and 383962E 6459189N, grid zone 50). Transects at this site had a steep gradient ranging between -0.2 and -4.8 mAHD. Water depths at the time of sampling ranged between 0.7 and 5.1 m.

Site DLK is popular for a variety of recreational pursuits. Many boats are moored in the bay and the protected waters are popular for water-based activities (Figure 7). The shoreline of Freshwater Bay is also a popular picnic spot, with green lawns almost to the water's edge.

Figure 7 *Boats moored adjacent to the Royal Freshwater Bay Yacht Club near DLK*

Rocky Bay (RCK – Minim Cove)

Transects at RCK were along the Mosman Park shoreline opposite the East Fremantle Yacht club (383811E 6456274N and 384329E 6456237N, grid zone 50) (Figure 8). It is the site closest to Fremantle Port, which is the mouth of the Swan-Canning estuary and therefore more influenced by marine biota than the other sites. The transect profiles at this site were quite varied, with some short and steep (-0.2 to -3 mAHD) and others longer with less of a gradient (-0.2 to 0.6 mAHD). Water depth along these transects ranged from 0.5 to 3.5 m.

There were significant dead shells of bivalves and molluscs observed in the site's sediment. This area of the river appears to be frequented by kayakers, fishermen (in waders) and dogs.

Figure 8 *Exposed limestone rocks along the shoreline of RCK site at Minim Cove*

Lucky Bay (LUB)

Site LUB is located on the Attadale shoreline between the Attadale and Point Walter reserves (387449E 6456737N and 386796E 6456943N, grid zone 50). This site was the shallowest sampled with very little gradient along the length of each transect (0 to -0.9 mAHD). Water depths at the time of sampling ranged between 0.5 and 0.9 m.

LUB is located within the Alfred Cove Marine Park (Figure 9) and is probably the least used or disturbed of the sites sampled in the estuary. The shoreline of Lucky Bay is home to a large public open space used for recreational activities and dog walking. Point Walter, which is at the western end of Lucky Bay (outside the marine park), is popular for picnics and water-based activities, such as swimming, kayaking, boating and kite surfing.

Figure 9 *Monitoring activities at LUB. Photo captures the westward shoreline of Lucky Bay towards Point Walter*

Heathcote (HTH – Whalen Bay)

Transects at HTH were located along the Applecross foreshore between the north-eastern point of Point Heathcote Reserve and the Applecross Jetty (390565E 6458695N and 389748E 6458366N, grid zone 50). Similar to RCK the transect profiles were quite varied, with transects to the west having very little gradient (-0.2 to -0.4 mAHD) compared with those closer to the reserve (-0.2 to -3.4 mAHD). Water depths at the time of sampling ranged between 0.2 and 2.2 m.

This site is probably the most exposed of all the sites: conditions depend on the direction of the wind, being particularly rough during southerly or south-westerly winds. The nuisance macroalga *Chaetomorpha linum* can be problematic at this site. Dolphins are regularly sighted here (Figure 10).

Figure 10 Chaetomorpha *floating above the* Halophila *seagrass at HTH. Sampling on a very calm day at HTH.*

Canning River (CAN)

Transects at site CAN were located along the Rossmoyne shoreline between 393043E 6455423N and 392535E 6454882N (grid zone 50). This site was furthest upstream from the mouth of the Swan-Canning estuary in the tannin-stained waters of the Canning Estuary (Figure 11). The transect profiles ranged between -0.2 and -1.6 mAHD, water depths at the time of sampling ranged between 0.6 and 2.6 m.

Seagrass establishment at this site appears to depend on salinity – conditions become more marine as freshwater river flows taper off.

Figure 11 *Monitoring seagrass at the CAN site along the Rossmoyne foreshore. The Mount Henry Bridge is in the background.*

3.2 Field program

Seagrass distribution, cover and composition were assessed in the Swan-Canning estuary in March 2012 and February/March 2013.

Shore transects

Ten fixed transects were positioned 50 m apart at each site In most cases the transects were 100 m long and ran perpendicular from the shore into the estuary (Figure 12, Appendices B & C).

Quadrats (30 cm x 30 cm) were used to assess seagrass species composition and cover. Ten quadrats were haphazardly thrown at every 10 m interval along the transect line, five quadrat observations to either side. In this way between 800 and 1000 observations were made at each site on each sampling occasion. When the gradient was steep (reaching depths > 4 m), the transects were shorter and fewer observations were made. At these depths it was impractical to make obervations from snorkelling and seagrass presence was also less likely.

Seagrass cover was categorised into six categories (Appendix D) that represented a percentage range of total seagrass cover. Species composition was noted for each quadrat but individual species were not assigned a specific cover class. The midpoint of the percentage range was used to analyse the data (Table 2).

Global Positioning System (GPS) coordinates and water depths were also recorded at each 10 m interval using a GARMIN 72H GPS and a Hondex LCD digital sounder. The GPS points were used to produce transect elevation profiles standardised to the Australian Height Datum (mAHD) obtained from recent bathymetry. Water depths measured in the field were used for comparative purposes only.

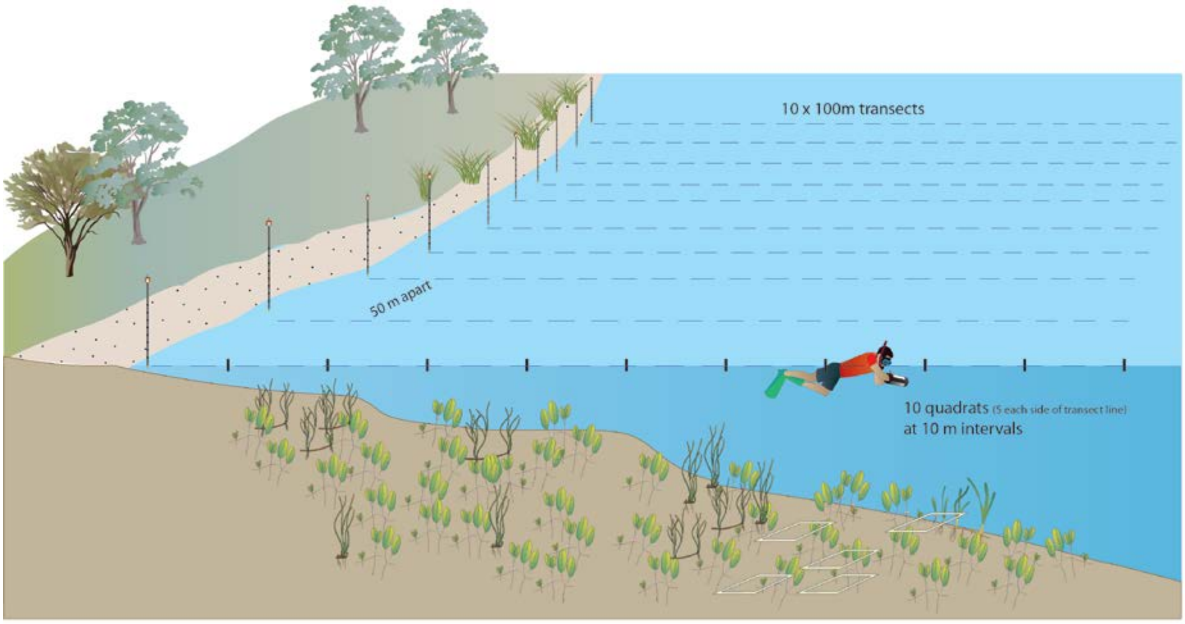


Figure 12 *Diagram of site layout: ten 100 m transects perpendicular to the shoreline are placed 50 m apart. Seagrass species and percentage cover, and water depth are recorded on snorkel from 10 randomly placed quadrats at 10 m intervals.*

Table 2 *Seagrass cover classes with respective percentage cover range and the midpoint percentage used for statistical analyses*

Cover class	Percentage range	Midpoint (%)
0	0	0
1	1–10	5.5
2	11–25	18
3	26–50	38
4	51–75	63
5	76–90	83
6	91–100	95.5

Boat surveys

Drop camera assessments of seagrass presence and cover were made from a boat at sites PPT, HTH, LUB and RCK using a Splashcam Deep Blue Pro underwater camera setup (Ocean Systems Inc.). Given seagrass distribution at these sites was far beyond the length of the individual transects, it was important to establish the maximum depth at which seagrass was present.

Transects followed the direction of the prevailing wind to avoid too much movement with the camera and sample points were about 50 m apart. In this way between 50 and 100 observations were made by boat using the underwater camera at each site on each sampling occasion. Seagrass densities were estimated from the field of view of the camera and were categorised into the same six cover classes as quadrat data from the transect work (Appendix D). Species composition was also noted. The midpoint of the percentage range was used to analyse the data (Table 2), however seagrass cover was assessed based on what was visible in the field of view rather than within a quadrat.

As with the quadrat assessments, GPS coordinates and water depths were recorded for each camera deployment using a GARMIN 72H GPS and a Hondex LCD digital sounder. The GPS points were used to obtain the standard elevation in mAHD from recently obtained bathymetry. Water depths, as with the shore transects, were used for comparative purposes only.

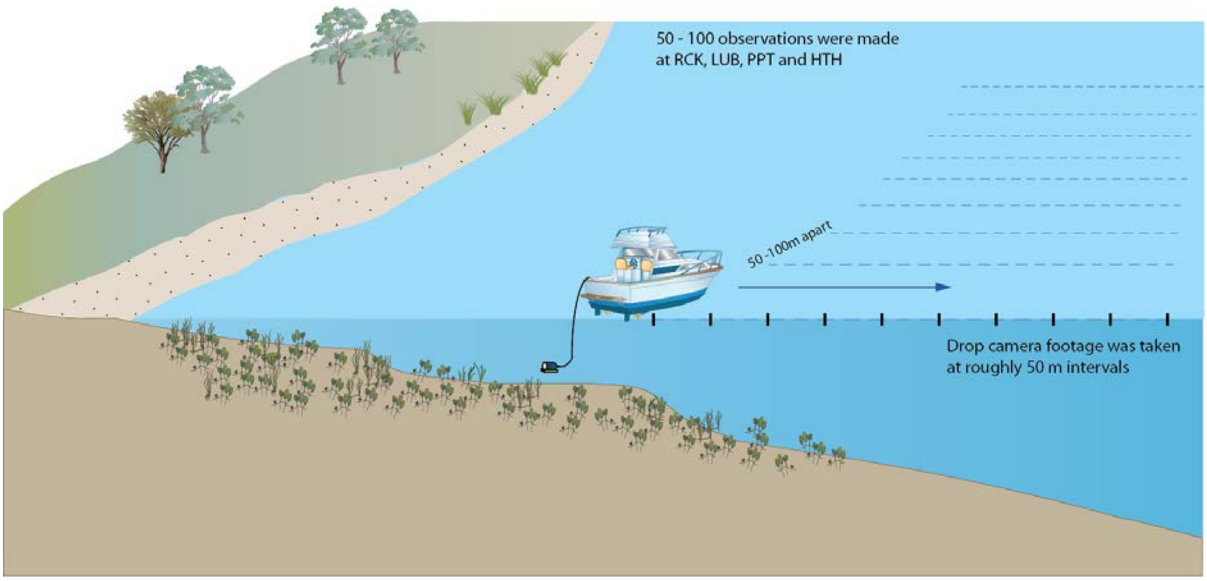


Figure 13 *Diagram of site layout: seagrass species and percentage cover, and water depth are recorded from underwater video cameras. The camera was dropped approximately every 50 m from navigable point along shore to the depth extent of the seagrass.*

3.3 Methodology bias-reduction and validation

A number of potential biases were identified with the methods employed to assess seagrass distribution in this study. These were addressed as follows:

Observer bias

One area for systematic error in surveys of seagrass is the effect of observer bias; that is, differences in cover estimated by the individual observer. There were two ways we attempted to reduce the impact of observer bias. The first was in the choice of fairly broad cover class categories, and the second was by cross-calibration. We minimised the number of individuals who actually carried out the observations, and when starting the observations, they examined a number of quadrats in duplicate to ensure the same cover classes for each sample quadrat were being returned.

No uniform breakdown for cover classes has been used in any previous seagrass surveys. A range of cover classes has been used by researchers to describe seagrass distribution; for example, Lyons et al. (2011) report on seagrass distribution for Moreton Bay of 0–10, 10–40, 40–70 and 70–100%, whereas Roelfsema et al. (2009) used 0, 1–25, 25–50, 50–75, 75–100% (also for Moreton Bay). Monitoring in Florida Keys adopts a modified Braun-Blanquet abundance scale with eight cover classes (0% cover, 3 cover classes describing composition of < 5%, and 5–25, 25–50, 50–75,75–100% cover) (Fourqurean et al. 2003). The decision for our monitoring program to use relatively broad categories (see Appendix D) of 0, 1–10, 11–25, 26–50, 51–75, 76–90 and 91–100% (especially broad around the moderate cover classes) was based on the thought that narrower categories would mean the estimation error was large compared with the size of category.

Power of study design

We were also interested to test whether the method employed was enough to adequately capture the coverage of seagrass present at the site. That is, if we repeated the sampling of a single transect, would we obtain the same results? We tested our transect methodology by repeating a single transect three times on the same day of sampling at each site and then analysed the data for differences observed. Results of these analyses can be found in Appendix E. These analyses showed no significant differences between transects for either presence/absence or for seagrass cover. We conclude that the number of observations is sufficient to adequately capture seagrass population attributes.

Timing of survey

Halophila ovalis is a fast-growing seagrass species (Kirkman & Kirkman 2000). One of our fundamental questions was around how critical the timing of observations was for adequately capturing seagrass populations in the estuary. We addressed this question by undertaking whole-site observations at HTH twice in 2013 (in February and March, about six weeks apart) and comparing these with the data obtained for HTH in March 2012. Results are discussed in detail in Appendix F. For species composition and presence/absence of seagrass, there was no effect of carrying out the survey at site HTH one month later. Some reduction in cover of seagrass occurred but this was smaller than the inter-annual variation observed in the previous year. These analyses suggest the survey methods were robust in terms of the survey's timing for making inter-annual comparisons, but warn that seagrass cover may be slightly over/under estimated if the peak seagrass standing crop is missed. It is therefore recommended that these surveys be carried out in February in the future.

4 Results

This section describes the changes in seagrass composition, presence and cover at the six reference sites sampled in 2012 and 2013 in the Swan-Canning estuary.

4.1 Species composition and presence

Three species of seagrass were recorded in the estuary in the 2012 and 2013 surveys: *Halophila ovalis*, *Ruppia megacarpa* and *Zostera muelleri* (Figure 14 and Figure 15). Note, although *Lepilaena sp*. have been previously recorded in the estuary, they are hard to distinguish from *Ruppia* when not in flower. All *Ruppia*-like plants have been recorded as *Ruppia megacarpa*.

Halophila ovalis was the dominant species at all sites in 2012 and 2013, observed in 61% of the quadrats in 2012 (n = 5440) and 73% of the quadrats in 2013 (n = 5420).

Ruppia megacarpa and *Zostera muelleri* were generally scattered sparsely among the *Halophila ovalis*, but occasionally also occurred in small patches. *R. megacarpa* was observed in 3% of the quadrats in 2012 (at DLK, LUB and PPT) and in 4% of quadrats in 2013 (at all sites except CAN). *Z. muelleri* was most prevalent at RCK (13% of quadrats in 2012 and 24% in 2013), the site closest to the marine entrance of the estuary. *Z. muelleri* also occurred at DLK further up the channel, observed in 2% of the quadrats in 2012 and in 4% of the quadrats in 2013. An unexpected observation was the occurrence of *R. megacarpa* together with *Z. muelleri* at DLK in 2012 and RCK, DLK and LUB in 2013. *R. megacarpa* tolerates a range of salinity conditions but is known to germinate when salinities are fresher (Brock 1982). *Zostera* favours marine conditions (Kerr & Strother 1985).

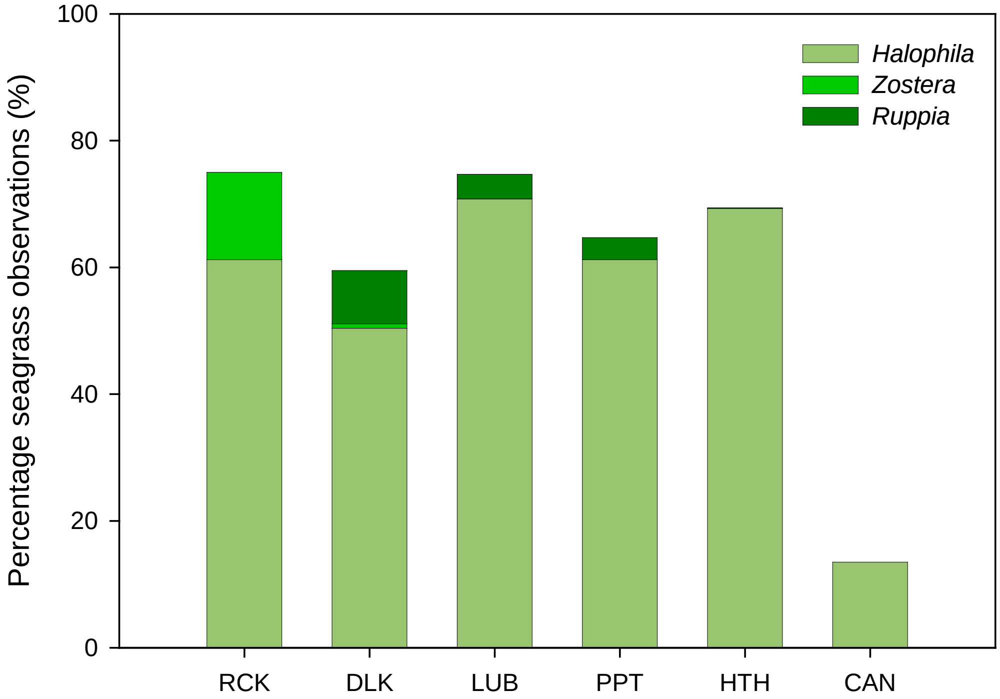


***Figure 14** Percentage of seagrass species observations in March 2012*

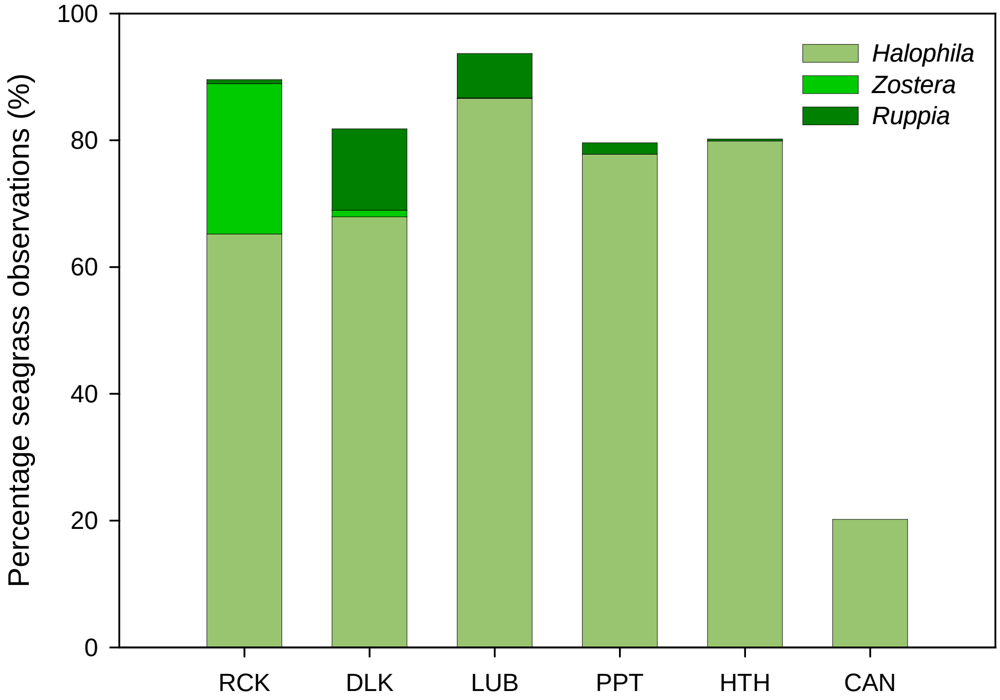


Figure 15 *Percentage of seagrass species observations in February/March 2013*

Overall, there was a significant increase in the number of observations of seagrass (all species) from 2012 (61%) to 2013 (74%) (Table 3). The greatest increase in seagrass presence was found at site LUB, and the smallest at CAN. At a site level all increases in seagrass presence were significant, except at DLK. Estuary-wide, seagrass was observed 13% more often in 2013 than 2012. *Halophila ovalis* was present in almost all observations.

Table 3 *The ratio of seagrass presence (P) relative to total number of observations (N^{obs}) for each site for 2012 and 2013, with Wilcoxon matched pair t-test results (N, T, Z) and p-value of significance (p<0.05 is significant) comparing seagrass presence between 2012 and 2013.*

	2012 P/N^{obs}	2013 P/N^{obs}	Difference	N	T	Z	*p*-value
PPT	0.647	0.796	+ 0.149	63	284.0	4.957	$p<0.05$
DLK	0.726	0.817	+ 0.091	21	77.0	1.338	$p=0.18$
RCK	0.752	0.893	+ 0.141	35	47.0	4.390	$p<0.05$
LUB	0.747	0.937	+ 0.190	67	81.0	6.609	$p<0.05$
HTH	0.694	0.802	+ 0.108	50	125.5	4.942	$p<0.05$
CAN	0.135	0.221	+ 0.086	36	181.0	2.388	$p<0.05$

4.2 Seagrass cover

Average seagrass cover at the six sites ranged between 8.5 and 42.8% in 2012 and increased at all sites in 2013 to between 11.5 and 70.8% (Table 4). The increase in average seagrass cover was significant at four out of the six sites (PPT, RCK, DLK and HTH) from 2012 to 2013 (Table 4). The greatest increase was recorded at site HTH where seagrass cover more than doubled from 2012 to 2013. The smallest significant increase in seagrass cover was recorded at PPT (Table 4). Overall, average seagrass cover increased by 20.3% across all sites.

Figure 16 to Figure 21 illustrate the changes in average seagrass cover for 2012 and 2013 at each 10 m interval along the transect profile at each site. Standard deviations were calculated for both cover and depth to highlight the variation between transects. The increase in seagrass cover at sites PPT, RCK, LUB, and HTH are clearly recognisable in Figure 16, Figure 18, Figure 19 and Figure 20.

The influence of depth on seagrass cover is also evident at DLK (Figure 17), which has a short steep gradient (from 0.75 to 1 mAHD difference between 0 and 100 m) with water depths up to 4.5 m at the time of sampling. The influence of depth was not so obvious at the remaining sites, which had shallower gradients, with maximum water depths ranging between 0.9 and 2.5 m, for example PPT (Figure 16), RCK (Figure 18), LUB (Figure 19), HTH (Figure 20) and CAN (Figure 21).

Table 4 *The average percentage cover of seagrass at each site for 2012 and 2013, with Wilcoxon matched pair t-test results (N, T, Z) and p-value of significance ($p<0.05$ is significant) comparing seagrass cover between 2012 and 2013.*

	2012 (%)	2013 (%)	Difference (%)	N	T	Z	*p*-value
PPT	42.8	58.9	+ 16.1	92	560.5	6.145	$p<0.05$
DLK	36.3	40.9	+ 4.6	70	1.2	1.314	$p=0.19$
RCK	26.6	51.1	+ 24.5	65	125.5	6.189	$p<0.05$
LUB	40.3	70.8	+ 30.5	100	125.0	8.525	$p<0.05$
HTH	23.9	66.5	+ 42.6	95	8.0	8.433	$p<0.05$
CAN	8.5	11.5	+ 3.0	39	281.0	1.521	$p=0.13$

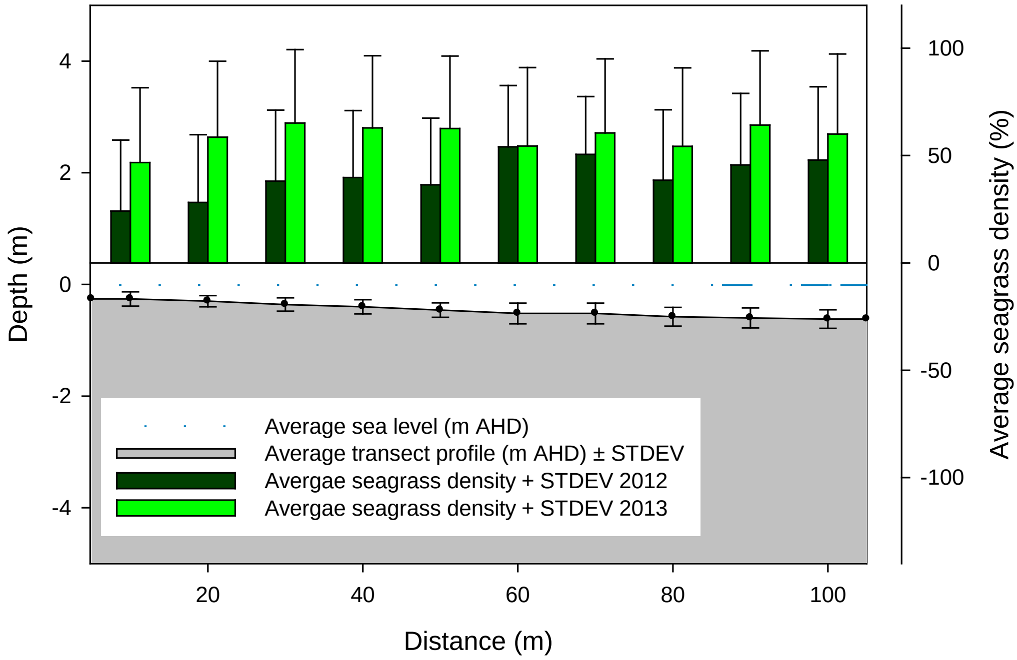


Figure 16 *Average seagrass cover as a percentage over the distance of 10 transects at PPT*

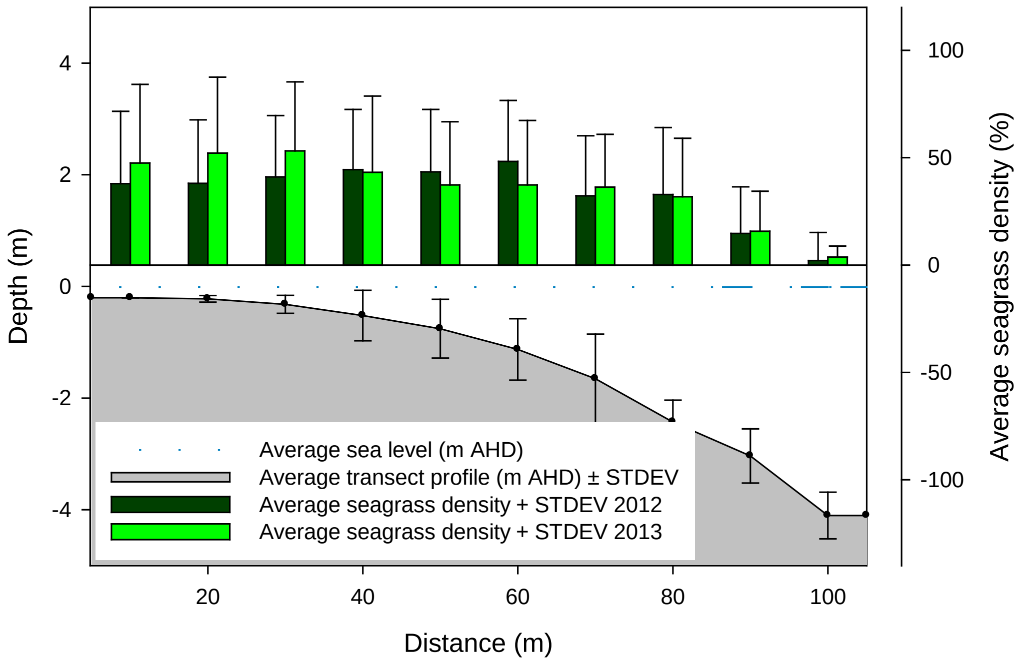


Figure 17 *Average seagrass cover as a percentage over the distance of 10 transects at DLK*

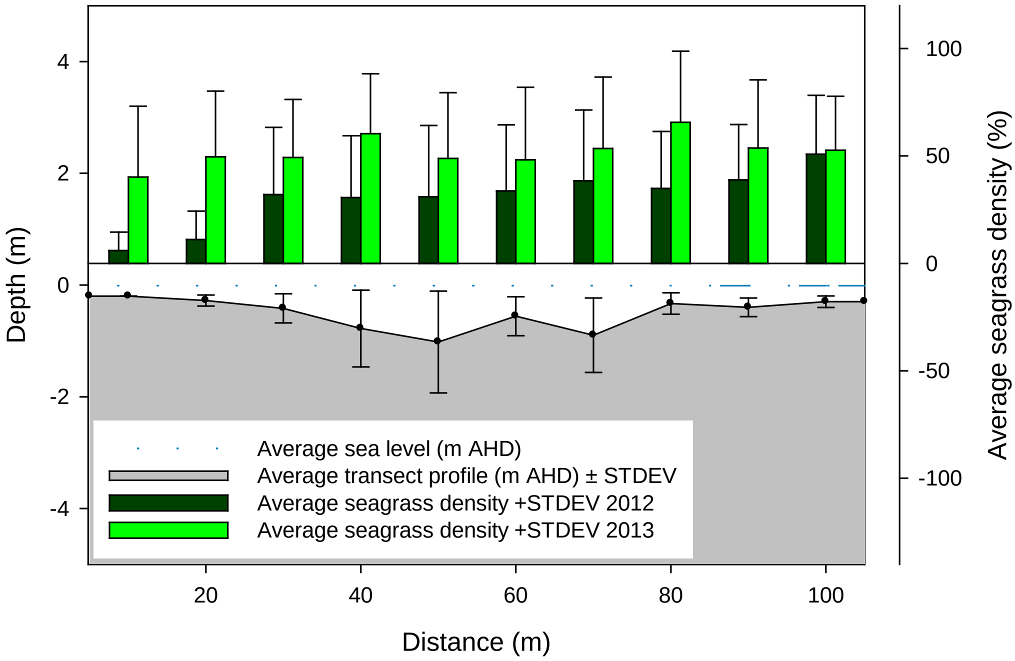


Figure 18 *Average seagrass cover as a percentage over the distance of 10 transects at RCK*

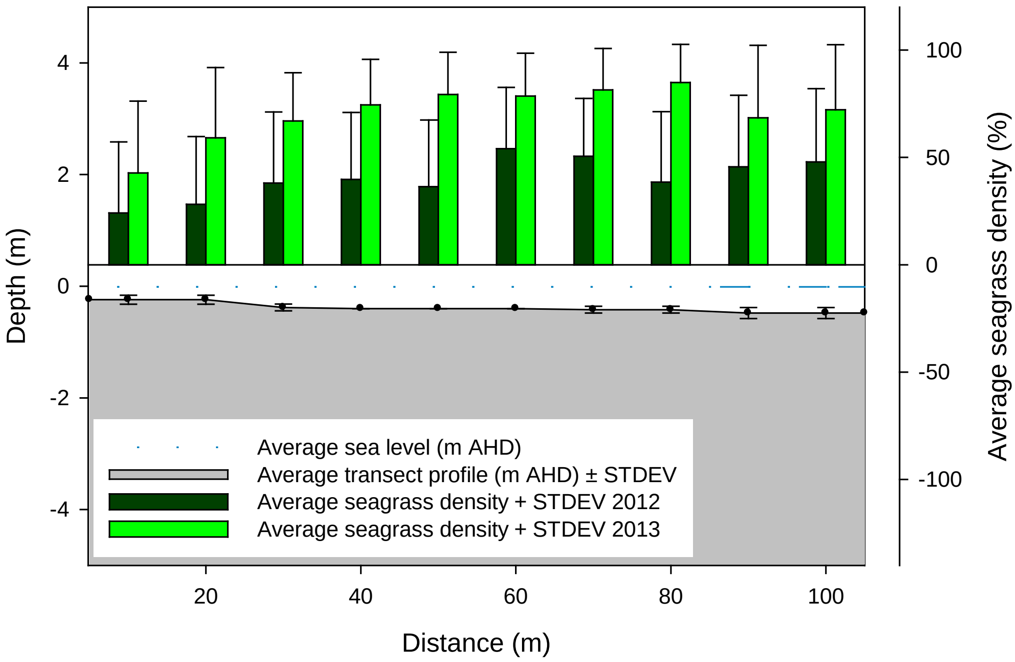


Figure 19 *Average seagrass cover as a percentage over the distance of 10 transects at LUB*

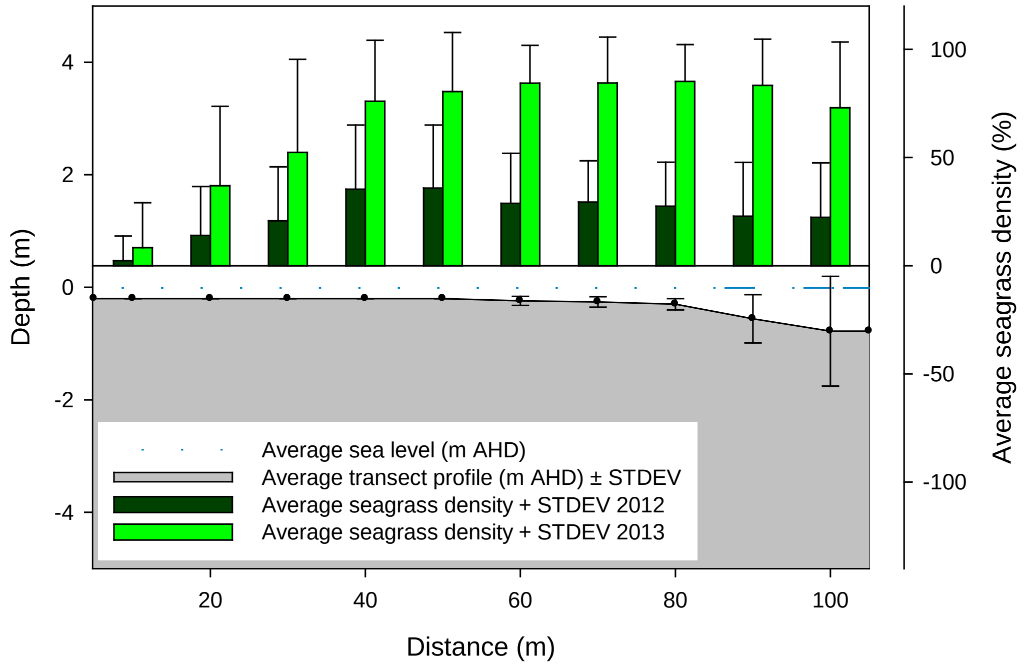


Figure 20 *Average seagrass cover as a percentage over the distance of 10 transects at HTH*

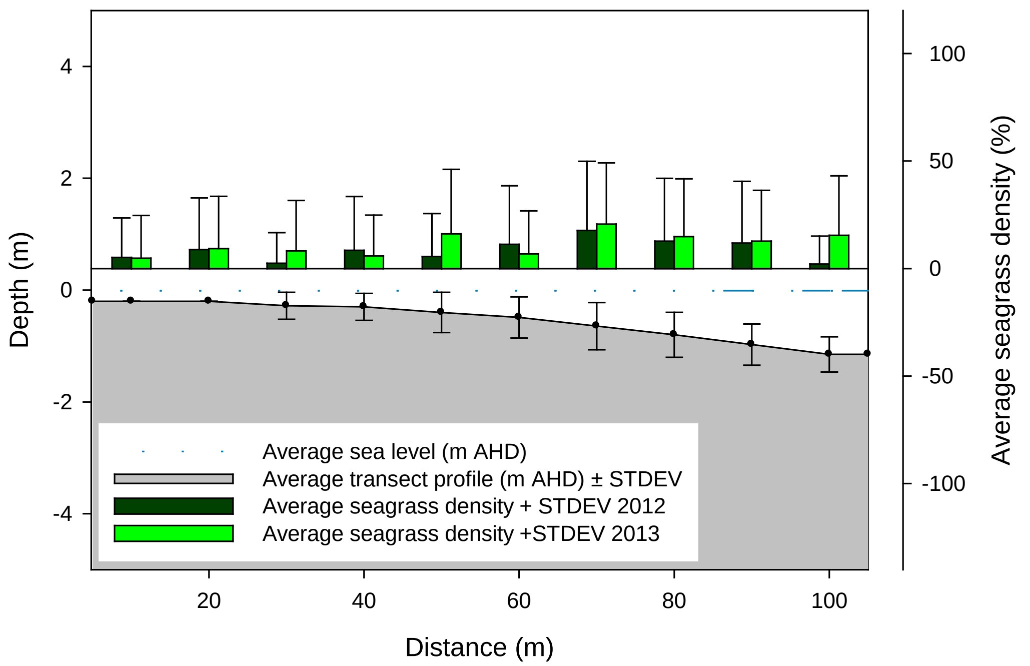


Figure 21 *Average seagrass cover as a percentage over the distance of 10 transects at CAN*

4.3 Seagrass depth limit

The deeper limit of seagrass distribution varied between -1.8 and -4 mAHD in 2012 and between -2.2 and -3.8 m AHD in 2013 (Figure 22) – full details in Appendix G. In relation to actual water depths at the time of sampling, the deeper limit of seagrass ranged between 2.2 and 4 m in 2012 and 2.2 and 4.5 m in 2013 (note: water depths are not constant). The depth limit of seagrass was greater towards the marine extent of the estuary. In both 2012 and 2013 the deepest limit of seagrass was observed at site DLK and the shallowest limit at site CAN.

Several conditions favour the deeper limit of seagrass growth at DLK. Most obvious is water clarity – which is improved by the site's location near the marine extent of the estuary where clear marine waters intrude with the tides. Site orientation is also important. DLK has an eastern orientation which shelters the site from prevailing weather conditions that would otherwise increase the suspension of particulates in the water column and thereby reduce light penetration to depth.

These conditions are in contrast with site CAN which is furthest from the marine entrance and mostly influenced by river flows. Water clarity is reduced by tannins and particulate matter in the water column washed down from the catchment.

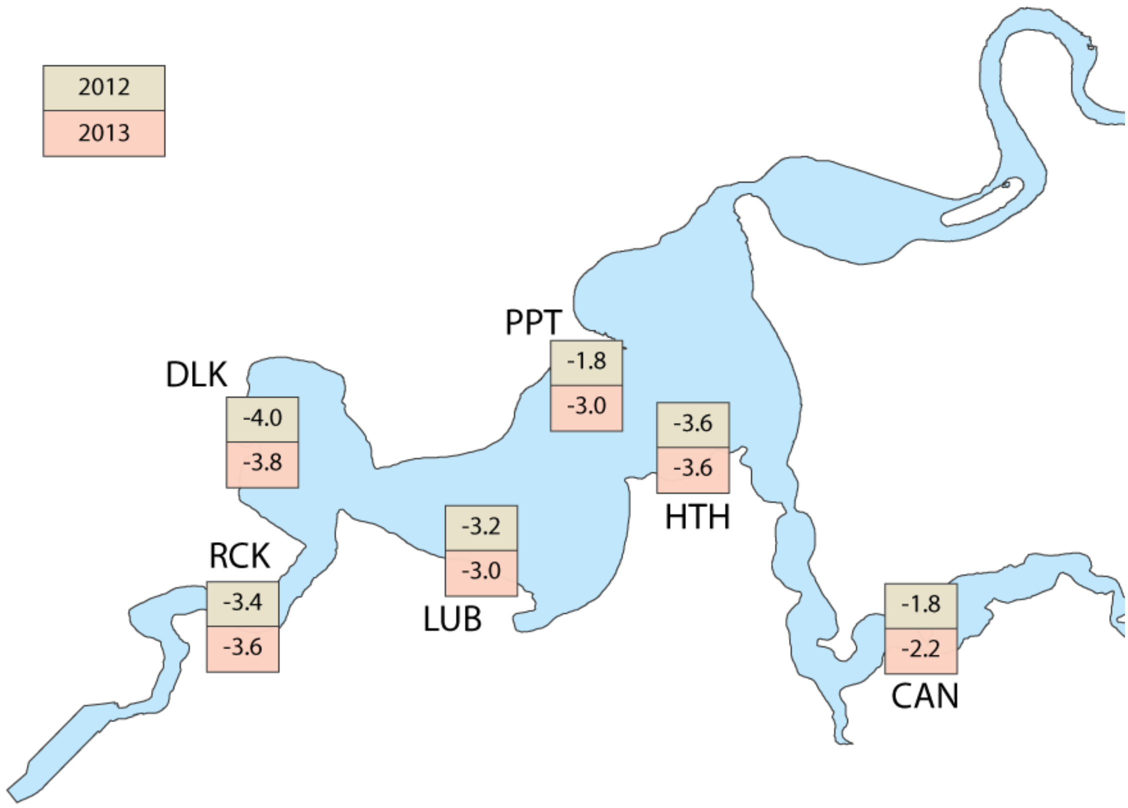


Figure 22 *The six site locations in the estuary (CAN = Canning River estuary, HTH = Heathcote, LUB = Lucky Bay, RCK = Rocky Bay, DLK = Freshwater Bay, PPT = Pelican Point), showing the maximum depth at which seagrass was recorded in 2012 and 2013*

5 Summary of seagrass changes

How the Swan-Canning seagrass population differed in 2013 from that observed in 2012 is summarised in Figure 23. Overall, seagrass presence (the number of observations of seagrass) and seagrass cover increased in 2013 compared with 2012. The depth at which seagrass was observed increased in 2013 compared with 2012 for three sites (RCK, PPT and CAN), although decreased slightly at DLK and LUB by 0.2 m. For most sites the number of species observed was the same between surveys. The increase in species number at sites RCK and LUB were due to a very small number of observations: *Ruppia megacarpa* was observed in 0.6% of quadrats at RCK and *Zostera muelleri* was observed in 0.1% of quadrats at LUB.

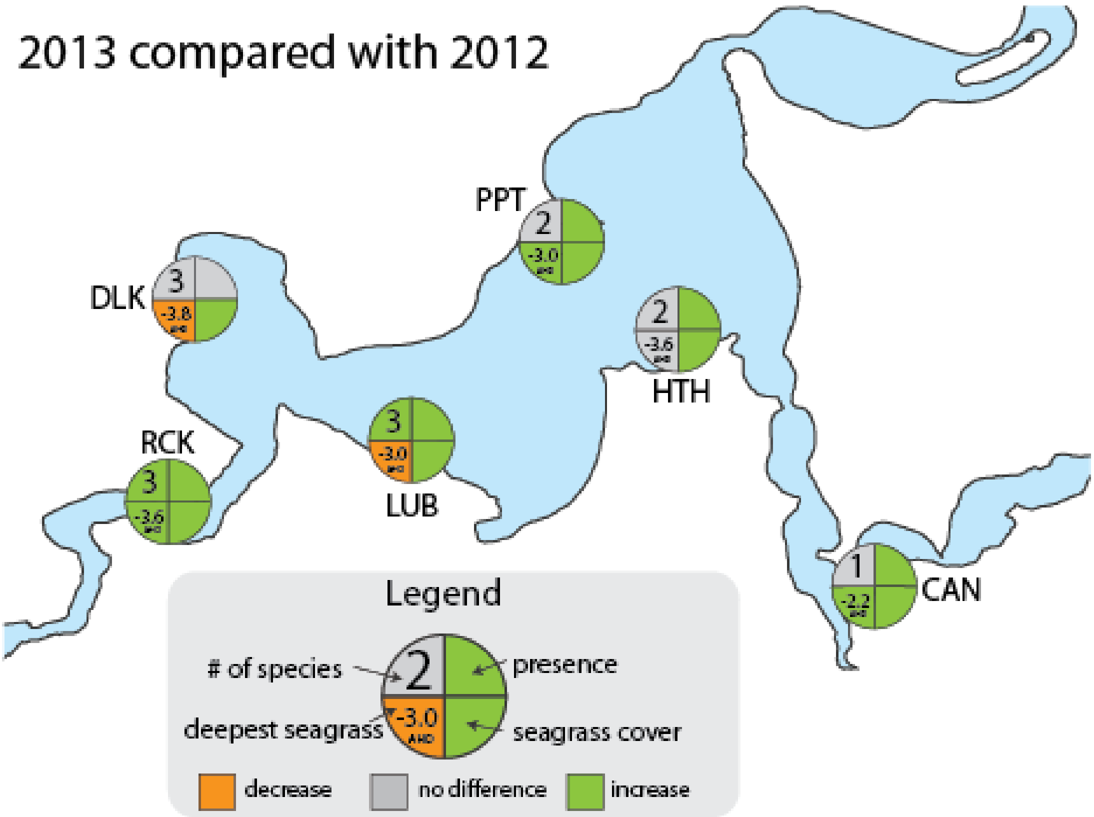


Figure 23 *Summary map comparing seagrass metrics from 2013 to 2012 for six sites in the Swan-Canning estuary*

The increased performance of seagrass in 2013 versus 2012 is most likely a reflection of climatological conditions experienced by the seagrass in the months leading up to the surveys in late summer. The Perth region's temperature, sunshine and rainfall observed for the period is summarised in Table 5. This summary shows that for the months most likely to contribute to peak distribution of seagrass, as observed in the late summer surveys (i.e. December, January and February):

- mean daily maximum temperature was fairly consistent between years (although a little higher than the long-term mean value)
- mean daily sunshine was greater for 2012–13 than 2011–12 (but lower than the long-term mean value)
- rainfall was greater in 2011–12 than in 2012–13.

More hours of bright sunshine and less rainfall in 2012–13 compared with 2011–12 is likely to have resulted in more favourable conditions for photosynthesis and thus the expansion and increased cover of seagrass.

Table 5 *Climate summaries for the Perth region taken from Bureau of Meteorology monthly weather reviews [http://www.bom.gov.au/climate/mwr/.](http://www.bom.gov.au/climate/mwr/)*

	2011–12	2012–13	Climatological value* (2012–13)
Mean daily maximum temperature			
December	30.5 ºC	31.2 ºC	28.9 ºC
January	33.5 ºC	31.7 ºC	31.0 ºC
February	31.1 ºC	34.1 ºC	31.4 ºC
March	31.4 ºC	28.0 ºC	29.7 ºC
Mean daily sunshine**			
December	10.2 h	10.8 h	11.5 h
January	11.3 h	11.3 h	11.5 h
February	10.5 h	11.0 h	11.0 h
March	10.6 h	9.2 h	9.6 h
Total precipitation (number of days)			
December	75.8 mm (3)	20.6 mm (6)	13.3 mm (3.8)
January	18.8 mm (5)	7.2 mm (5)	9.7 mm (2.4)
February	23.6 mm (3)	0.8 mm (2)	12.7 mm (2.1)
March	0.2 mm (1)	69.6 mm (6)	19.2 mm (4.1)

** Climatological value refers to long-term means based on observations from all available years of record.*

*** Mean daily sunshine refers to the number of hours of bright sunshine (as measured using the Campbell-Stokes sunshine recorder, which uses a glass sphere to focus the sun's rays onto a calibrated paper card. When the sky is clear the focused rays burn a trace on the card, which is then used to determine the daily length of 'bright sunshine').*

Inter-annual variation in seagrass distribution (particularly seagrass cover) is expected. *Halophila ovalis* (the dominant seagrass present) is a fast-growing species that can readily take advantage of improved conditions. It is where these changes in distribution are not readily explainable by variations in climate that relating the performance of seagrass to the physiological condition measured at each site becomes important. The physiological assessment of seagrass condition in 2011–12 already concluded that 2011–12 was a sub-optimal year for seagrass growth (Kilminster & Forbes 2014) and the current study suggests this conclusion was valid.

6 Conclusions

Collection of multiple years of survey data at these sites will allow for trends in coverage to be established. It is important to realise, however, that seagrass coverage is unlikely to respond in a linear fashion to any increased stresses on the system. For this reason using an approach at the meadow or habitat scale, together with physiological indicators to understand the impacts of these stresses (and potentially the thresholds of the seagrass to cope with the stresses), will create a robust measure of seagrass condition to address both the performance of the seagrass and also its vulnerability. It is these indicators of seagrass performance and vulnerability that will enable us to answer the deceptively simple questions 'How's the seagrass doing?' and in turn 'How's the estuary doing?'. It will also give management the opportunity to respond in a measured way to issues affecting seagrass habitats at both a local and estuary-wide scale.

In summary:

- this transect monitoring program has provided new and useful insights into seagrass species composition and abundance in the different subsections of the Swan-Canning estuary
- undertaken annually, this monitoring program can provide timely information about the seagrass meadows in the six key areas in the Swan-Canning estuary
- the transect monitoring provides detailed information on the distribution, percentage cover, composition and depth range of seagrasses at a meadow-habitat scale that can, in the future, be related to conditions at those sites
- this dataset serves to complement future estuary-wide assessments of seagrass distribution.

Appendices

A. Estuary-wide survey of seagrass in the Swan-Canning estuary in 2011 using rapid-eye imagery

This appendix summarises the most recent estuary-wide survey of seagrass in the Swan Canning estuary. Undertaken by the Water Science Branch of the Department of Water in 2011, the study's purpose was to update information about the distribution of seagrass in the estuary. The last assessment of seagrass distribution in the estuary was undertaken by Wilshaw and Phillips (1996).

To do this, seagrass composition, presence, and cover were assesses by underwater video along transects in the estuary. This was a trial study to develop a standard methodology to map seagrass in the Swan-Canning estuary. Historical comparisons of seagrass extent have been problematic due to the absence of a standard survey methodology.

Survey methods

Mapping seagrass in the Swan-Canning estuary was a three-part process involving remote sensing, ground-truthing and image interpretation.

RapidEye imagery (remote sensing) of the Swan-Canning estuary was captured in December 2010. The bands used in the image highlighted the presence of aquatic vegetation. Using this imagery, transects and sampling points were generated to cover representative habitats highlighted by the image (Figure 24).

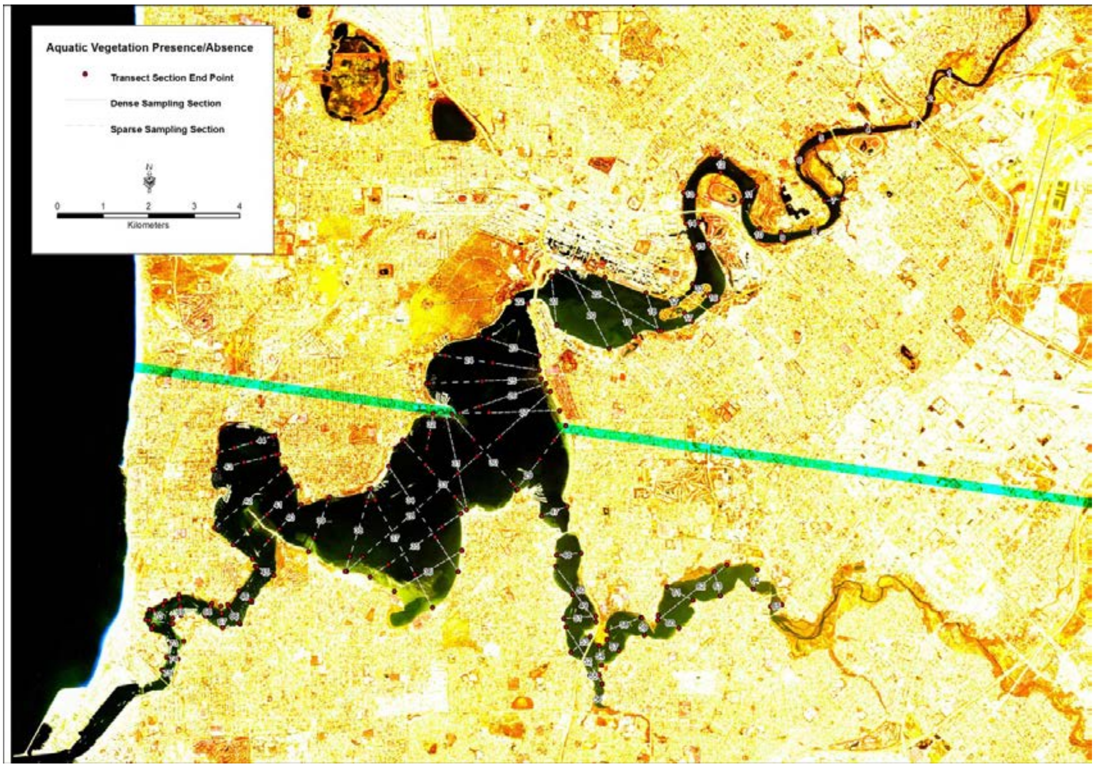


Figure 24 *RapidEye satellite image captured in December 2010*

The sampling intensity along these transects was divided into dense and sparse levels of intensity with effort determined by the bathymetry. Dense sampling (with sampling points 50 m apart) occurred at depths < 3 m and sparse sampling (with sampling points 250–500 m apart) occurred in deeper sections of the estuary (> 3 m) (Figure 25).

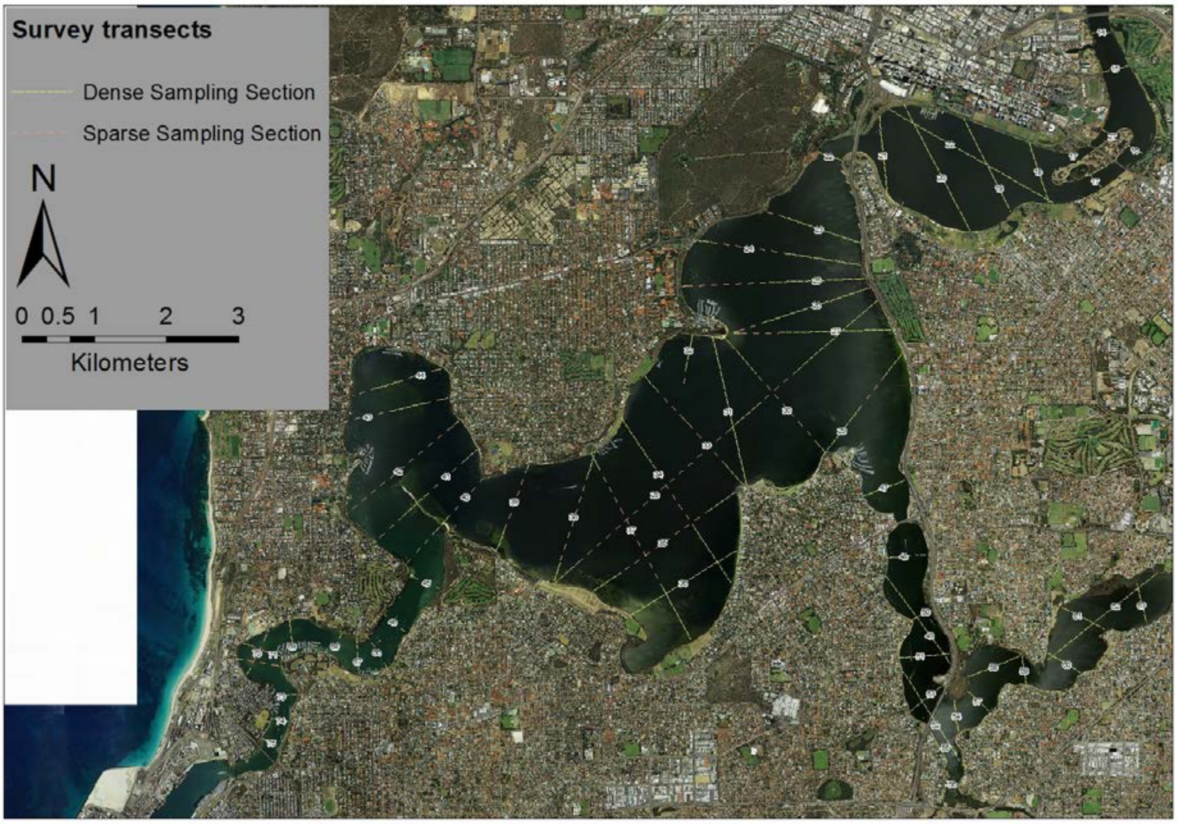


Figure 25 *The transects and points generated for the 2011 survey*

Information collected at each point included data on seagrass species composition and cover (by underwater video), water depths, and light readings of photosynthetic active radiation (PAR). Seagrass cover was estimated on a scale of 0 to 100% incorporating 8 categories (0, 1-10%, 11-25%, 26-50%, 51-75% and 76-100%). Macroalgal cover was noted but no attempt was made to identify species.

A seagrass distribution map was generated by physically drawing polygons around habitats visible in the image using ArcMap. Polygons were classified as seagrass based on the video data.

Results of survey

Three species were noted during the survey – *Halophila ovalis, Ruppia megacarpa* and *Zostera muelleri*. *Halophila ovalis* was the dominant species. Some isolated meadows and smaller patches of *Ruppia megacarpa* were observed in Whalen Bay, Lucky Bay and Freshwater Bay. *Zostera muelleri* predominantly occurred in the marine extent of the estuary and was observed as far upstream as Freshwater Bay. Small areas of *Halophila ovalis* were found to occur along the north western margin and on a shallow shelf opposite Coode St Jetty in Perth Water.

Halophila ovalis was predominantly found, and was most dense in the shallow waters (up to 3m) of the estuarine basin. *Halophila* was found in deeper waters (depth >3 m) in the marine extent of the estuary (Freshwater bay to the mouth).

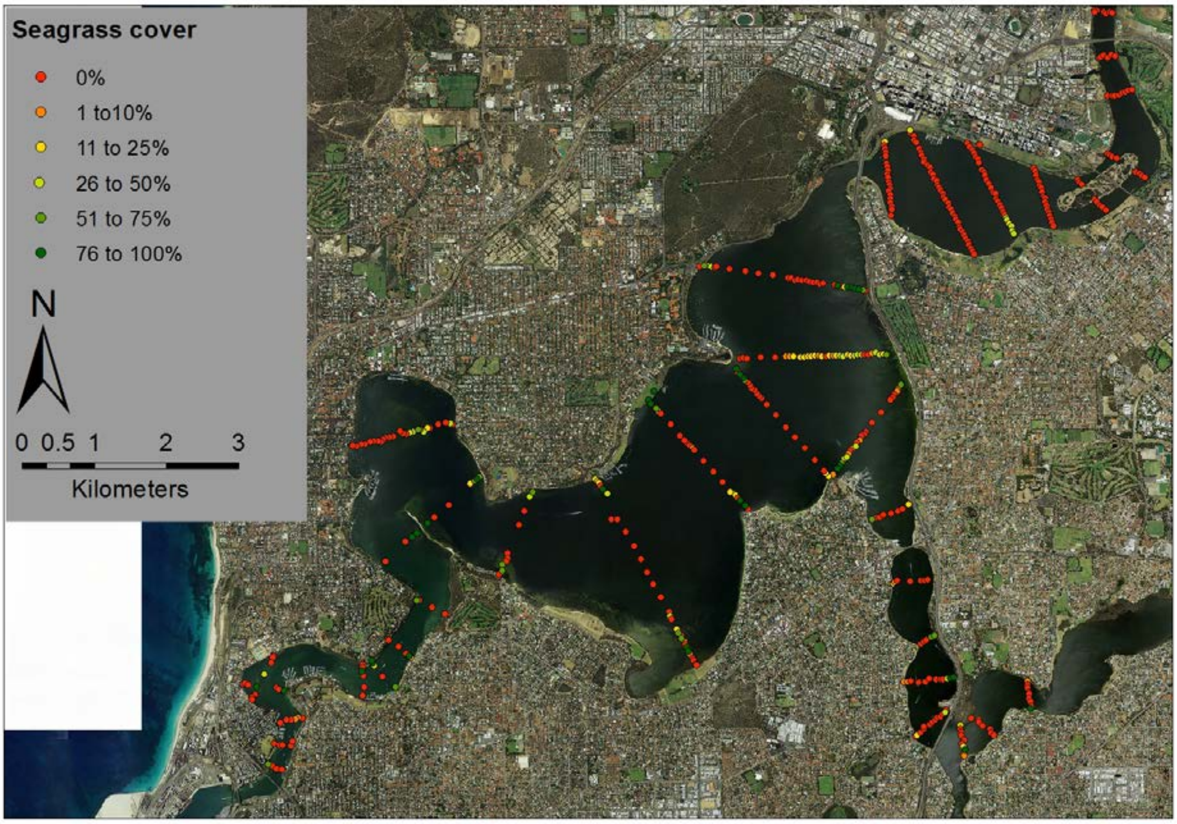


Figure 26 *Seagrass density recorded along monitored transects in the 2011 survey*

The depth distribution of *H. ovalis* was found to relate closely to availability of light for photosynthesis and the maximum depth at which that light would be available. Light extinction curves were calculated from the depth profile of PAR readings at each transect point. This data enabled us to calculate the maximal depth at which seagrass could occur, based on the minimum light requirement of seagrasses of 11 % ambient irradiance (Table 6). Light conditions improved closer to the marine extent of the estuary. The deepest occurrence of *Halophila ovalis* was at a water depth of 4 m. Seagrass was estimated to cover an area of approximately 403 ha (Figure 27).

Table 6 *Maximal depths calculated for the Swan-Canning estuary*

Region	Perth Water	Melville Water	Freshwater Bay and Marine channel
Depth range	< 1 m	1 to 3m	3 to 5m

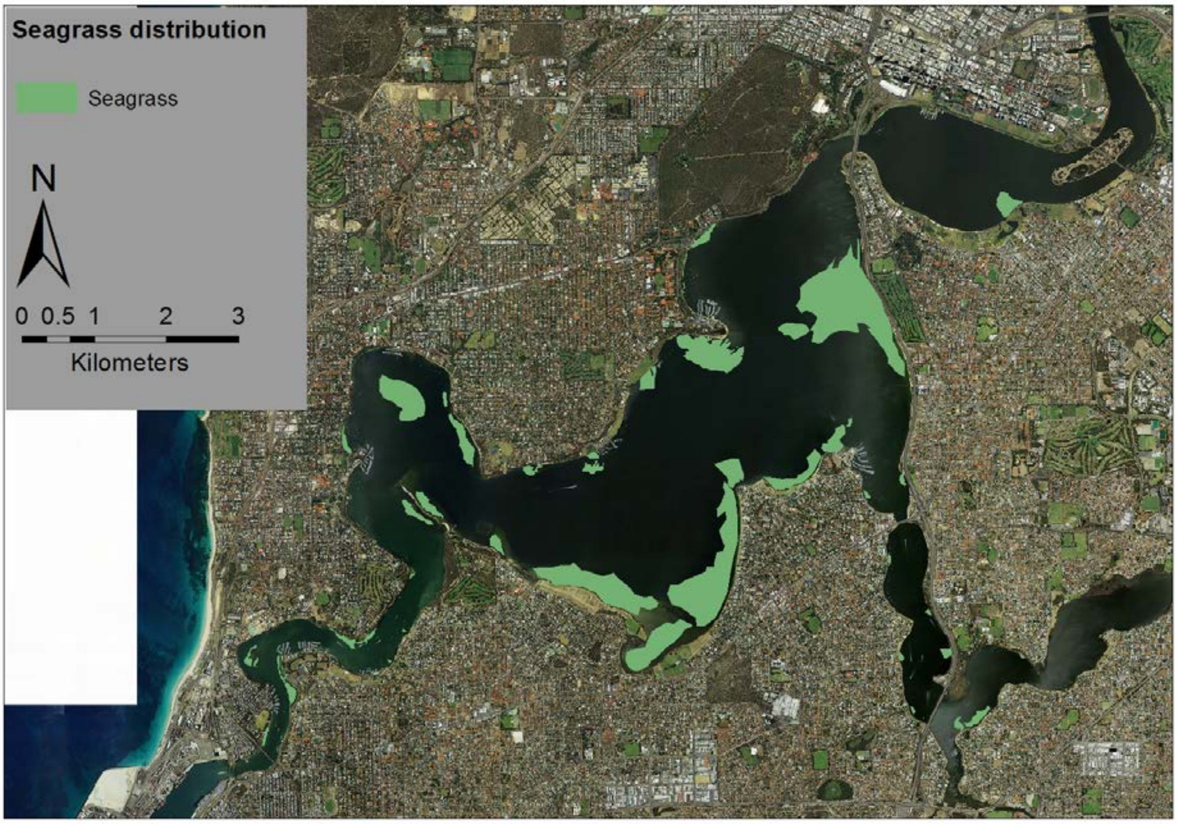


Figure 27 *Seagrass distribution in the Swan-Canning estuary*

Conclusions

To date, there has been no consistent method employed to determine seagrass distribution, nor quantitative estimates of errors in the methods of survey for the Swan-Canning estuary. This makes it very difficult to be confident about estuary-wide change in seagrass distribution. However, a decrease in areal coverage from almost 600 ha in the early 1980s, to around 400 ha thirty years later, is likely to reflect a real decline in seagrass coverage.

A number of methods are available to seagrass habitats from side scan sonar to aerial imagery. Each comes with advantages and disadvantages, and often related to the balance between suitability, accuracy and cost.In the current survey, the methods were found to be most suitable for the shallower clearer waters. Accuracy declined in the deeper waters where seagrass boundaries could not clearly be defined. Advancements in hyperspectral and multispectral imaging may eventually resolve these issues. The cost of the current survey was relatively low, but was time-intensive. Further efforts are required to develop a suitable estuary-wide survey method.

A more ideal approach may be to incorporate better technologies in imagery acquisition and use editing and classification techniques to define seagrass habitats. This may require less intensive ground-truthing and offer a standardised approach for calculating seagrass areal coverage.

B. Transect coordinates

Site	Transect	Start (10 m)		Stop (100 m)	
		Easting	**Northing**	**Easting**	**Northing**
PPT	**A**	388766	6460369	388763	6460283
	B	388817	6460367	388802	6460277
	C	388869	6460364	388872	6460272
	D	388926	6460355	388939	6460267
	E	388984	6460349	388969	6460261
	F	389025	6460340	389014	6460253
	G	389080	6460339	389080	6460249
	H	389144	6460314	389170	6460230
	I	389220	6460320	389278	6460256
	J	389251	6460372	389334	6460368
DLK	**A (40 m)**	383974	6459182	383988	6459175
	B (60 m)	383944	6459133	383986	6459109
	C (70 m)	383935	6459086	383989	6459081
	D (80 m)	383927	6459053	383998	6459047
	E (90 m)	383917	6458985	384000	6458983
	F	383918	6458930	384009	6458942
	G	383923	6458875	384003	6458918
	H	383940	6458831	384013	6458870
	I	383962	6458788	384041	6458832
	J (90 m)	384014	6458740	384066	6458811
RCK	**A (50 m)**	384308	6456214	384328	6456179
	B (40 m)	384286	6456193	384305	6456172
	C (50 m)	384256	6456165	384287	6456137
	D (50 m)	384236	6456138	384258	6456108
	E (70 m)	384200	6456113	384209	6456059
	F	384164	6456124	384136	6456036
	G	384123	6456137	384100	6456051
	H (90 m)	384074	6456146	384050	6456068
	I (90 m)	384024	6456153	383994	6456079
	J (70 m)	383975	6456178	383948	6456124

Site	Transect	Start (10 m)		Stop (100 m)	
		Easting	**Northing**	**Easting**	**Northing**
LUB	**A**	386910	6456964	386929	6457051
	B	386971	6456943	387001	6457025
	C	387026	6456933	387059	6457018
	D	387081	6456926	387108	6457012
	E	387138	6456910	387160	6456997
	F	387183	6456903	387211	6456988
	G	387247	6456893	387299	6456967
	H	387297	6456871	387341	6456950
	I	387352	6456836	387401	6456913
	J	387414	6456811	387477	6456876
HTH	**A**	390568	6458680	390525	6458759
	B	390556	6458631	390484	6458672
	C	390534	6458568	390455	6458609
	D	390513	6458525	390430	6458567
	E	390486	6458492	390423	6458537
	F	390458	6458450	390392	6458509
	G	390427	6458416	390353	6458465
	H	390392	6458377	390312	6458419
	I	390344	6458342	390293	6458414
	J	390306	6458323	390260	6458401
CAN	**A (50 m)**	392914	6455181	392886	6455206
	B	392883	6455144	392817	6455209
	C	392863	6455108	392794	6455167
	D	392821	6455067	392769	6455138
	E	392789	6455030	392743	6455109
	F	392768	6454995	392711	6455068
	G (90 m)	392708	6454951	392667	6455036
	H	392665	6454929	392608	6455010
	I (80 m)	392610	6454928	392575	6454990
	J	392565	6454930	392523	6455006

C. Site maps

Pelican Point (PPT)

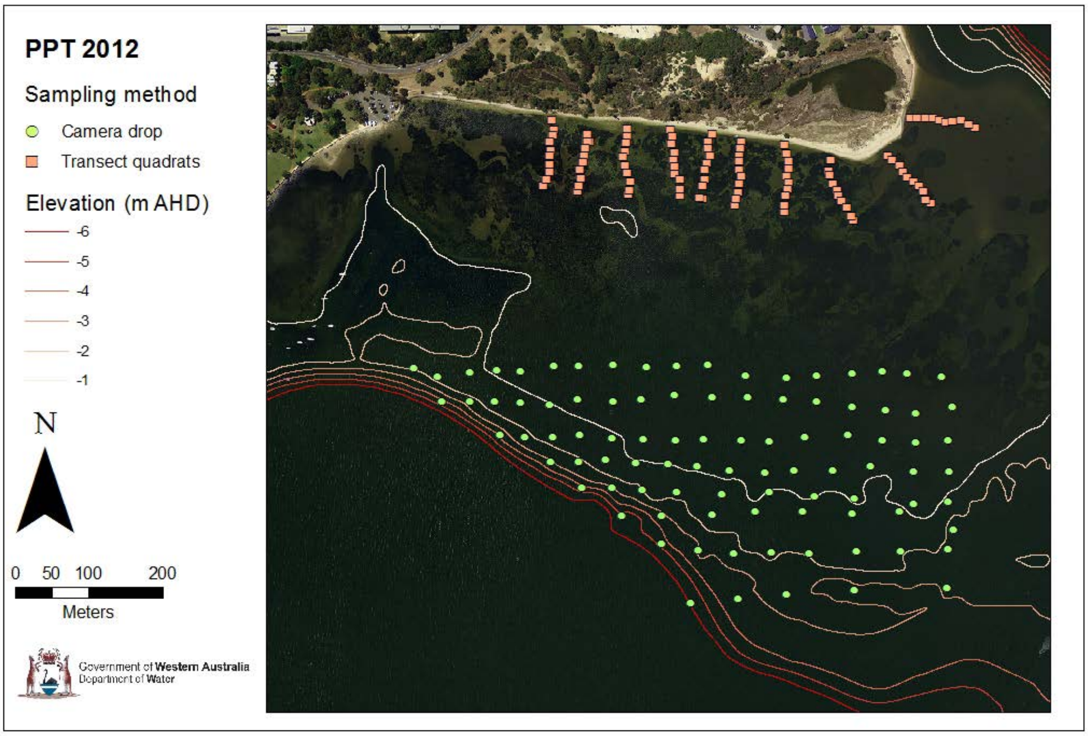


Figure 28 *Actual sampling locations at PPT in 2012, showing boat and shore transects*

Figure 29 *Actual sampling locations at PPT in 2013, showing boat and shore transects*

Freshwater Bay (DLK)

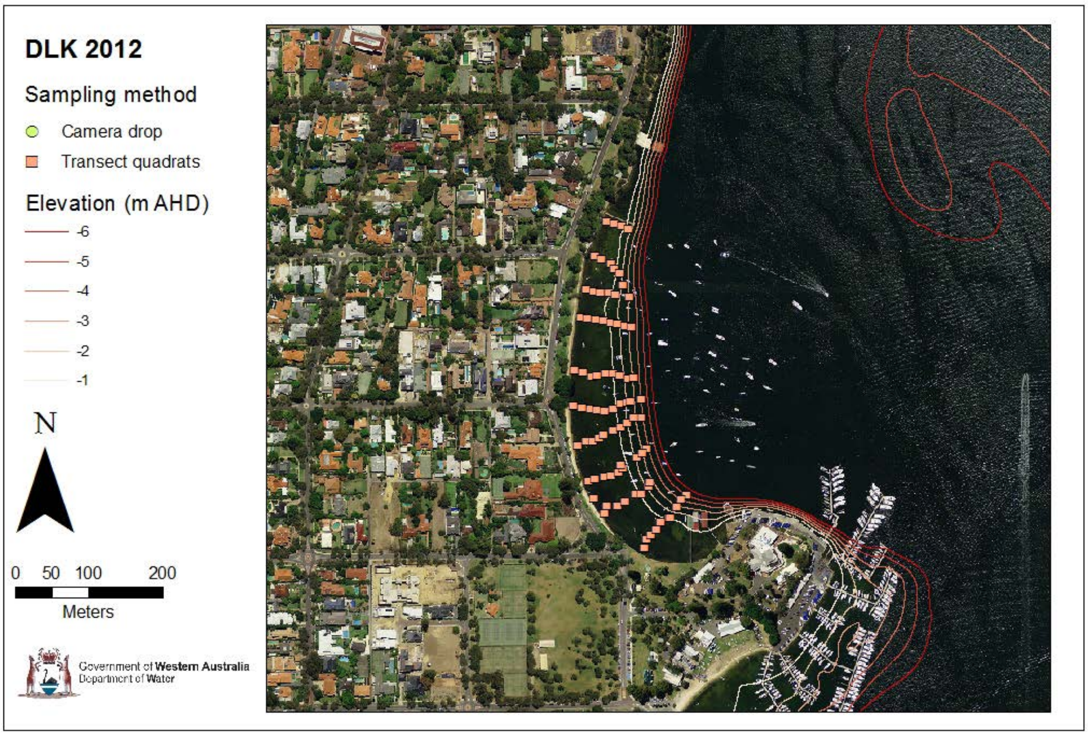


Figure 30 Actual sampling locations at DLK in 2012, showing boat and shore transects

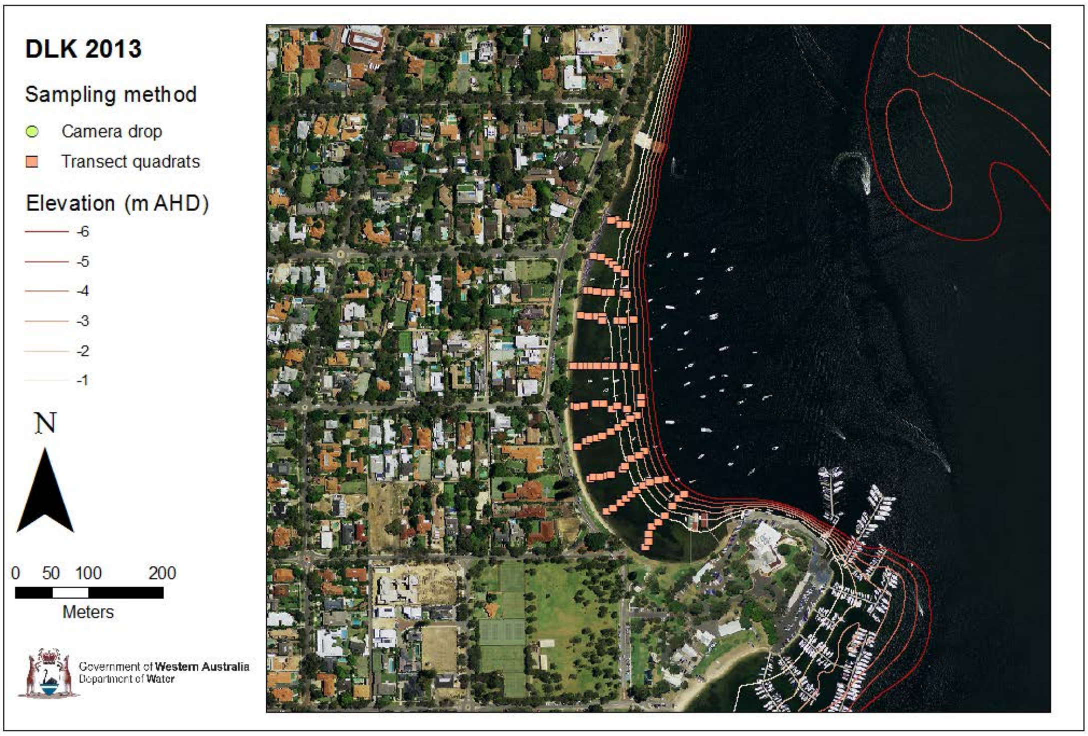


Figure 31 Actual sampling locations at DLK in 2013. Note shore transects only.

Rocky Bay (RCK)

Figure 32 *Actual sampling locations at RCK in 2012, showing boat and shore transects*

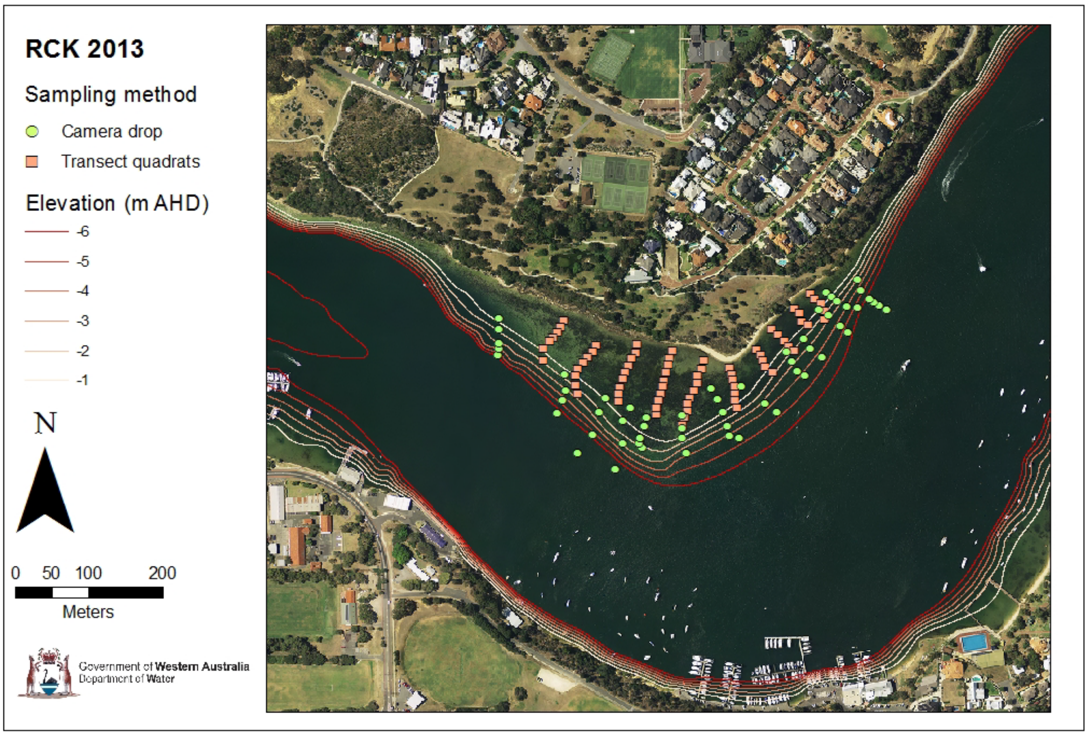


Figure 33 *Actual sampling locations at RCK in 2013, showing boat and shore transects*

Lucky Bay (LUB)

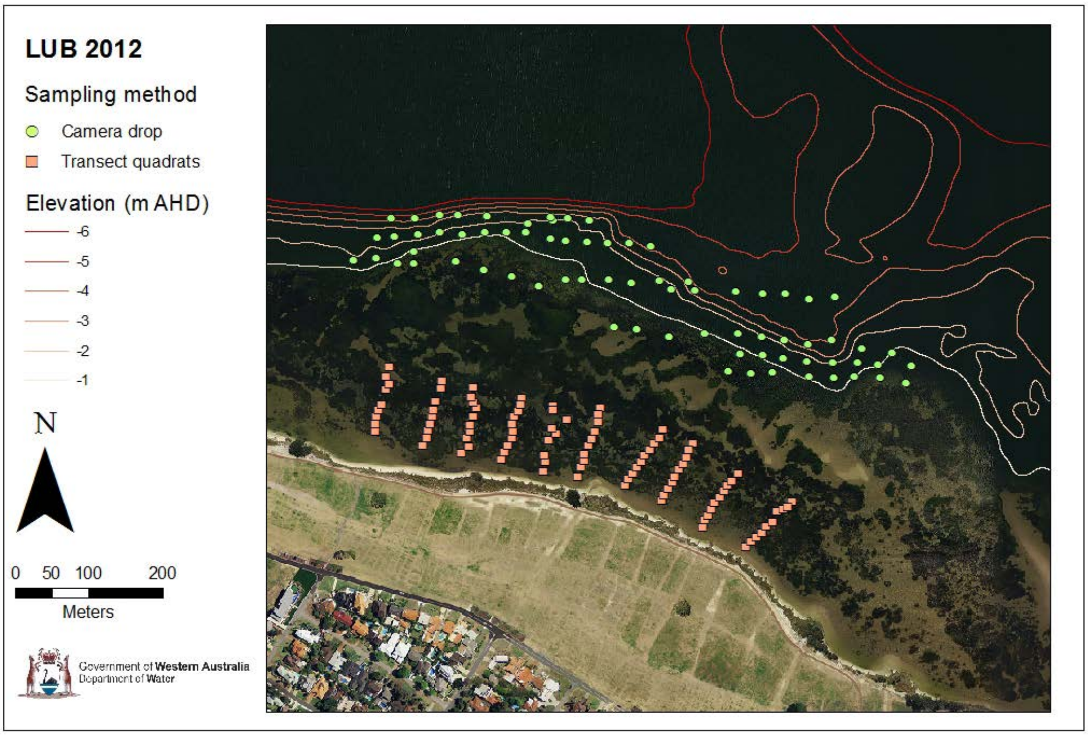


Figure 34 *Actual sampling locations at LUB in 2012, showing boat and shore transects*

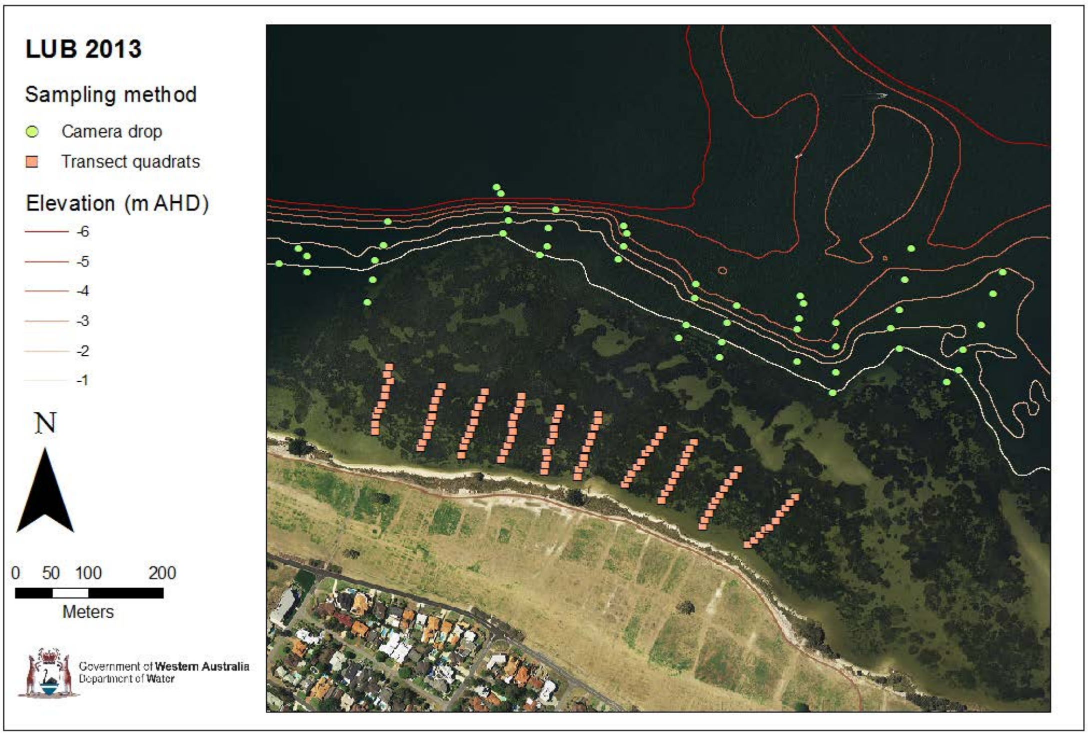


Figure 35 *Actual sampling locations at LUB in 2013, showing boat and shore transects*

Heathcote (HTH)

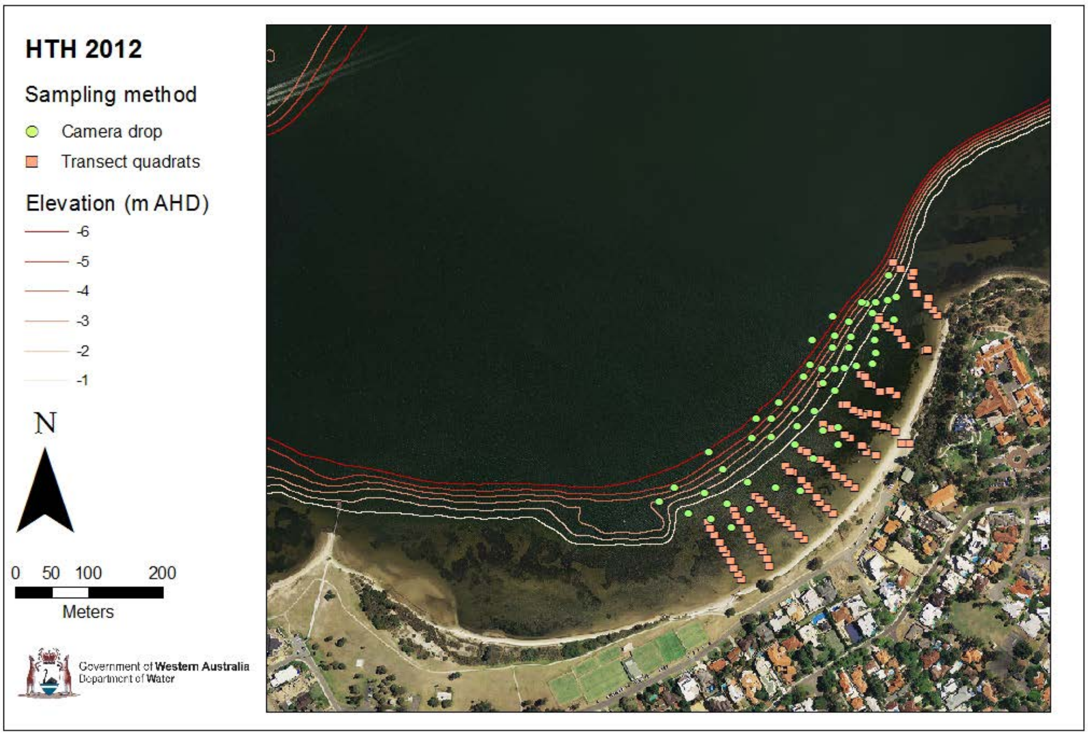


Figure 36 *Actual sampling locations at HTH in 2012, showing boat and shore transects*

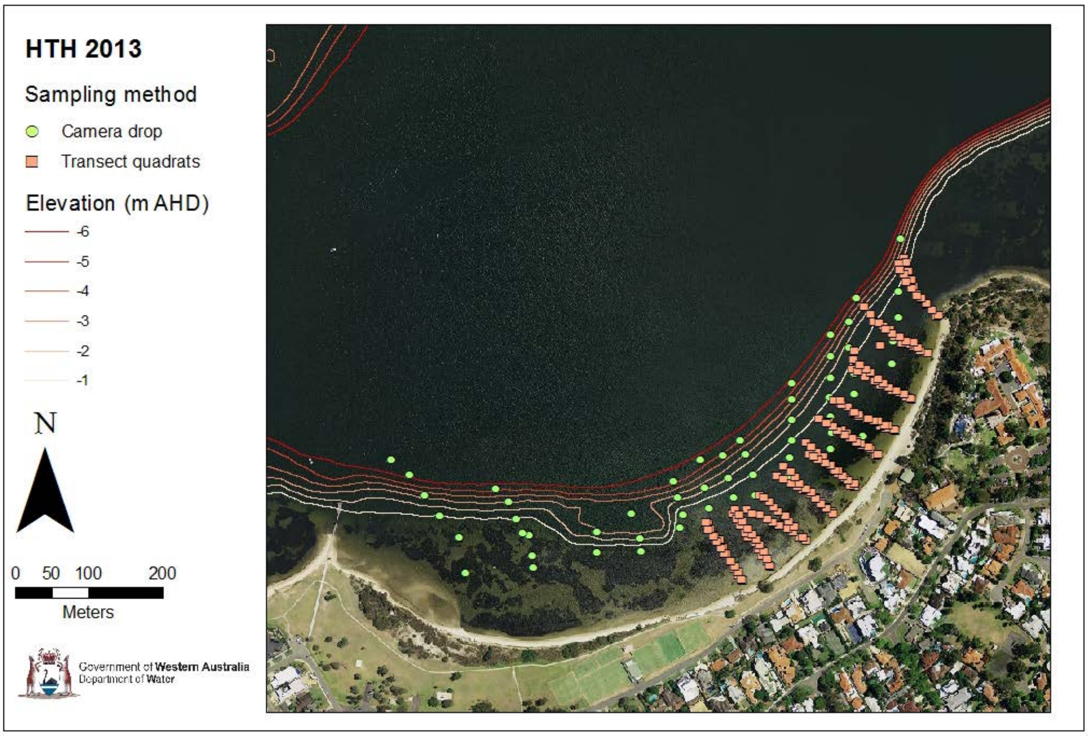


Figure 37 *Actual sampling locations at HTH in 2013, showing boat and shore transects*

Canning (CAN)

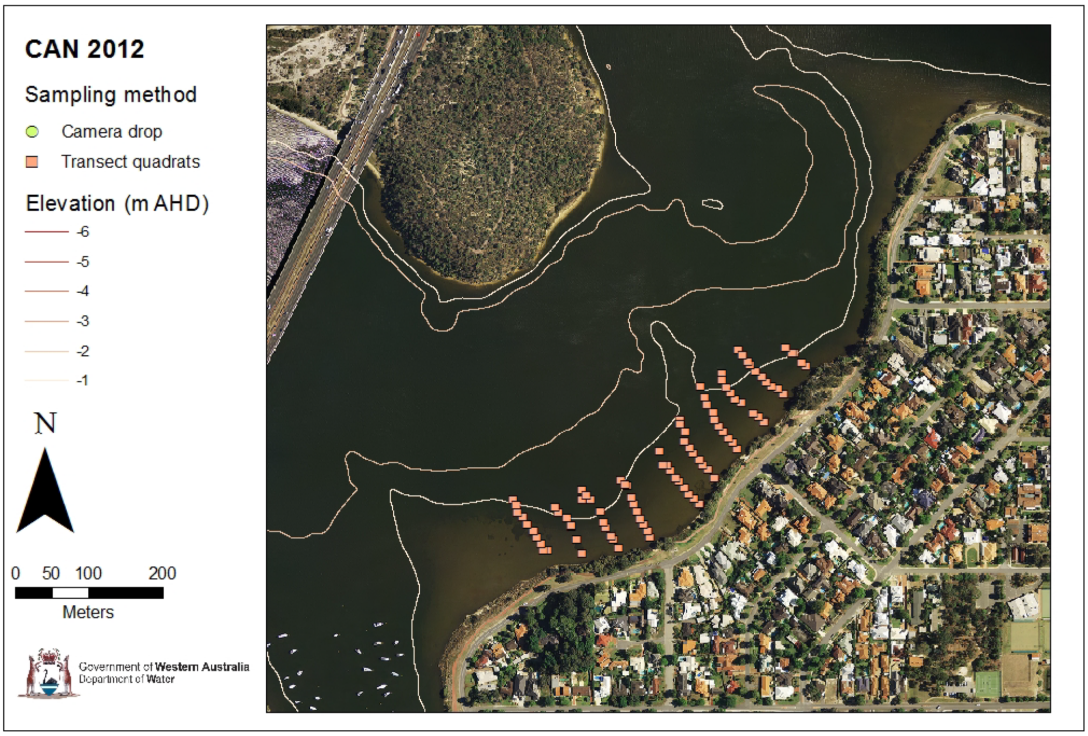


Figure 38 *Actual sampling locations at CAN in 2012. Note shore transects only.*

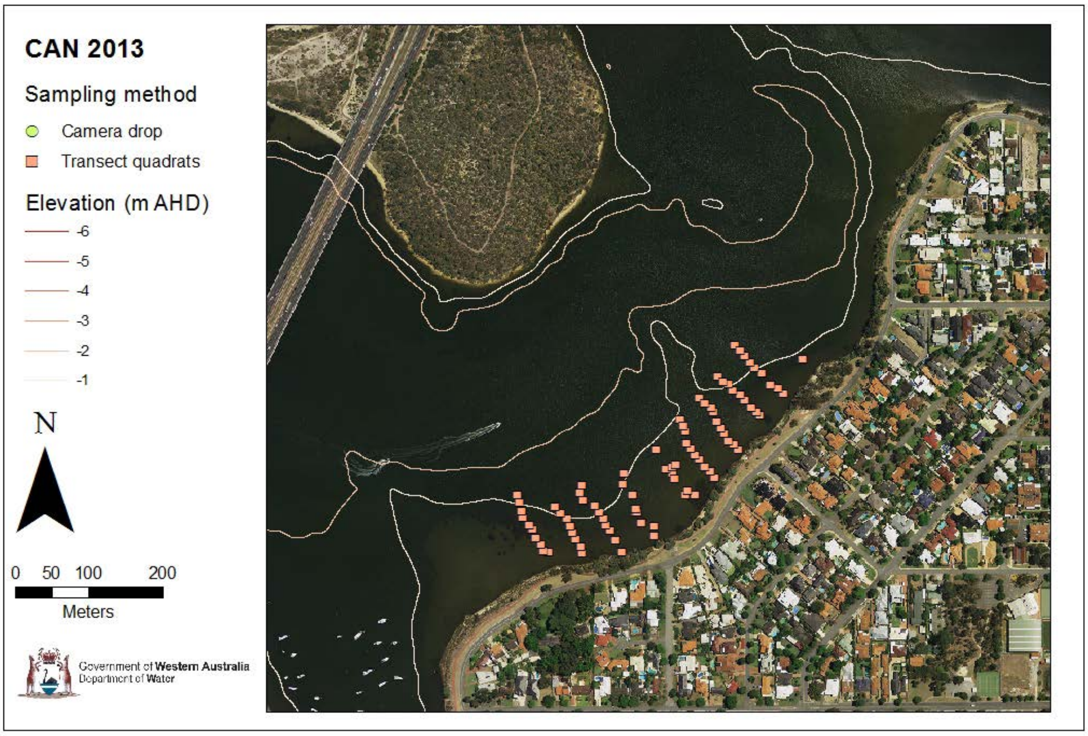
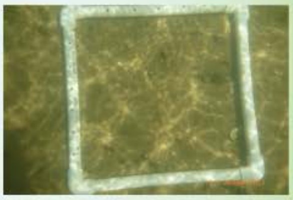
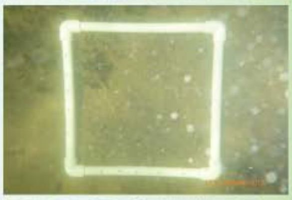


Figure 39 *Actual sampling locations at CAN in 2013. Note shore transects only.*

D. Summary of seagrass cover classes

Seagrass score	Seagrass cover (%)	Description	
0	0%	Absence	
1	1-10 %	Very light cover, single to a few leaves visible	
2	11-25%	Light cover, many leaves but predominantly sand	
3	26-50%	Moderate cover, more sand than seagrass visible.	
4	51-75%	Moderate cover, more seagrass than sand visible	
5	76-90%	Dense cover, only some sand visible	
6	91-100%	Very dense cover, little to no sand visible	

E. Testing the power of the sampling methods

This appendix is a summary of results to test the power of the sampling methods to sufficiently capture the coverage of seagrass at each site. To do this, seagrass composition, presence and cover was assessed three times (T1, T2 and T3) along one transect at each site. The null hypothesis for this test was that there would be no significant difference in the seagrass metrics between T1, T2 and T3, and in so doing show the methodology to be sufficient to capture seagrass population attributes.

Species composition and presence

There was very little change in the seagrass species observed when transect assessments were repeated. Only at site RCK was *Zostera muelleri* detected in the last replicate (T3) of transect D (Table 7). Despite not being detected in T1 and T2, there remains sufficient replication in the 10 transects at RCK (and the other sites) to detect sparsely distributed species like *Zostera muelleri* and show the relative contribution of this species to the composition of seagrass habitat. In this case being 13% (2012) and 24% (2013) at RCK.

Table 7 *Seagrass species composition along replicate transects at each site*

	PPT	DLK	RCK	LUB	HTH	CAN
H. ovalis	✓	✓	✓	✓	✓	✓
R. megacarpa		✓	✓	✓	✓	
Z. muelleri			✓ (T3 only*)			

*T3 = third replicate of transect D

There was no significant difference in the number of observations of seagrass presence along T1, T2 or T3 at all sites (Table 8). At sites PPT, LUB, HTH and CAN differences were less than 4%, equivalent to four observations. There were no differences in the number of observations of seagrass presence between T1, T2 and T3 at sites DLK and RCK. This demonstrates that the 10 randomly thrown quadrats were sufficient to give adequately consistent results for seagrass presence and absence.

Table 8 *The ratio of seagrass presence (P) relative to total number of observations (N^{obs}) for replicates T1, T2 and T3 at sites PPT, DLK, RCK, LUB, HTH and CAN (transect ID in brackets). Also shown are results for Friedman ANOVA comparing seagrass observations for T1, T2 and T3 at each site. Chi^2 equals the Chi-square result, N represents the total number of observations, and d.f. the degrees of freedom. The p-values of significance comparing T1, T2 and T3 are also shown (p<0.05 is significant).*

	T1 (P/N^{obs})	T2 (P/N^{obs})	T3 (P/N^{obs})	Chi^2	N	*d.f.*	*p*-value
PPT (E)	1.00	0.98	0.99	3.00	100	2	p = 0.221
DLK (H)	1.00	1.00	1.00	0	-	-	-
RCK (D)	1.00	1.00	1.00	0	-	-	-
LUB (C)	0.98	0.97	0.98	0.33	100	2	p = 0.846
HTH (E)	0.85	0.86	0.86	0.29	100	2	p = 0.867
CAN (C)	0.23	0.19	0.20	0.89	100	2	p = 0.639

Seagrass cover

There were also no significant differences in seagrass cover measures among the repeated transects (T1, T2 and T3) at all sites ($p>0.05$, Table 9 and Figure 40 to Figure 45). This is also reflected in the small differences in the average seagrass cover for each transect which ranged between 0.2% (RCK) and 6.2% (DLK). This result again demonstrates that the 10 randomly thrown quadrats were sufficient to give adequately consistent results.

Table 9 *Average seagrass cover as a percentage (%)for replicates T1, T2 and T3 at sites PPT, DLK, RCK, LUB, HTH and CAN (transect ID in brackets). Also shown are results for Friedman ANOVA comparing seagrass observations for T1, T2 and T3 at each site. Chi^2 equals the Chi-square result, N represents the total number of observations, and d.f. the degrees of freedom. The p-values of significance comparing T1, T2 and T3 are also shown (p<0.05 is significant).*

	T1 (%)	T2 (%)	T3 (%)	Chi^2	N	*d.f.*	*p*-value
PPT (E)	73.5	75.7	75.6	4.951	100	2	$p=0.084$
DLK (H)	31.6	32.8	37.2	3.813	90	2	p=0.149
RCK (D)	61.5	61.7	61.5	0.234	50	2	$p=0.889$
LUB (C)	75.4	76.7	76.1	0.217	100	2	$p=0.897$
HTH (E)	76.5	74.6	76.0	0.722	100	2	$p=0.697$
CAN (C)	12.6	11.0	9.8	0.150	98	2	$p=0.928$

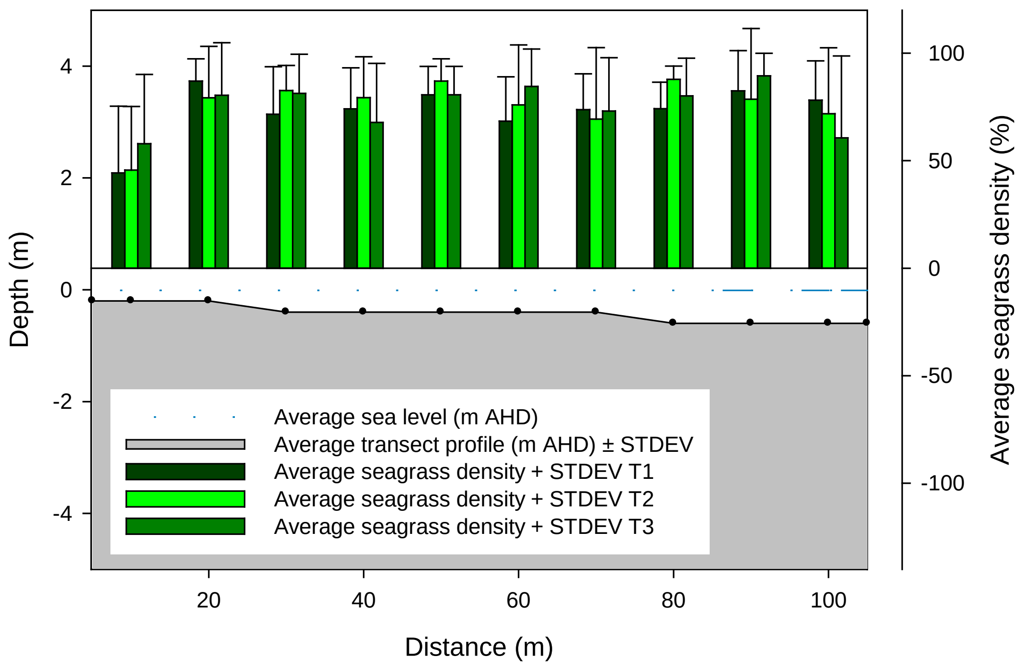


Figure 40 *Average seagrass cover as a percentage cover along transect E time 1 (T1), time 2 (T2) and time 3 (T3) repeats at PPT*

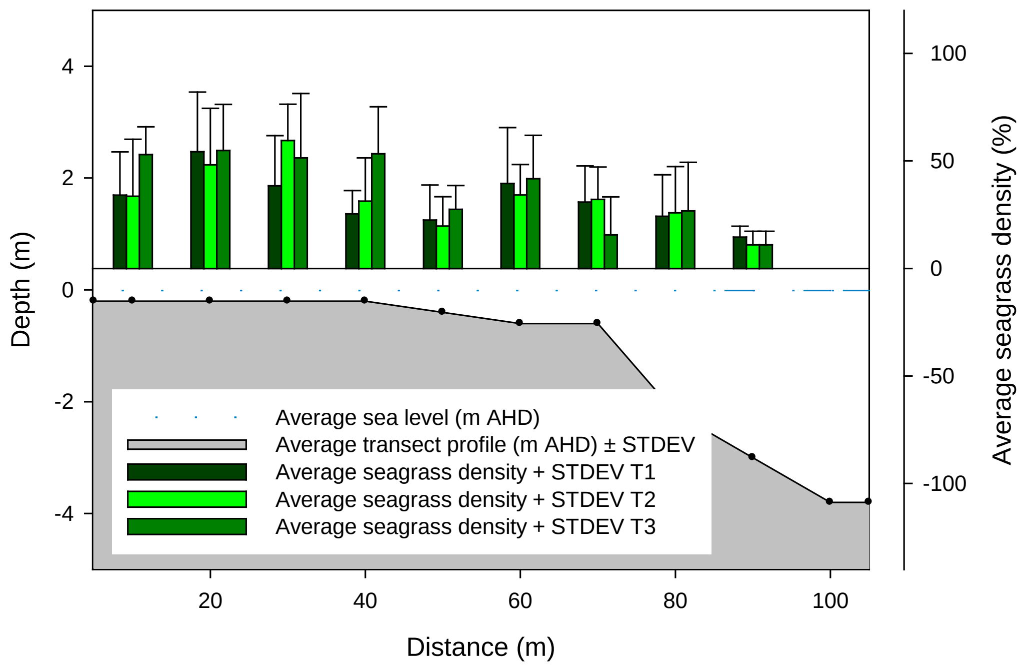


Figure 41 *Average seagrass cover as a percentage cover along transect H for time 1 (T1), time 2 (T2) and time 3 (T3) repeats at DLK*

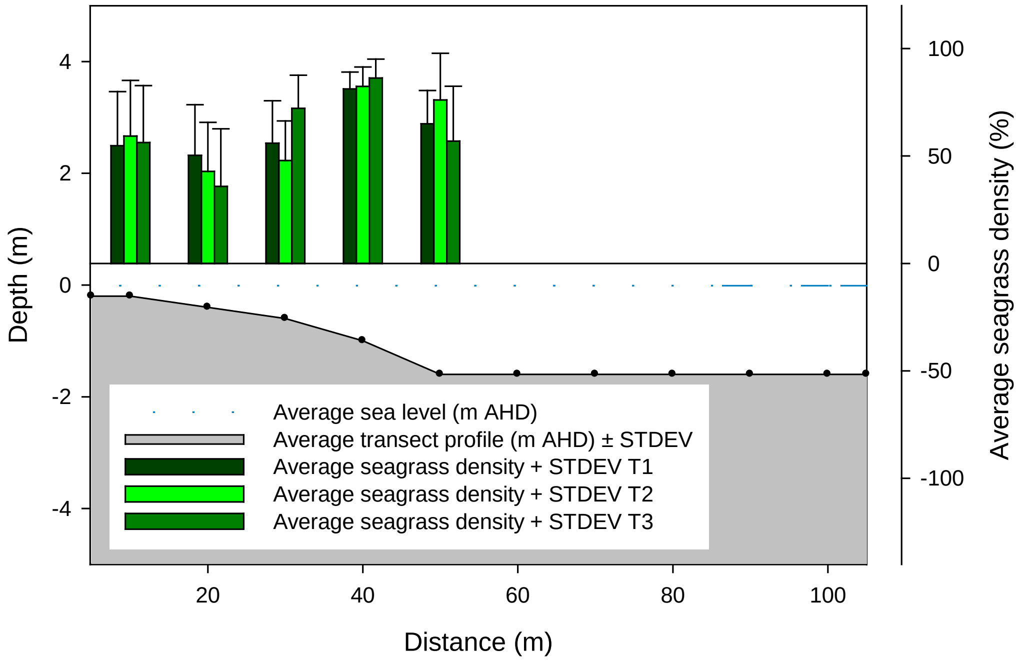


Figure 42 *Average seagrass cover as a percentage cover along transect D for time 1 (T1), time 2 (T2), and time 3 (T3) repeats at RCK*

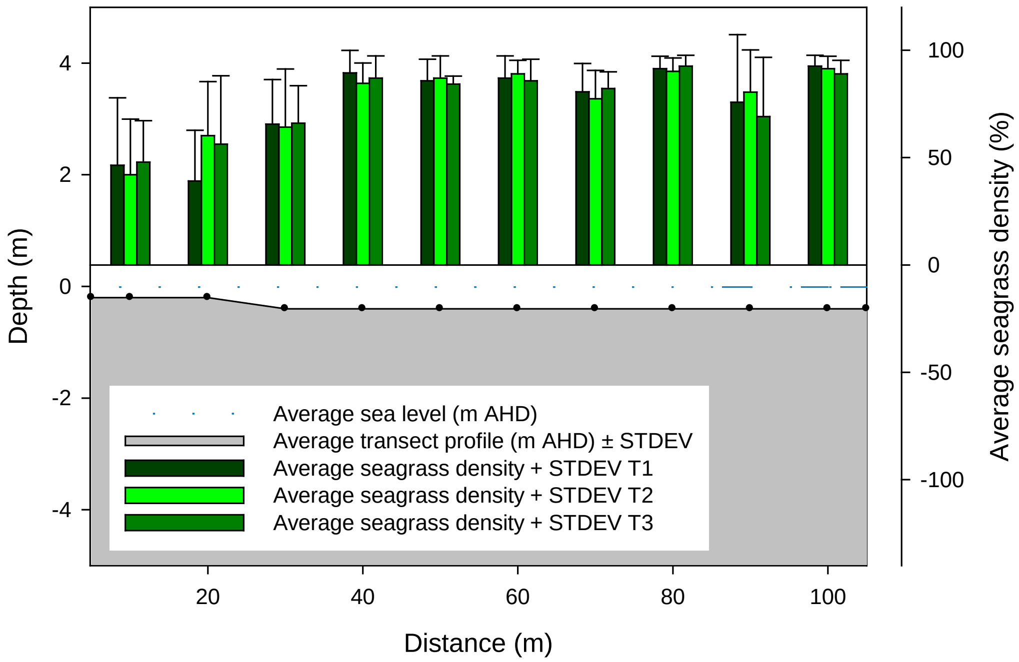


Figure 43 *Average seagrass cover as a percentage cover along transect C for time 1 (T1), time 2 (T2) and time 3 (T3) repeats at LUB*

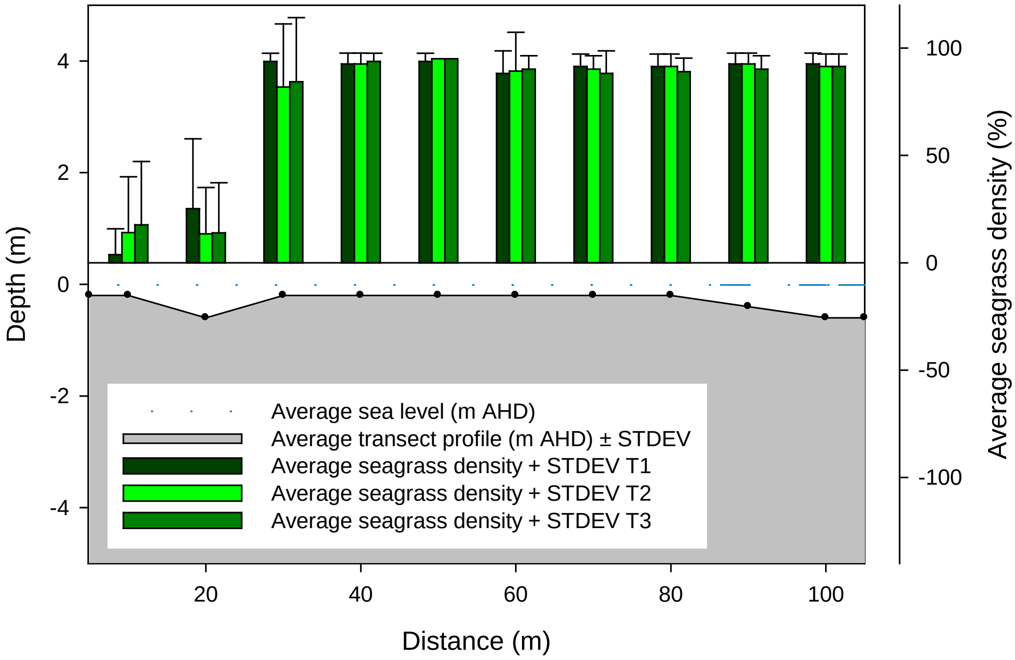


Figure 44 *Average seagrass cover as a percentage cover along transect E for time 1 (T1), time 2 (T2) and time 3 (T3) repeats at HTH*

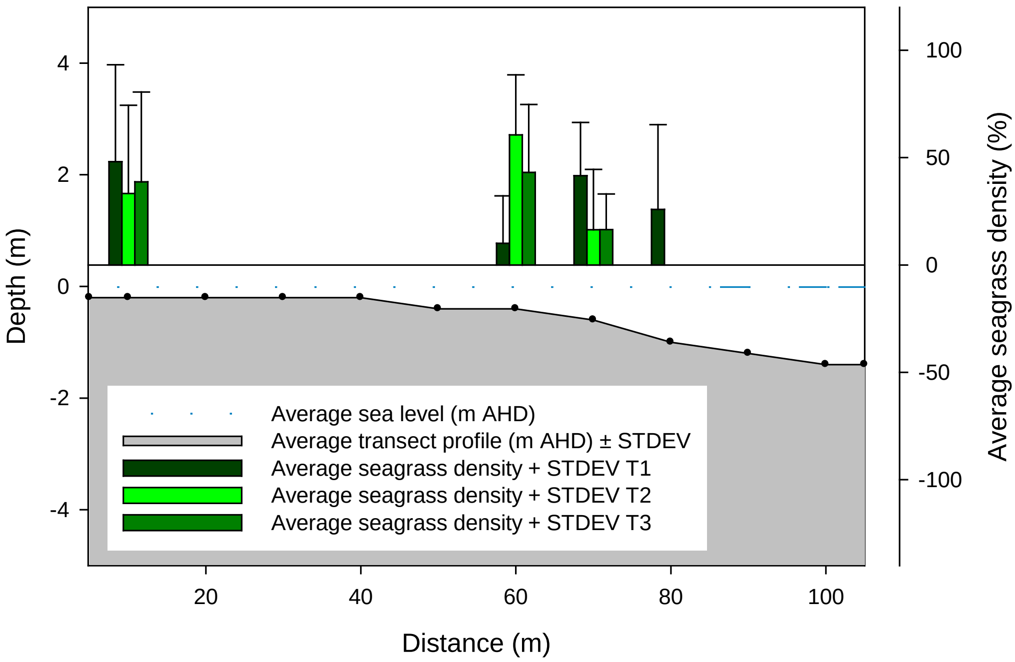


Figure 45 *Average seagrass cover as a percentage cover along transect C for time 1 (T1), time 2 (T2) and time 3 (T3) repeats at CAN*

F. How important is the timing of the survey?

To obtain the best measure of seagrass performance in the estuary it is important to time the surveys when seagrass reaches its peak biomass. On average in the Swan-Canning estuary, peak biomass for *H. ovalis* was found in February but could vary on a site level by up to a month (Kilminster & Forbes 2014). To explore the effect of the difference in the timing of the surveys in 2012 and 2013, we undertook whole-site observations at HTH twice in 2013 (in February and in March – six weeks apart). We used these data to explore inter-annual and monthly variation at site HTH. The primary null hypothesis for this test was that there would be no significant difference in the seagrass metrics collected at site HTH in February and March 2013. We also compared the two years of data at HTH to validate inter-annual differences.

Species composition and presence

Species composition at HTH did not change between the 2012 and 2013 March surveys, or between the February and March 2013 surveys. *Halophila ovalis* was the dominant species in all three surveys (Figure 46). *Ruppia megacarpa* was very sparse and accounted for less than 1% of the observations.

There was a significant increase in the number of seagrass observations from March 2012 to both February and March 2013. There was no significant different between February 2013 and March 2013, although there was a slight downward trend in observations from February to March 2013 (Figure 46 and Table 10).

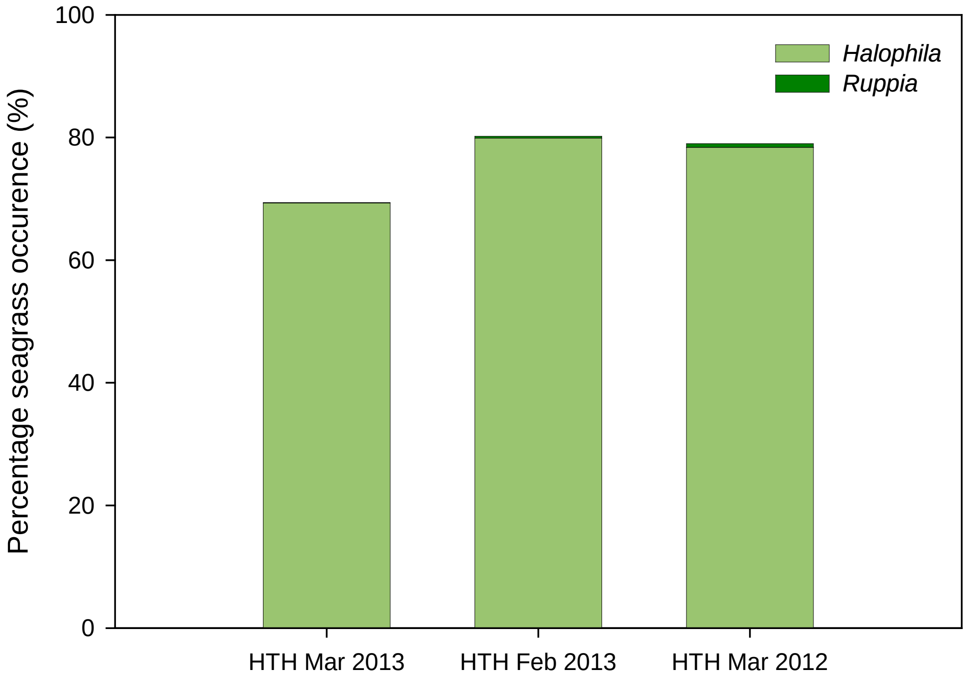


Figure 46 *Percentage of seagrass species observations in March 2012, February 2013 and March 2013 at site HTH*

Table 10 *The ratio of seagrass presence (P) relative to total number of observations (N^{obs}) at HTH in March 2012, and February and March 2013, with Wilcoxon matched pair t-test results (N, T, Z) and p-value of significance (p<0.05 is significant) comparing the two months.*

	Mar 2012 P/N^{obs}	Feb 2013 P/N^{obs}	Mar 2013 P/N^{obs}	Difference	N	T	Z	*p*-value
HTH		0.802	0.790	- 0.012	39	356.0	0.475	$p=0.635$
	0.694		0.790	+ 0.096	51	183.0	4.499	$p<0.05$
	0.694	0.802		+ 0.108	50	125.5	4.942	$p<0.05$

Figure 47 shows that although not statistically significant, there were less seagrass observations in March than in February, and that the reduction occurred at the site's deeper margin. Seagrass observations otherwise increased along the site profile between March 2012, and February and March 2013.

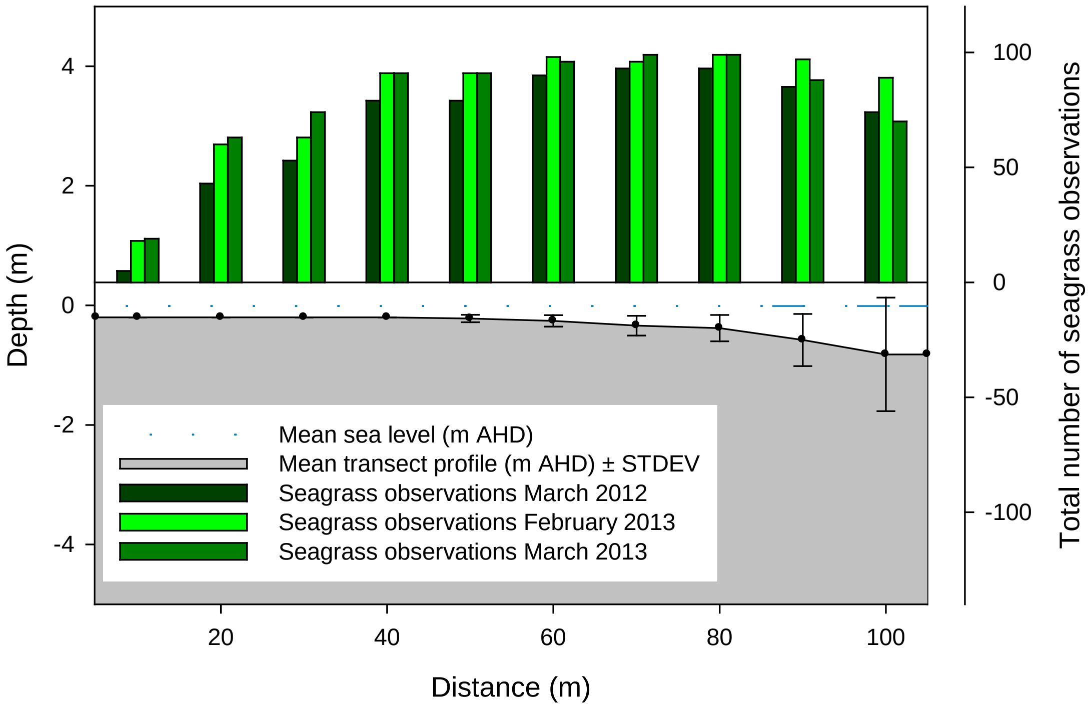


Figure 47 *Sum of seagrass observations in March 2012, and February and March 2013 at site HTH*

Seagrass cover

There was a significant increase in seagrass cover between March 2012, and February and March 2013 (Table 11). The reduction in seagrass cover between February and March 2013 was approximately 12%, which was less than the increased cover observed between 2012 and 2013 (30-43%). As with the seagrass observation data, seagrass decline was most prominent along the site's deeper margin (Figure 48). This fits with our understanding that seagrasses at their depth limit will be most vulnerable to changes in environmental conditions. Light conditions in particular are affected by water depth and clarity, and is a primary factor influencing plant growth. In a study by Kilminster and Forbes (2014), the amount of photosynthetic active radiation (light available for photosynthesis) started to decline from February 2012, showing the expected decrease in light availability moving into winter. Assuming the timing of this pattern was similar in 2013, the reduction of seagrass observations between February and March could be part of the natural decline that occurs over winter.

Table 11 *The average percentage cover of seagrass at each site for 2012 and 2013, with Wilcoxon matched pair t-test results (N, T, Z) and p-value of significance (p<0.05 is significant) comparing seagrass cover between 2012 and 2013.*

	Mar 2012 (%)	Feb 2013 (%)	Mar 2013 (%)	Difference (%)	N	T	Z	*p*-value
HTH		66.5	54.6	- 11.9	95	871.0	5.230	$p<0.05$
	23.9		54.6	+ 30.7	94	47.5	8.239	$p<0.05$
	23.9	66.5		+ 42.6	95	8.0	8.433	$p<0.05$

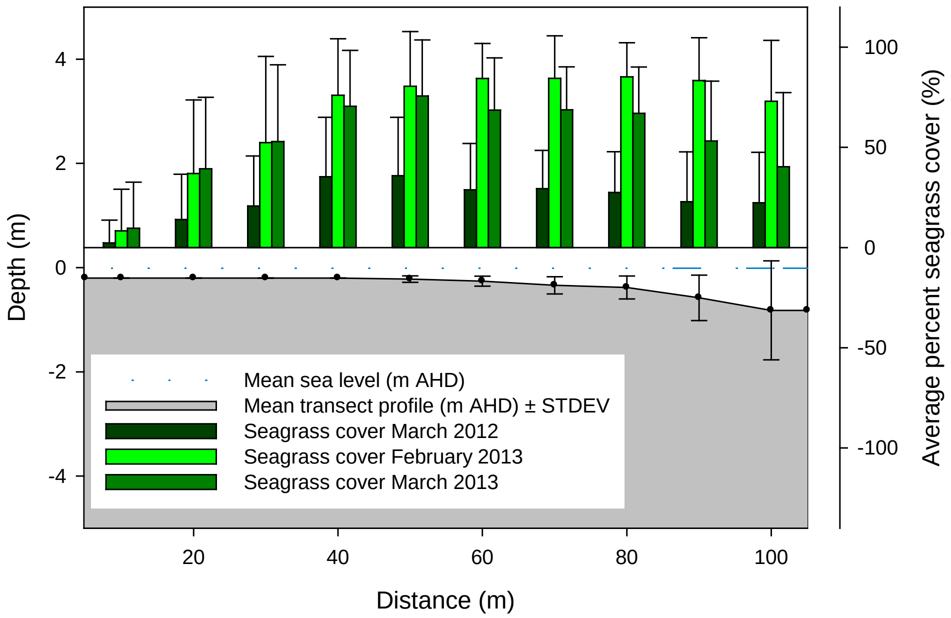


Figure 48 *Percentage of seagrass cover in February 2013 and March 2013 at site HTH*

We found the null hypothesis to be true for the presence/absence data, however small differences were observed with the cover data. These analyses suggest a robustness of the survey methods in terms of the survey's timing for making inter-annual comparisons. Seagrass cover appears to be more sensitive to changes in environmental conditions, likely driven by seasonal cycles. It is therefore recommended that future surveys be conducted in February to capture the peak cover of the seagrass.

G. Seagrass presence/absence observations by depth

Table 12 *The ratio of seagrass presence (P) relative to total number of observations (N) made along shore based transects at each site, and within five depth categories is shown for March 2012 and February 2013. The values in brackets indicate the total number of observations made within each depth category.*

		N	P/N <1 m	P/N 1–2 m	P/N 2–3 m	P/N 3–4 m	P/N >4 m	P/N Ave	Max AHD
PPT	*2012*	1000	0.65$^{(1000)}$	-	-	-	-	0.65	-0.8 m
	2013	1000	0.79$^{(1000)}$	-	-	-	-	0.79	-0.8 m
DLK	*2012*	820	0.85$^{(500)}$	0.78$^{(120)}$	0.66$^{(110)}$	0.05$^{(60)}$	0.03$^{(20)}$	0.73	-4.0 m
	2013	760	0.86$^{(500)}$	0.80$^{(120)}$	0.70$^{(120)}$	1.00$^{(20)}$	-	0.77	-3.8 m
RCK	*2012*	690	0.76$^{(570)}$	0.76$^{(90)}$	0.67$^{(30)}$	-	-	0.75	-2.2 m
	2013	710	0.89$^{(570)}$	0.90$^{(100)}$	0.95$^{(40)}$	-	-	0.89	-2.8 m
LUB	*2012*	1000	0.75$^{(1000)}$	-	-	-	-	0.75	-0.6 m
	2013	1000	0.94$^{(1000)}$	-	-	-	-	0.94	-0.6 m
HTH	*2012*	1000	0.69$^{(960)}$	1.00$^{(30)}$	-	0.20$^{(10)}$	-	0.69	-3.6 m
	2013	1000	0.79$^{(960)}$	1.00$^{(30)}$	-	1.00$^{(10)}$	-	0.80	-3.6 m
CAN	*2012*	930	0.17$^{(690)}$	0.03$^{(240)}$	-	-	-	0.14	-1.0 m
	2013	1000	0.26$^{(690)}$	0.10$^{(230)}$	-	-	-	0.22	-1.0 m
Estuary	***2012***	**5440**	**0.65**	**0.64**	**0.67**	**0.13**	**0.03**	**0.71**	**-4.0**
	2013	**5390**	**0.76**	**0.70**	**0.83**	**1.00**	**-**	**0.82**	**-3.8**

Table 13 *The ratio of seagrass presence (P) relative to total number of observations (N) made by boat and drop camera at PPT, RCK, LUB and HTH, and within five depth categories is shown for March 2012 and February 2013. The values in brackets indicate the total number of observations made within each depth category.*

		N	<1 m	1–2 m	2–3 m	3–4 m	>4 m	Ave	Max AHD
PPT	*2012*	94	1.00$^{(45)}$	1.00$^{(28)}$	0.00$^{(9)}$	0.00$^{(7)}$	0.00$^{(5)}$	0.78	-1.8 m
	2013	69	1.00$^{(27)}$	1.00$^{(20)}$	0.50$^{(6)}$	0.14$^{(7)}$	0.00$^{(9)}$	0.74	-3.0 m
RCK	*2012*	64	0.87$^{(15)}$	0.88$^{(8)}$	0.89$^{(9)}$	0.40$^{(10)}$	0.00$^{(22)}$	0.50	-3.4 m
	2013	58	0.90$^{(10)}$	0.55$^{(11)}$	0.50$^{(8)}$	0.38$^{(8)}$	0.00$^{(21)}$	0.38	-3.6 m
LUB	*2012*	73	0.71$^{(21)}$	0.79$^{(24)}$	0.38$^{(13)}$	0.17$^{(6)}$	0.00$^{(9)}$	0.55	-3.2 m
	2013	50	0.80$^{(10)}$	0.92$^{(12)}$	0.40$^{(10)}$	0.17$^{(6)}$	0.00$^{(12)}$	0.48	-3.0 m
HTH	*2012*	53	0.84$^{(19)}$	0.50$^{(12)}$	0.00$^{(6)}$	0.00$^{(5)}$	0.00$^{(11)}$	0.42	-1.8 m
	2013	62	0.77$^{(31)}$	0.75$^{(8)}$	0.20$^{(5)}$	0.00$^{(6)}$	0.00$^{(12)}$	0.50	-2.2 m
Estuary	***2012***	**284**	**0.86**	**0.79**	**0.32**	**0.14**	**0.00**	**0.56**	**-2.55 m**
	2013	**239**	**0.87**	**0.81**	**0.40**	**0.17**	**0.00**	**0.53**	**-2.95 m**

Glossary

Biomass	The quantity of living matter, usually expressed as weight per unit area
Ephemeral	Short-lived or transitory
Inter-annual	Between years, and for seagrass is likely to reflect differences observed where the year encompasses the growing season
Physiological	Relating to the physiology or normal functioning of an organism
Transect	To cut across
Quadrat	A square plot used for the study of plants and/or animals in ecology

Data sources

The Department of Water has produced the maps for this report with the intent that they be used for this report only. While the department has made all reasonable efforts to ensure the accuracy of these data, it accepts no responsibilities for any inaccuracies, and persons relying on them do so at their own risk.

The Department of Water acknowledges the following datasets and their custodians in the analysis of the data and the production of the maps. For any queries about the spatial datasets, please contact Vanessa Forbes, Water Science Branch, Department of Water.

Table 14 *Data reviewed in the seagrass monitoring program*

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/comments
Study areas				
SwanCoastPlain_Central_Feb_2012_15cm_z50	Landgate	2012	2012	Raster dataset, satellite image, 1:25 000, 15 cm pixel size
SwanCoastPlain_Central_Jan_2013_15cm_z50	Landgate	2013	2013	Raster dataset, satellite image, 1:25 000, 15 cm pixel size
Swan Canning Bathymetric Contours	Department of Parks and Wildlife (DPaW)	2012	2009–12	Vector dataset, delineates hydrographic depth sounding as for the Swan-Canning estuary supplied by the Department of Transport, 20 cm contours
				Used for site illustrations (maps)

The maps have been provided using the following data and projection information:

Vertical datum: AHD (Australian Height Datum)
Horizontal datum: GDA 94 (Geocentric Datum of Australia 1994)
Projection system: Map Grid of Australia (MGA) 1994 Zone 50

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