A Survey of Selected Seagrass Meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound

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Prepared for Cockburn Sound Management Council

Data Report

June 2015

Department of Parks and Wildlife

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ISSN [ISSN] (print)
ISSN [ISSN] (online)
ISBN [ISBN] (print)
ISBN [ISBN] (online)

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The recommended reference for this publication is:
Department of Parks and Wildlife, 2013, *A Survey of Selected Seagrass Meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound*, Department of Parks and Wildlife, Perth.

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Acknowledgments

The author wishes to thank Vaughn Chapple, Steve Goodlich, Sean Emmett, Miecha Bradshaw, Pam Sutton, Mel Evans and Cindy Bessey (all from Parks and Wildlife) for assistance with logistics and the field survey. Kathy Murray (Parks and Wildlife) provided GIS support. Hans Kemp (OEPA) provided valuable discussion about the longer-term direction of this program and helped to clarify some of the finer points around changes made to the Environmental Quality Criteria.

Summary

In 2015, the Department of Parks and Wildlife, Marine Science Program (MSP) undertook seagrass monitoring on behalf of the Cockburn Sound Management Council (CSMC) as part of the CSMC long-term seagrass monitoring program. A number of seagrass (*Posidonia sinuosa)* meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound were surveyed over six days between the 5th and the 12th February 2015. A total of 25 permanent sites were surveyed comprising 16 'potential impact' sites, five 'reference' sites and four 'depth transect' sites. Three additional 'reference' sites inside the Shoalwater Islands Marine Park were also surveyed. At all sites seagrass shoot densities, shoot heights and epiphyte loads were surveyed following the Standard Operating Procedure (SOP) and data were assessed against CSMC guidelines for the health of seagrass meadows.

Following changes to the Environmental Quality Criteria (EQC), which guard against declines in seagrass density in Warnbro Sound, each of the reference sites were assessed against an historical baseline termed the 'Absolute Minimum Criteria' (AMC). Shoot densities at most reference sites failed in this assessment for one or both of the 20th and 5th percentile tests. This means that the AMC will need to be used in many cases for the subsequent assessment under the EQC.

Half of the potential impact sites and almost all of the Warnbro Sound reference sites have shown significant declines in shoot density since the start of the monitoring program. Research is currently underway to investigate the causes of these declines.

The Lower Depth Limit of seagrass distribution at depth transect sites has increased at several sites while remaining stable at Warnbro Sound and the northern Garden Island site.

As part of the ongoing review and improvement of the seagrass monitoring program in Cockburn Sound, it is recommended that:

1. the CSMC consider the process for implementing additional reference data, and how these data will be used in the future;
2. the CSMC consider formalising the use of the additional reference sites in SIMP and JBMP as part of the CSMC long-term monitoring program;
3. reporting of trends and comparisons between sites is only presented for mean values in future years. This is because the mean and median values are very similar, and the use of means provides additional information (e.g. variance estimates) above medians;
4. the procedure for determining the correct trigger value for comparisons with the 1st percentile where needed, be defined;
5. the procedure for replacing missing transects/quadrats including the process for gaining approvals from the CSMC be defined;
6. the depth profiles required at each of the depth transect sites as stated in the revised SOP documentation be constructed; and,
7. the CSMC consider how the density data from the depth transect sites is used in the future as these data are not currently used or reported against.

1. Introduction

Seagrass meadows are recognised for their ecological and economic importance in supporting a diverse range of flora and fauna, stabilising sediments and protecting shorelines (Heck et al., 2003). Seagrasses are also highly productive and are considered the dominant ecosystem engineers in many soft-bottom ecosystems (Connolly, 2012; Larkum et al., 1989). Physical damage, broad-scale losses, and fragmentation of seagrass meadows are evident worldwide as a result of anthropogenic pressure, such as coastal development and climate change (Orth et al., 2006; Waycott et al., 2009). Major fragmentation or loss of seagrass meadows will have major implications for food-webs, coastal geomorphology, and biogeochemical cycles (Short and Neckles, 1999). Twenty-five seagrass species occur in Western Australia, and fourteen of these species inhabit Perth's coastal waters (Walker, 1991).

In 1994, the Department of Environment and Conservation (DEC) commissioned Edith Cowan University (ECU) to assess seagrass health at locations throughout Cockburn and Warnbro Sounds in the Perth metropolitan area. The initial health assessment (Lavery, 1994) was complemented by a simultaneous assessment of changes in seagrass area in the region. Since 1998 the survey of seagrass health has been repeated annually (in summer), on behalf of the Environmental Protection Authority, DEC and Cockburn Sound Management Council (CSMC). Since 2000, the CSMC has commissioned seagrass monitoring where surveys incorporated quantitative measurements of a number of variables at each assessment site and at a series of permanently marked transects at the lower depth limit of seagrass meadows. In 2005, the program was reviewed (Environmental Protection Authority, 2005) and a standard methodology was implemented (Environmental Protection Authority, 2004). This heralded a key change in sampling technique with a shift from random quadrats to permanent or semi-permanent transects and quadrats. In 2013, CSMC contracted the then Department of Environment and Conservation's Marine Science Program (MSP) to conduct the annual seagrass monitoring program. The Department of Parks and Wildlife completed the monitoring again in 2014 and in 2015.

This report delivers results from the 2015 surveys and focuses some attention on temporal changes at each monitoring site within Cockburn Sound. Seagrass meadows are patchy in time and space and current reporting draws from only one sampling time each year. Any trends observed in the data should be treated with caution as conclusions are made about characteristics that may vary at timescales shorter than those measured. As much as possible, the sampling design attempts to reduce this source of variability by comparing data from the same time of year (February) and from exactly the same patches of seagrass habitat. The results can be used to indicate any changes in seagrass meadows over time that may warrant more intensive investigation.

1.1 Changes to the data report format

Mohring and Rule (2013a) adopted terminology that was consistent with the Environmental Quality Criteria (EQC) document (Environmental Protection Authority, 2005), and thus, sites were referred to as either ‘potential impact’ or ‘reference’, and this has been continued here.

The way in which data are analysed has changed from previous reports, where seagrass density at ‘potential impact’ sites have been compared to the ‘reference’ sites in Warnbro Sound using the protocols defined in the EQC (Environmental Protection Authority, 2013). Previously, this analysis was also undertaken by a second, independent biostatistician contracted by the CSMC. Following discussions with the CSMC (Hans Kemp pers. comm.), this analysis has not been conducted here; rather only the median values for the ‘potential impact’ sites and the percentile values for the ‘reference‘ sites have been presented. These will be independently assessed against the EQC by the CSMC.

Current revisions of the EQC (Environmental Protection Authority, 2013) have highlighted the need for changes in reporting, particularly when identifying declines in seagrass health. Although the 2005 EQC document (Environmental Protection Authority 2005a) included measures to protect against a declining reference, these have not typically been implemented in previous data reports. The Office of the Environmental Protection Authority (Environmental Protection Authority, 2013) have recommended the use of Absolute Minimum Criteria (AMC) in instances where reference trigger values fall below an acceptable level. The use of reference trigger values is defined in Section 2.4.1. According to the Draft EQC (Environmental Protection Authority, 2013) if the reference trigger values fall below the AMC defined in Table 1b of the EQC (Environmental Protection Authority, 2013), then these published values should be used as a benchmark against which median seagrass density at ‘potential impact’ sites should be compared. Thus, in this report the AMC has been used to test the integrity of the ‘reference’ sites.

In a report to the Office of the Auditor General, Lavery and McMahon (2011) recommended that an analysis of trends in seagrass density be performed annually to highlight declines; an approach which has been adopted by the current revisions of the EQC (Environmental Protection Authority, 2013). Here, trend analyses have been completed on: 1) mean and median values from all sites; and, 2) all 1st, 5th and 20th percentile values from the Warnbro Sound ‘reference’ sites.

Following the revised Standard Operating Procedures (Environmental Protection Authority, 2014), the Leading Edge measurement of seagrass distribution along the depth transect is no longer recorded.

Finally, a trend analysis has been performed on the Lower Depth Limit of seagrass distribution at each site to examine changes in the vertical distribution of seagrass. This has not been included in previous data reports.

2 Methods

2.1 Sites Surveyed

Seagrass community condition was surveyed at 16 ‘potential impact’ sites, five ‘reference’ sites, and four ‘depth transect’ sites (Figure 1, Table 1). A description of the each of these sites is provided in Lavery and Gartner (2008). Seagrass meadows were sampled on six days between the 5th and the 12th February 2015. The additional reference sites at Seal Island, Penguin Island and Becher Point were surveyed in the following week, while the additional reference sites at Boullanger Island (Jurien Bay) were not surveyed in 2015.

2.2 Methods and Metrics Measured

Methods used in the current project are consistent with the methods set out in the ‘Manual of Standard Operating Procedures’ (Environmental Protection Authority, 2004) and the standard protocols used at ‘potential impact’, ‘reference’ and ‘depth transect’ sites are outlined below. For a detailed description of the data collection methodology, see Environmental Protection Authority (2004).

2.2.1 Shoot Density

Shoots of *Posidonia sinuosa* and *Posidonia australis* were counted by SCUBA divers in 24 permanent 20 x 20 cm quadrats at each of the seagrass ‘potential impact’ and ‘reference’ sites (Table 1) according to the methods described by Lavery & Gartner (2008). For all comparisons under the EQC, only the densities of *P. sinuosa* are used, and as such, all results presented here are based solely on the *P. sinuosa* data.

Comparisons of seagrass shoot density at ‘potential impact’ and ‘reference’ sites are made between median seagrass shoot densities at each ‘potential impact’ and either the 1st, 5th or 20th percentile values calculated from the comparable ‘reference’ site (see Section 5.1). Prior to calculating medians and percentiles, all ‘zero’ counts were removed from the dataset (Environmental Protection Authority, 2004).

2.2.2 Shoot Height and Percentage Cover

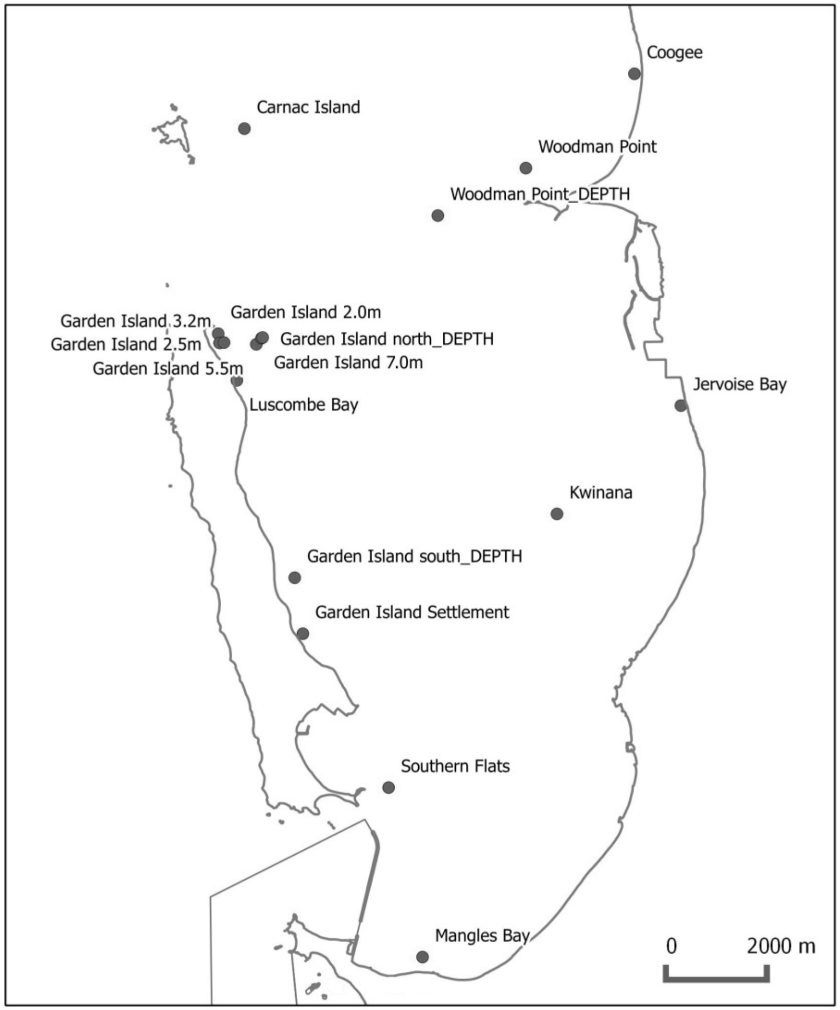
The height of the tallest shoot was measured in each quadrat to the nearest centimetre. The ‘average’ leaf length was also measured as long leaves are often necrotic for much of their length and the maximum length may be unrepresentative of the meadow. Average leaf length is defined as the 80th percentile of shoot heights (Duarte and Kirkman, 2001). Thus, the tallest 20% of leaves inside a quadrat were excluded and the height of the tallest of the remaining leaves was measured.

At each site, ten 1 x 1m photographic quadrats were collected along each transect to obtain quantitative estimates of seagrass cover. An image was taken from a standard height (~1m) every 1m along each transect (n = 40). These images were processed using a standard point-count analysis with six randomly allocated points per image.

The data collected for these metrics have not been included in this report; however, they are available if required.

Table 1: Characteristics of seagrass sites surveyed in Cockburn Sound, Owen Anchorage, and Shoalwater Islands Marine Park; including site types (‘potential impact’ = PI; ‘reference’ = Ref; depth transect = Depth; newly added reference sites = ‘New’), level of ecological protection, depths originally assigned when the site was established and measured again in 2013 (see Mohring and Rule, 2013b). The most appropriate reference sites for comparisons under the EQC are also listed.

Site name	Area	Site type	Protection level	Depth		Comparison ref depth
				Original	2013	
Garden Is. Settlement	CS	PI	High	2.0	1.2	WS2.0m
Luscombe Bay	CS	PI	High	2.0	1.4	WS2.0m
Southern Flats	CS	PI	High	2.5	2.1	WS2.0m
Garden Island 2.0m	CS	PI	High	2.0	1.8	WS2.0m
Bird Island	SIMP	PI	-	2.0	2.0	WS2.0m
Mersey Point	SIMP	PI	-	3.0	2.7	WS2.5m
Carnac Island	OA	PI	-	4.5	3.9	WS3.2m
Mangles Bay	CS	PI	High	3.2	3.2	WS3.2m
Woodman Point	OA	PI	-	2.5	4.1	WS3.2m
Jervoise Bay	CS	PI	Moderate	2.5	3.1	WS3.2m
Garden Island 2.5m	CS	PI	High	2.5	3.0	WS3.2m
Garden Island 3.2m	CS	PI	High	3.2	3.3	WS3.2m
Kwinana	CS	PI	High	5.2	4.5	WS5.5m
Garden Island 5.5m	CS	PI	High	5.2	5.1	WS5.5m
Coogee	OA	PI	High	5.0	5.4	WS5.5m
Garden Island 7.0m	CS	PI	High	7.0	5.9	WS5.5m
Warnbro Sound 2.0m	SIMP	Ref	-	2.0	2.1	-
Warnbro Sound 2.5m	SIMP	Ref	-	2.5	2.4	-
Warnbro Sound 3.2m	SIMP	Ref	-	3.2	2.8	-
Warnbro Sound 5.5m	SIMP	Ref	-	5.2	5.0	-
Warnbro Sound 7.0m	SIMP	Ref	-	7.0	7.0	-
Garden Island North	CS	Depth	High	-	-	-
Garden Island South	CS	Depth	High	-	-	-
Woodman Point	OA	Depth	-	-	-	-
Warnbro Sound	SIMP	Depth	-	-	-	-
Becher Point	SIMP	New	-	-	3.6	-
Penguin Island	SIMP	New	-	-	2.7	-
Seal Island	SIMP	New	-	-	4.2	-



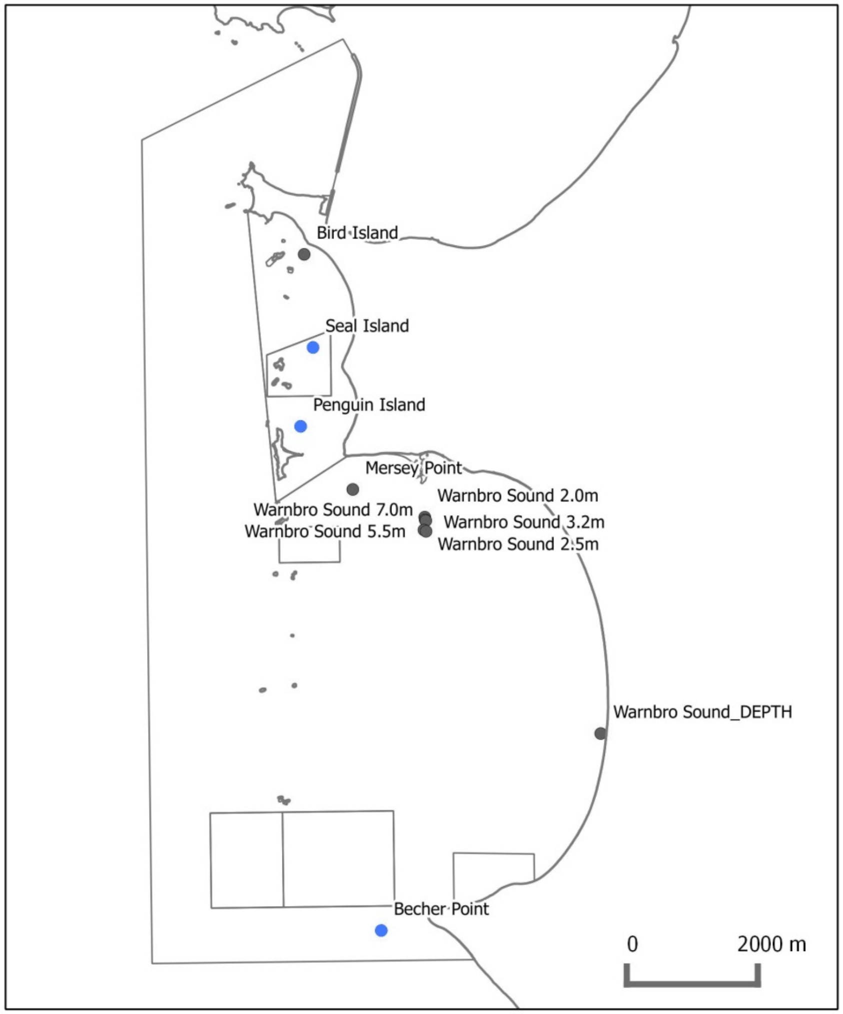


Figure 1: Map of Cockburn Sound (left) and Shoalwater Islands Marine Park (right) indicating position of ‘potential impact’ and ‘reference’ sites. Sites in blue were established in 2013, under the standard protocol, and may be used as additional reference sites.

2.2.3 Depth transect sites

All of the metrics listed above were measured along three depth transects at each of the Garden Island North, Garden Island South, Warnbro Sound and Woodman Point sites, according to the methods described in Lavery & Gartner (2008). At each transect the 'start' picket was located and a tape measure was extended down the slope to 20m length. Quadrats were sampled every 2 m along the transect from 0 to 20 m. In addition, the Lower Depth Limit (LDL) of seagrass distribution along each transect was recorded. The LDL (Figure 2) is defined as the maximum depth and distance at which seagrass shoots are observed within a 1m belt either side of the transect line (i.e. shoots may fall outside the quadrats; Figure 2) (Environmental Protection Authority, 2004). Once the LDL had been identified, the depth at that point was measured using a standard dive computer laid on the bottom.

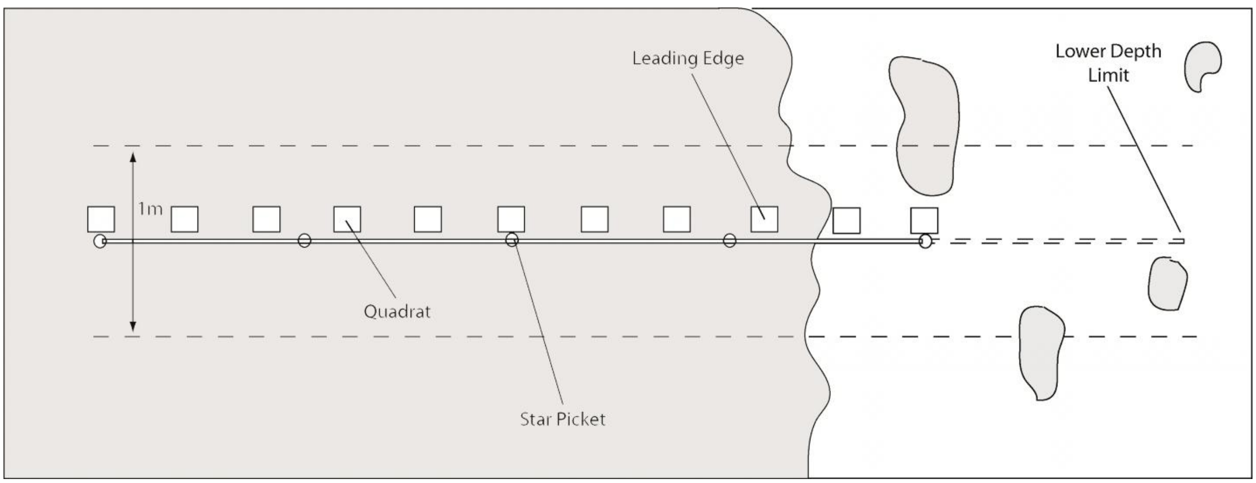


Figure 2: Diagram of the technique for surveying the depth limit of seagrass (seagrass meadow presented in grey). The Lower Depth Limit (LDL) is the distance along the tape where the last shoots of seagrass fall inside a belt 1m on each side of the tape. Note that the Leading Edge is no longer measured.

2.3 QA/QC

2.3.1 Field surveys

Prior to commencing field surveys, all observers were required to identify, count and measure seagrass shoots within several test quadrats, with results compared to ensure consistency. Identification, counts and measurements were checked periodically throughout the survey period, on different days, to ensure continued consistency between samplers and through time at the different sites.

2.3.2 Data management

To ensure the integrity of data and eliminate errors associated with data entry, two different analysts undertook data entry and spread sheets were cross-checked. Only when cross checks showed data in both sheets was identical did data analysis commence.

2.4 Data analysis

2.4.1 Reference trigger values and the Absolute Minimum Criteria

The trigger values for each reference depth were calculated using the rationale described in the CSMC guidelines (Environmental Protection Authority, 2013, 2004). The trigger values are the 1st, 5th and 20th percentiles of a minimum of 100 quadrats previously collected at each site, i.e. data pooled from the current and previous four years (2011 – 2015). Zero values were removed before undertaking calculations of percentiles (Environmental Protection Authority, 2005).

In 2014, the Office of the Environmental Protection Authority (2013) revised the EQC and incorporated several changes. One key change was the implementation of an Absolute Minimum Criteria (AMC) which is based on historical baseline data and can be used to test the quality of the 'reference' sites (Lavery and McMahon, 2011). The AMC was implemented to guard against the possibility of declining seagrass shoot density at the Warnbro Sound reference sites influencing the EQC over time. Following this recommendation, we compared the calculated 'reference' trigger values to the AMC (Table 1b; Environmental Protection Authority, 2013) using the following three step process to determine the most appropriate trigger value for each reference depth:

i. For each depth, compare the updated rolling 20th percentile and 5th percentile shoot density against the absolute minimum 5th percentile and 1st percentile respectively;

ii. If either the updated rolling 20th percentile or 5th percentile shoot density is greater than the absolute minimum 5th percentile or 1st percentile respectively, then the updated rolling percentiles are used as the EQS;

iii. If either the updated rolling 20th percentile or 5th percentile shoot density is less than the absolute minimum 5th percentile or 1st percentile respectively, then it is assumed that seagrass shoot density at the reference depth has significantly declined and may no longer be a useful reference. In this case the absolute minimum 5th percentile or 1st percentile values are used as the EQS for high and moderate ecological protection areas respectively.

2.4.2 Median values at 'potential impact' sites

In previous years this data report has compared seagrass density at 'potential impact' sites to the 'reference' sites in Warnbro Sound using the protocols defined in the EQC (Environmental Protection Authority, 2013). Following discussions with the CSMC, these comparisons have not been presented in this report as they are performed independently by a biostatistician contracted by the CSMC. Here only the medians for the 'potential impact' sites and the 1st, 5th and 20th percentile values for the 'reference' sites have been presented. Following the protocol defined in the standard operating procedure (Environmental Protection Authority, 2004) all zero values were removed from the dataset prior to the calculation of median values.

2.4.3 Trend analysis

Following the recommendation of Lavery and McMahon (2011), Mann-Kendall trend analyses have been completed in 2015 on: 1) mean values from all sites; 2) median values from all 'potential impact' sites; and 3) all 1st, 5th and 20th percentile values from the Warnbro Sound 'reference' sites. In addition, trends in the Lower Depth Limit (LDL) between 2000 and 2015 were assessed using a Mann-Kendall trend analysis. At the request of CSMC, all trends these have been assessed at both the $\alpha = 0.05$ and the $\alpha = 0.2$ levels. This is to ensure that declines which are not statistically significant are still highlighted as potential issues.

2.4.4 Comparisons with additional reference sites

Three new 'reference' sites (Seal Island, Penguin Island, and Becher Point), were established in Shoalwater Islands Marine Park (SIMP) in 2013 following the protocols described by the Environmental Protection Authority (2004). In 2015, a full 100 quadrats of data have been collected from these sites, allowing a calculation of percentile values as described in the SOP (Environmental Protection Authority, 2004).

The three sites in the JBMP have been surveyed regularly since 2003 (2003-2005, 2007, 2008, 2010-2014), and sufficient data were available for the calculation of percentiles, however, these were not surveyed in 2015 and thus the results reported here are only from 2014.

No additional reference sites are currently available at 2m or 7m, and thus only the comparisons of sites at 2.5, 3.2 and 5.2 are available.

Here, shoot densities from the Warnbro Sound reference sites were compared to values from the appropriate new reference sites in SIMP and JBMP using a one way Analysis of Variance. Prior to analysis all data were checked for homogeneity of variances using Levene's test. As new data were not collected from Jurien Bay in 2015, analyses were performed against 2014 data.

3 Results

3.1 Reference trigger values and the Absolute Minimum Criteria

Rolling trigger values (5th, 20th percentiles) were calculated for each depth and compared to the AMC (see section 2.4.1) to determine the most appropriate trigger values, against which medians from the potential impact sites should be compared. For the reference 20th percentile values (Table 2; high protection area in a single year), both Warnbro Sound 2.0m and Warnbro Sound 5.5m failed the test against the AMC, and thus cannot be used as trigger values for the comparisons with potential impact sites at these depths.

Table 2: Trigger values for comparisons against the 20th percentile (high protection area, single year). Percentiles are based on the current and past three years' data, i.e. 100 quadrats.

Site	Ref. Depth	2015 rolling value (20th percentile)	5th percentile AMC	Value to use for comparisons against the 20th percentile
Warnbro Sound 2.0m	1.5 - 2.0m	550	666	AMC
Warnbro Sound 2.5m	2.0 - 3.0m	575	500	Rolling
Warnbro Sound 3.2m	3.0 - 4.0m	250	171	Rolling
Warnbro Sound 5.5m	5.0 - 6.0m	250	419	AMC
Warnbro Sound 7.0m	6.0 - 7.0m	100	59	Rolling

With the exception of Warnbro Sound 7.0m, all reference sites failed against the AMC for the 5th percentile values (Table 3; High protection Area in consecutive years; moderate protection area in a single year). The AMC must be used as the trigger values for any comparisons against these depths.

Table 3: Trigger values for comparisons against the 5th percentile (High protection Area, consecutive years; moderate protection area, single year). Percentiles are based on the current and past three years' data, i.e. 100 quadrats.

Site	Ref. Depth	2015 rolling value (5th percentile)	1st percentile AMC	Value to use for comparisons against the 5th percentile
Warnbro Sound 2.0m	1.5 - 2.0m	50	412	AMC
Warnbro Sound 2.5m	2.0 - 3.0m	250	275	AMC
Warnbro Sound 3.2m	3.0 - 4.0m	87.5	100	AMC
Warnbro Sound 5.5m	5.0 - 6.0m	118.75	324	AMC
Warnbro Sound 7.0m	6.0 - 7.0m	32.5	25	Rolling

3.2 Median seagrass shoot density at potential impact sites

Median shoot densities ranged from 300 shoot m^{-2} at Mangles Bay to 1363 shoots m^{-2} at Garden Island 2.0m (Table 4). It must be noted that the median values from both Woodman Point and Jervoise Bay were calculated from a small number of samples as both sites have been affected by sand movement and the subsequent loss of permanent replicates (Table 4).

Table 4: Median shoot density (per m^2) for each potential impact site in 2015. The number of replicates (n) used for the calculation are also shown.

Protection level	Site	Ref Site	n	Median shoot density (m^{-2})
High Protection Area	Garden Island Settlement	Warnbro Sound 2.0m	24	525
	Luscombe Bay	Warnbro Sound 2.0m	24	812.5
	Garden Island 2.0m	Warnbro Sound 2.0m	24	1362.5
	Southern Flats	Warnbro Sound 2.0m	21	775
	Garden Island 2.5m	Warnbro Sound 3.2m	24	687.5
	Mangles Bay	Warnbro Sound 3.2m	23	300
	Garden Island 3.2m	Warnbro Sound 3.2m	22	687.5
	Kwinana	Warnbro Sound 5.2m	24	687.5
	Garden Island 5.5m	Warnbro Sound 5.2m	23	550
	Coogee	Warnbro Sound 5.2m	24	687.5
	Garden Island 7.0m	Warnbro Sound 5.2m	22	575
Moderate Protection	Jervoise Bay	Warnbro Sound 3.2m	10	625
Undesignated	Bird Island	Warnbro Sound 2.0m	22	687.5
	Mersey Point	Warnbro Sound 2.5m	24	500
	Carnac Island	Warnbro Sound 3.2m	24	800
	Woodman Point	Warnbro Sound 5.2m	14	412.5

3.3 Depth Transect Sites

In 2015, the mean LDL had increased at all depth transect sites since 2014 (Figure 3). A significant ($\alpha = 0.05$) trend (increase in depth) was returned for the LDL at both Garden Island South and Woodman Point (Table 5; Figure 3), while the maximum depth of seagrass has not increased at either Garden Island North or Warnbro Sound. Trends must be interpreted with caution as data are missing from 2008-2011 and analyses have only been conducted on the available data.

Table 5: Mann-Kendall trend analysis on the mean LDL from each of the depth transect sites. Only statistics which are significant at α = 0.05 (**bold**). P-values > 0.05 are designated by 'ns'.

Site	Mann-Kendall statistic	*p* value
Garden Island North	-	ns
Garden Island South	0.807	**0.001**
Woodman Point	0.550	**0.024**
Warnbro Sound	-	ns

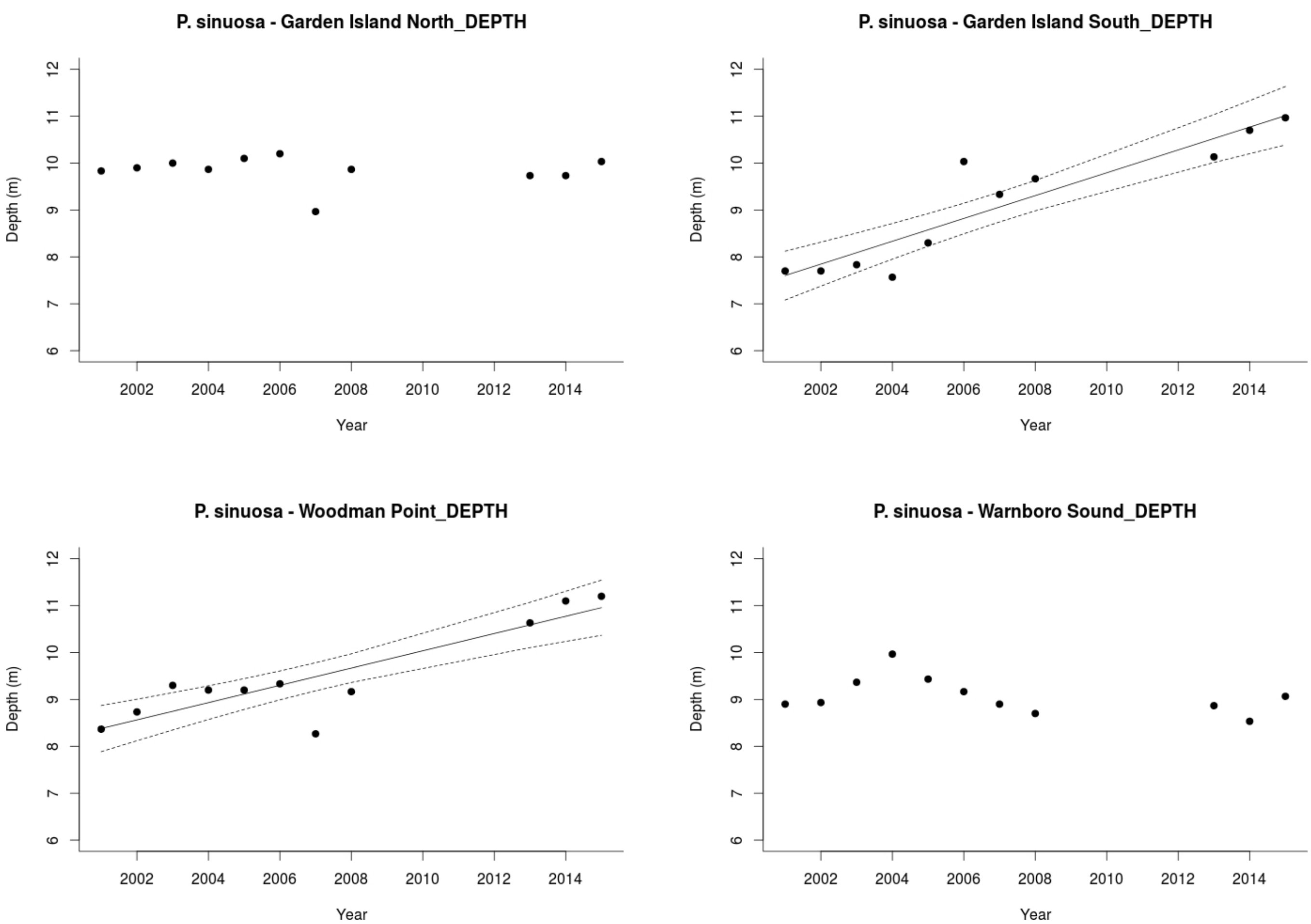


Figure 3: Difference in mean (n = 3) depth of the lower depth limit (i.e. the depth where seagrass was no longer present one meter on either side of the tape) of the seagrass meadows between 2001 and 2015.

3.4 Trends in rolling trigger values

A trend analysis was performed on the trigger values for each reference site. For almost all analyses, a significant (α = 0.05) negative trend in trigger values was revealed (Table 6; Figure 4). In addition, the 5th percentile values for Warnbro Sound 3.2 and Warnbro Sound 7.0m showed a negative trend at α = 0.2. The only trigger value which did not show a negative trend was the 1st percentile value for Warnbro Sound 7.0m

Table 6: Results of the Mann-Kendall trend analysis on the 1st, 5th and 20th percentile (trigger) values from the Warnbro Sound reference sites. Only statistics which are significant at α = 0.05 (**bold**) or α = 0.2 ('*') are shown. P-values > 0.2 are designated by 'ns'.

	20th percentile		5th percentile		1st percentile	
Site	**Mann-Kendall statistic**	***p* value**	**Mann-Kendall statistic**	***p* value**	**Mann-Kendall statistic**	***p* value**
Warnbro Sound 2.0m	-0.911	**>0.001**	-1.000	**>0.001**	-0.920	**>0.001**
Warnbro Sound 2.5m	-0.582	**0.029**	-0.796	**0.002**	-0.835	**0.002**
Warnbro Sound 3.2m	-0.598	**0.023**	-0.477	0.071*	-0.630	**0.021**
Warnbro Sound 5.2m	-0.815	**0.002**	-0.874	**0.001**	-0.883	**0.001**
Warnbro Sound 7.0m	-0.883	**0.001**	-0.489	0.069*	-	ns

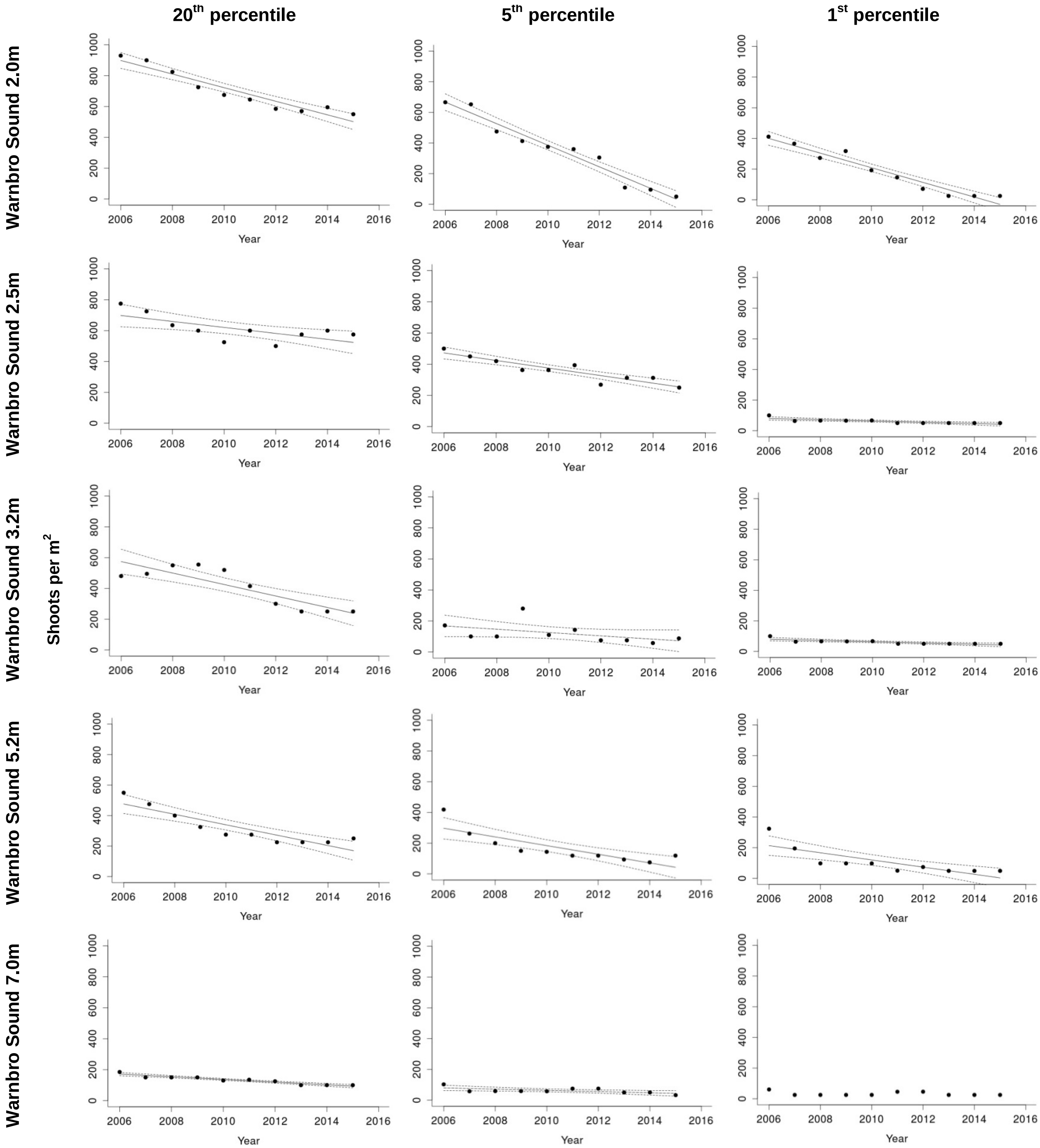


Figure 4: Results of the trend analysis on trigger values for each of the Warnbro Sound reference sites. Where trends are significant at α = 0.05 (solid lines) or α = 0.2 (dotted lines) 95% confidence bands are displayed.

3.5 Trends in reference site shoot density

Although the mean and median density of seagrass was higher at some reference sites in 2015 than in the previous year (Figure 5) significant negative trends were still revealed for both mean shoot density and median shoot density (Table 7; Figure 5) for almost all sites. The only exception was Warnbro Sound 2.5m where no trend was detected (Table 7).

Table 7: Summary of the Mann-Kendall trend analysis on mean shoot density at the Warnbro Sound reference sites. Only statistics which are significant at α = 0.05 (**bold**) or α = 0.2 ('*') are shown. P-values > 0.2 are designated by 'ns'.

	Mean shoot density		Median shoot density	
Site	**Mann-Kendall statistic**	***p* value**	**Mann-Kendall statistic**	***p* value**
Warnbro Sound 2.0m	-0.436	**0.044**	-0.400	0.067*
Warnbro Sound 2.5m	-	ns	-	ns
Warnbro Sound 3.2m	-0.513	**0.017**	-0.555	**0.010**
Warnbro Sound 5.2m	-0.538	**0.012**	-0.468	**0.032**
Warnbro Sound 7.0m	-0.527	**0.029**	-0.534	**0.032**

3.6 Trends in potential impact site shoot density

Negative trends in both mean and median shoot density were recorded at six of the 11 sites in the 'high protection area' (Table 8; Figure 7). Of these, Garden Island Settlement, Southern Flats, Kwinana, and Garden Island 5.5m were all significant at α = 0.05, indicating a true, statistically significant decline in density. Garden Island 3.2m and Garden Island 7.0m recorded trends significant at α = 0.2.

Neither mean nor median shoot density at Coogee (Figure 6), Luscombe Bay, Mangles Bay (Figure 7), Garden Island 2.0m, Garden Island 2.5m (Figure 8), Jervoise Bay (the only site designated as 'moderate protection'), Carnac Island or Bird Island (Figure 9) displayed a negative trend (Table 8).

Of the sites which are not designated in an 'ecological protection area', only the mean shoot densities at Woodman Point and Mersey Point displayed negative trends significant at α = 0.02 (Table 8; Figure 9). No negative trends in median values were reported from these sites.

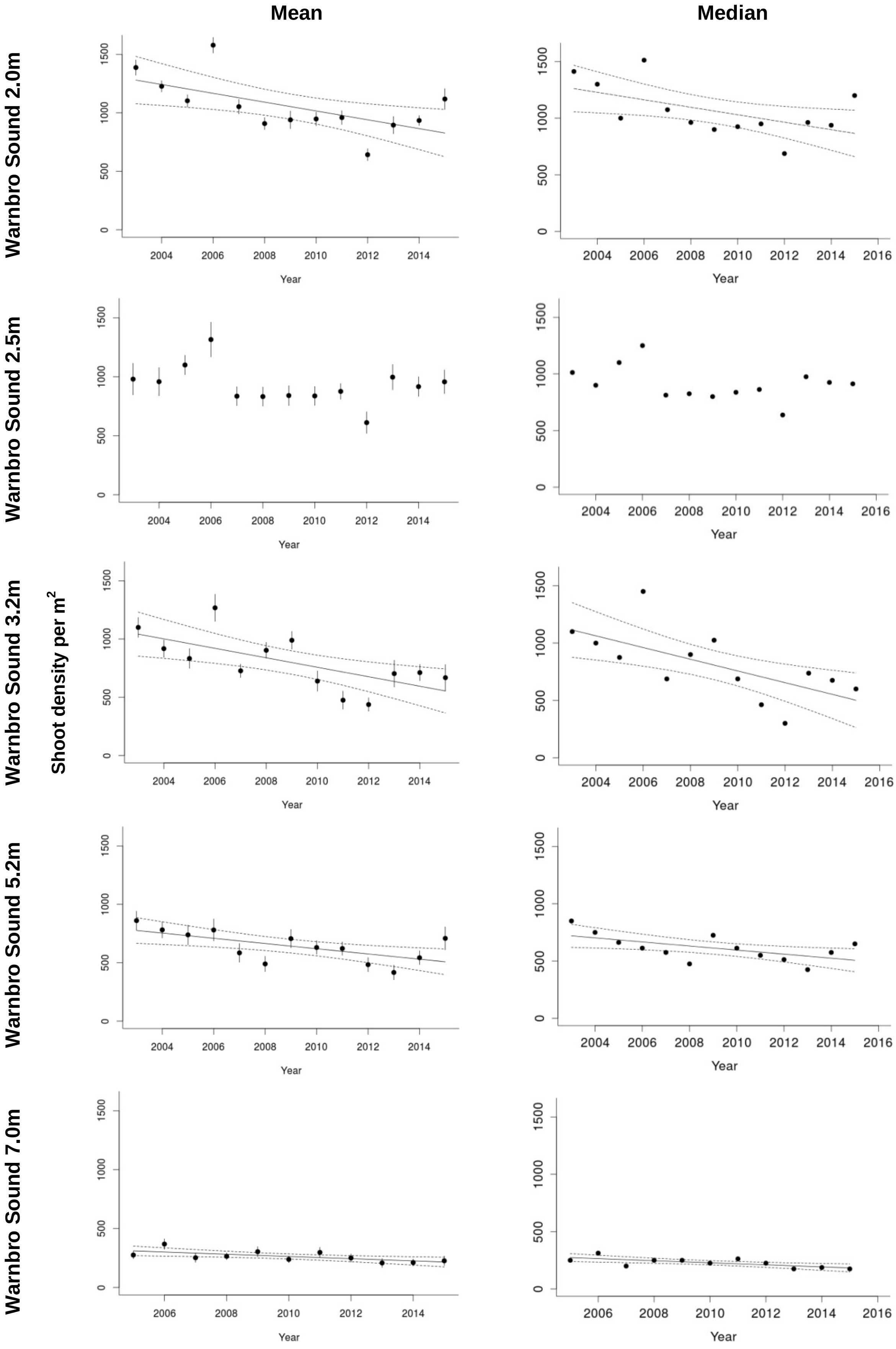


Figure 5: Trends in mean (±SE) and median shoot density values at the Warnbro Sound reference sites. Where trends are significant at α = 0.05 (solid lines) or α = 0.2 (dotted lines), 95% confidence bands are displayed

Table 8: Summary of the Mann-Kendall trend analysis on mean shoot density at the potential impact sites designated as High Protection Areas. Only statistics which are significant at α = 0.05 (bold) or α = 0.2 (‘*’) are shown. P-values > 0.2 are designated by ‘ns’

Protection level	Site	Mean shoot density		Median shoot density	
		Mann-Kendall statistic	*p*-value	Mann-Kendall statistic	*p*-value
High protection	Garden Island Settlement	-0.778	**0.002**	-0.689	**0.007**
	Luscombe Bay	-	ns	-	ns
	Garden Island 2.0m	-	ns	-	ns
	Southern Flats	-0.436	**0.044**	-0.458	**0.037**
	Garden Island 2.5m	--	ns	-	ns
	Mangles Bay	-	ns	-	ns
	Garden Island 3.2m	-0.282	0.200*	-0.323	0.142*
	Kwinana	-0.491	**0.043**	-0.537	**0.028**
	Garden Island 5.5m	-0.692	**0.001**	-0.693	**0.001**
	Coogee	-	ns	-	ns
	Garden Island 7.0m	-0.385	0.077*	-0.374	0.087*
Moderate protection	Jervoise Bay	-	ns	-	ns
Not designated	Carnac Island	-	ns	-	ns
	Woodman Point	-0.367	0.155*	-	ns
	Bird Island	-	ns	-	ns
	Mersey Point	-0.378	0.152*	-	ns

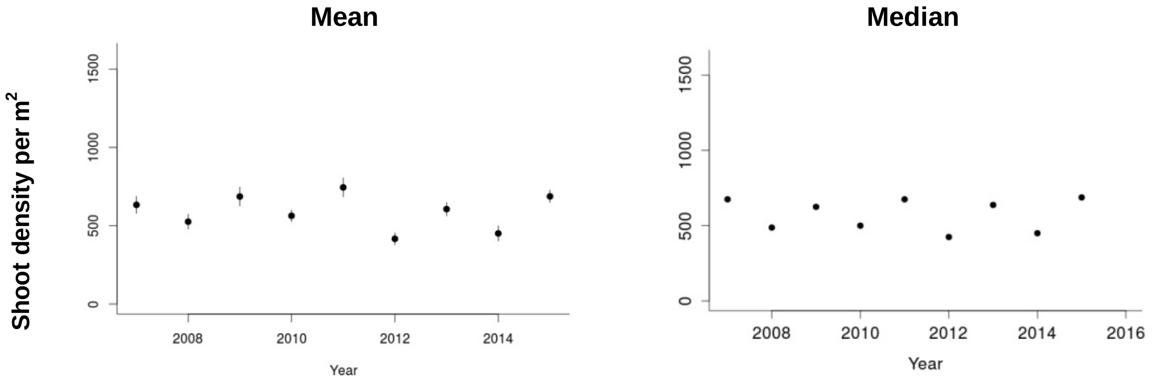


Figure 6: Trends in mean (±SE) and median shoot density values at Coogee in Cockburn Sound (High Protection Area).

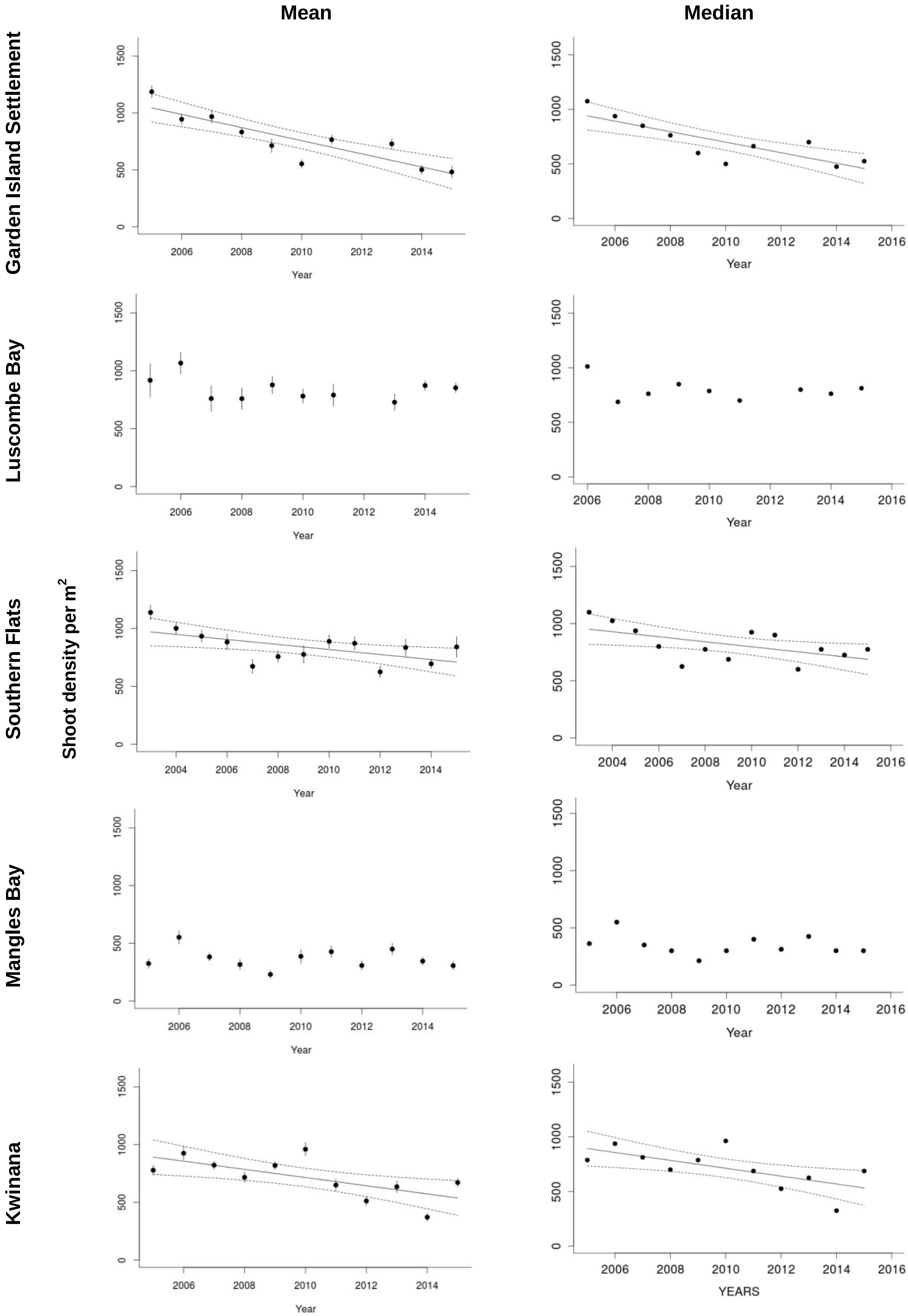


Figure 7: Trends in mean (±SE) and median shoot density values at potential impact sites in Cockburn Sound (High Protection Area). Where trends are significant at α = 0.05 (solid lines) or α = 0.2 (dotted lines), 95% confidence bands are displayed.

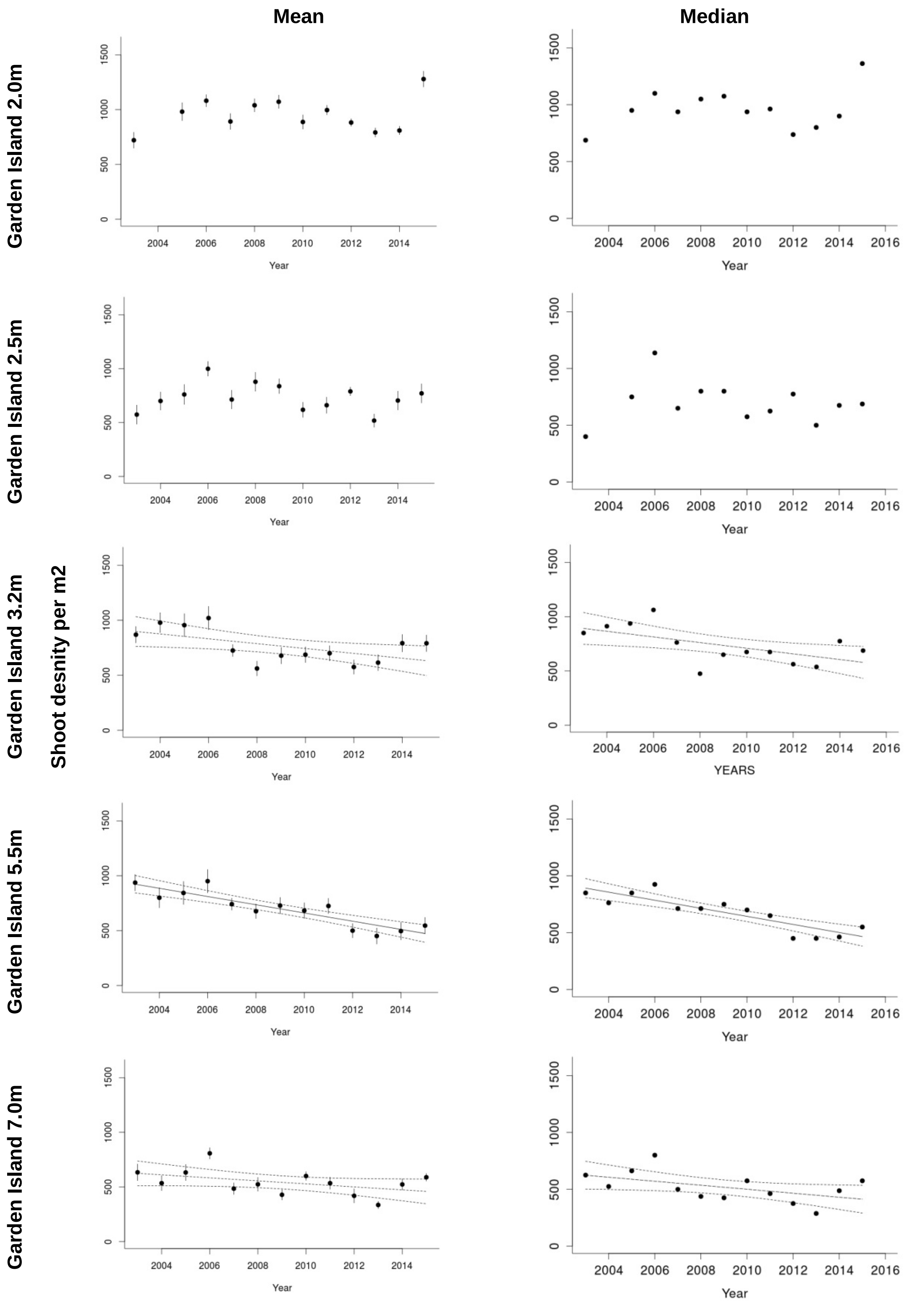


Figure 8: Trends in mean (±SE) and median shoot density values at potential impact sites in Cockburn Sound (High Protection Area). Where trends are significant at α = 0.05 (solid lines) or α = 0.2 (dotted lines), 95% confidence bands are displayed

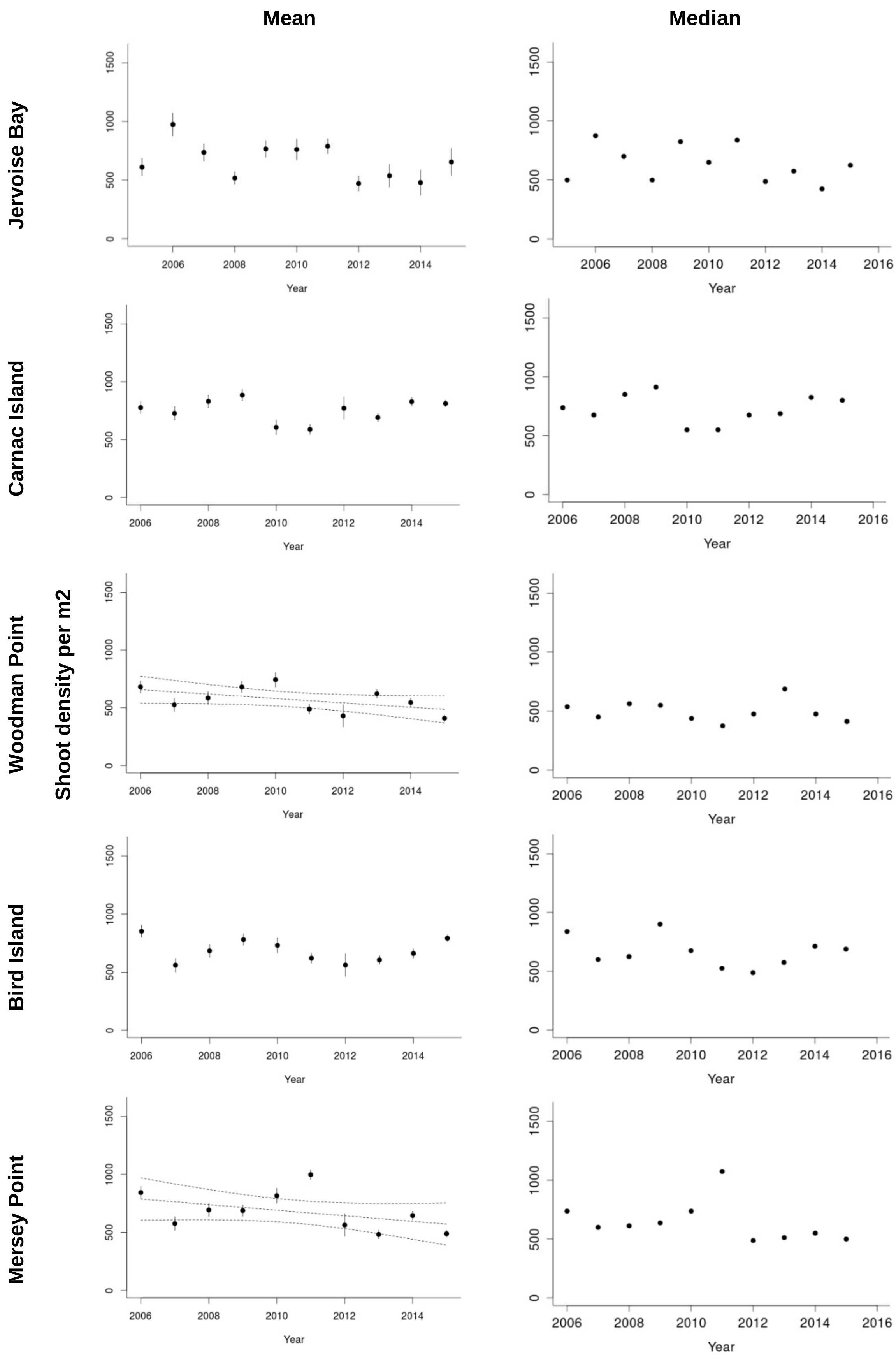


Figure 9: Trends in mean and median shoot density values at potential impact sites designated as Moderate Protection Areas or undesignated areas. Where trends are significant at α = 0.05 (solid lines) or α = 0.2 (dotted lines), 95% confidence bands are displayed

3.7 Comparisons with additional Reference Sites

Mean shoot densities at the additional reference sites in SIMP ranged from 580 - 804 shoot m^{-2}, while in JBMP in 2014, mean values ranged from 622 -798 shoots m^{-2} (Table 9). These values are comparable to the Warnbro Sound reference sites in the same depth range (2-5m) which ranged from 490-957 shoots m^{-2}. Indeed, no significant differences were observed/recorded between any of the Warnbro Sound reference sites and the appropriate new sites in SIMP (Table 9). In contrast, the Warnbro Sound 2.5m site had significantly higher mean values than its counterpart in Jurien Bay (Table 10). It must be noted, however, that the data from Jurien Bay were collected in 2014 and are not be strictly comparable

Table 9: Mean (±SE) and median (per m^2) shoot density values from the additional reference sites in the SIMP and JBMP. The values from the respective Warnbro Sound reference sites are also included.

Depth	Site	Mean value	Median value
2.5m	Warnbro Sound 2.5m	957.9 (97.7)	912.5
	Penguin Island	804.2 (74.3)	887.5
	Boullanger Island 2.5m*	621.9 (46.6)	612.5
3.5m	Warnbro Sound 3.2m	668.2 (99.6)	600.0
	Becher Point	654.5 (42.1)	587.5
	Boullanger Island 3.5m*	797.9 (65.8)	787.5
5.5m	Warnbro Sound 5.5m	708.3 (57.4)	650.0
	Seal Island	580.2 (39.4)	537.5
	Boullanger Island 5.5m*	685.4 (35.6)	700.0

*No new data collected in 2015; results are from 2014

Table 10: Summary of the one-way ANOVA of shoot density conducted between the Warnbro Sound reference sites and comparable sites in SIMP and JBMP. Only statistics which are significant at α = 0.05 (**bold**) are shown. P values >0.05 are designated by 'ns'.

	SIMP		JBMP	
Reference site	**Comparison site**	***p* - value**	**Comparison site**	***p* - value**
Warnbro Sound 2.5	Penguin Island	ns	Boullanger Island 2.5*	**0.003**
Warnbro Sound 3.2	Becher Point	ns	Boullanger Island 3.5*	ns
Warnbro Sound 5.5	Seal Island	ns	Boullanger Island 5.5*	ns

*No new data collected in 2015; results are from 2014

Trend analysis was performed on the data from JBMP which showed a significant (α = 0.05) negative trend in both mean and median shoot density at the 2.5m site (Table 11). The 5.5m site showed a decline in median shoot density significant at α = 0.2, while no trend was observed at the 3.5m site. There are not currently sufficient data to perform trend analyses for the SIMP sites.

Table 11: Summary of the Mann Kendall trend analyses performed on mean and median shoot densities at the additional JBMP sites. Trends significant at α = 0.05 (bold) or α = 0.2 (‘*’) are shown. P-values > 0.2 are designated by ‘ns’.

	Mean shoot density		**Median shoot density**	
Site	**Mann-Kendall statistic**	**p-value**	**Mann-Kendall statistic**	**p-value**
Boullanger Island 2.5m	-0.511	0.050	-0.514	0.049
Boullanger Island 3.5m	-	ns	-	ns
Boullanger Island 5.5m	-	ns	-0.405	0.127*

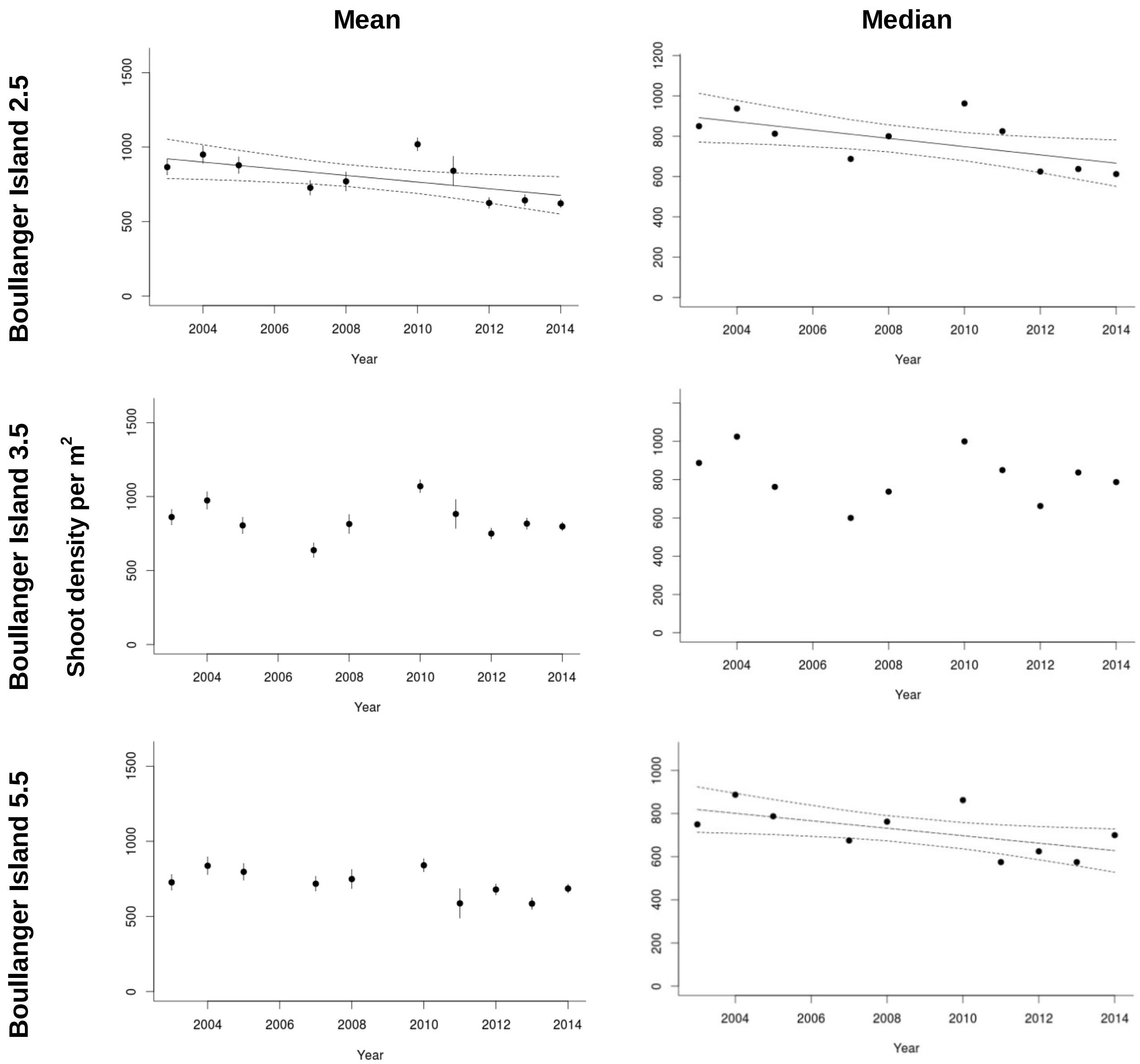
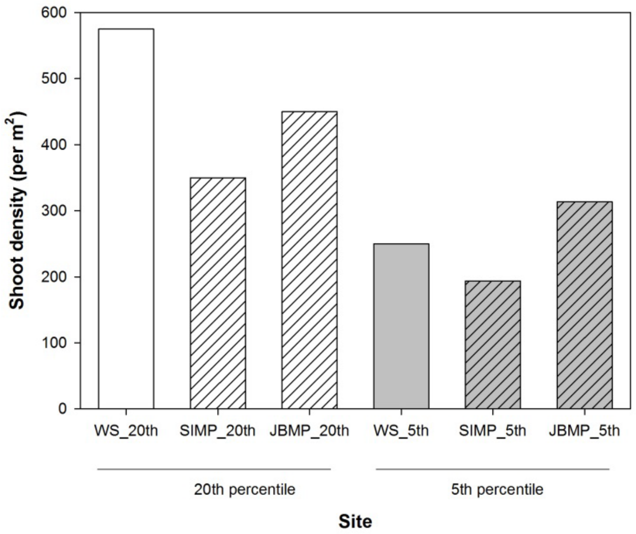


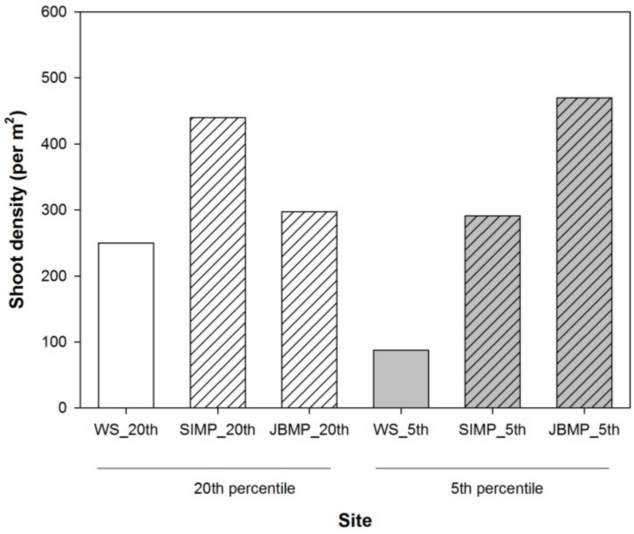
Figure 10: Trends in mean shoot density values at JBMP reference sites. Where trends are significant at α = 0.05 (solid lines) or α = 0.2 (dotted lines), 95% confidence bands are displayed

The 20th and 5th percentile values from the 2.5m, 3.5m and 5.5m Warnbro Sound sites were compared against the respective values from additional reference sites in SIMP and JBMP. Both the 20th and 5th percentile values from the 2.5m site were comparable to the SIMP and JBMP values at this depth. In contrast, both the 20th and 5th percentile values from the Warnbro Sound 3.5m and 5.5m sites were considerably lower than their counterparts in SIMP and JBMP. Again, it must be noted that no new data were collected from JBMP in 2015, so percentiles are based on 2014 results.

a) 2.5m sites



b) 3.5m sites



c) 5.5m sites

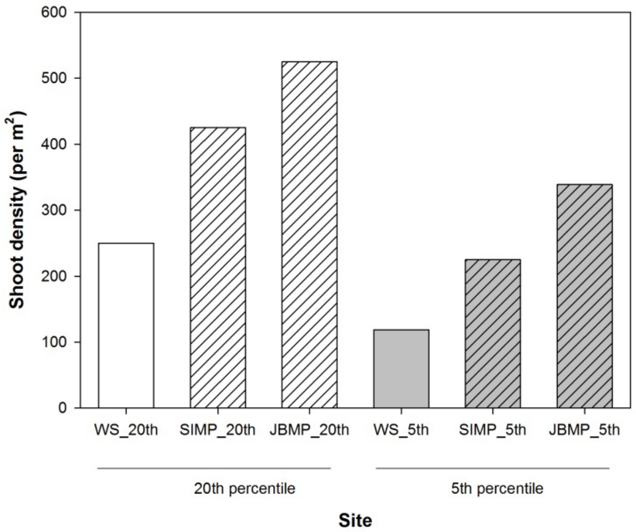


Figure 11: 20th (white bars) and 5th (grey bars) percentile values from the 2.5m, 3.5m and 5.5m sites in Warnbro Sound (unfilled bars), SIMP and JBMP (hatched bars).

4 Discussion and recommendations

The declines in seagrass shoot density noted by previous reports (Wave Solutions, 2012, Mohring and Rule, 2013a, 2013b, 2014) have continued in 2015 despite some sites having higher shoot densities than in previous years. Of the 16 ‘potential impact’ sites surveyed in 2015, eight displayed declining trends ($\alpha = 0.20$) in seagrass mean shoot density and/or median shoot density. Four sites; Garden Island Settlement, Southern Flats, Kwinana and Garden Island 5.5m showed statistically significant ($\alpha = 0.05$) declines in condition. Of greater concern, is the performance of the Warnbro Sound reference sites, which, with the exception of Warnbro Sound 2.5m, all showed significant ($\alpha = 0.05$) declines in mean and/or median shoot density values.

The continued declines in seagrass condition in Warnbro Sound have resulted in serious reductions of trigger values against which the median shoot density at potential impact sites are compared under the EQC. Indeed, the 20th, 5th and 1st percentile values from almost all reference sites have shown statistically significant declines since the program began. This translates into a substantial reduction of the protection afforded the Cockburn Sound impact sites under the EQC. This is an issue which requires urgent attention. Fortunately, the introduction of the Absolute Minimum Criteria does provide protection against this scenario, and use of the AMC will need to be initiated in 2015 for some comparisons.

The declines at most of the Warnbro sites are likely to be a result of the continued erosion and development of ‘blow outs’ in the area of the reference sites. In some cases (e.g. Warnbro Sound 2.0m), erosion is occurring very rapidly and has resulted in the loss of whole transects. While these have been duly replaced, consideration should be given to moving the location of these permanent transects or including some other mechanism to account for such changes in the physical structure of seagrass meadows. For instance, if a transect is lost, quadrats could possibly be randomly cast in areas where seagrass is still dense.

The maximum depth of seagrass distribution at the ‘depth transect’ sites has increased at both Garden Island South and Woodman Point, while at Garden Island North and Warnbro Sound, the maximum depth distribution has remained stable since the program began in 2000. The mechanism driving this increase in vertical distribution is currently unknown but is likely to be a result of the general improvement of water quality and the improved light environment inside Cockburn Sound.

The mean and median shoot densities at the Warnbro Sound reference sites are generally not significantly different from those at the additional reference sites in SIMP and JBMP. However, at both the 3.5m and 5.5m depths, the 20th and 5th percentile values (i.e. trigger values) are considerably lower than the respective values at either of the additional reference areas. This inconsistency suggests that the seagrass distribution is patchier at the deeper Warnbro Sound sites than at the respective sites in SIMP and JBMP. The implications of this are not yet clear, but it may be that the erosion and sand movement across the northern part of Warnbro Sound is driving increased patchiness in seagrass density.

4.1 Recommendations

It is clear that the health of the Warnbro Sound reference sites has declined to an unsatisfactory level. While the AMC provides a base reference for comparisons of the Cockburn Sound sites, this issue cannot be ignored. Data are now available from the additional reference sites in SIMP and JBMP which could supplement the data collected from Warnbro Sound; however, there is no protocol in place to use these extra data under the EQC. There are several approaches which could be taken, namely; 1) data from additional sites are incorporated into the calculation of percentiles under the EQC; or, 2) as has been done here, data are simply used as a regional reference to gauge the level of change at the Warnbro/Cockburn Sound sites. In addition, a decision about the future of these additional sites is required. If the monitoring of these additional sites is to be continued, this needs to be formalised as part of the program. This has obvious budget implications for the CSMC as additional funds will be required to survey these sites.

Recommendation 1: Consideration of the process for implementing additional reference data, and how these data will be used in the future by the CSMC program, is required.

Recommendation 2: The use of the additional reference sites in SIMP and JBMP needs to be made a formal component of the CSMC long-term monitoring program.

From the analyses presented here, it is obvious that the median and mean values for almost all sites are very similar, thus assessing trends and differences for both metrics in the way presented each year here is unnecessary. While median values are used to compare impact sites to the reference sites under the EQS, the use of mean values allows the variance around means (e.g. standard error) to be calculated. These estimates provide more information than just median values as they allow an assessment of the 'spread' of data, which may be important in future years as meadows change and possibly become more patchily distributed.

Recommendation 3: Reporting of trends at impact and reference sites is only presented for mean values in future years.

The revised EQC clearly describes a procedure for assessing the utility of the 5^{th} and 20^{th} percentile trigger values against the AMC, which has been employed here. However, for comparisons made against the 1^{st} percentile (e.g. Moderate Protection Areas; Jervoise Bay) it is unclear in the EQC how the rolling trigger values are assessed against the AMC.

Recommendation 4: The procedure for determining the correct trigger value for comparisons with the 1^{st} percentile needs to be defined.

The median values from several sites (e.g. Woodman Point and Jervoise Bay) were calculated from very few quadrats as these sites have been affected by erosion. While several sites have had additional quadrats established over the past few years, there remains no clear decision-making procedure to guide the re-establishment of lost replicates.

Recommendation 5: The procedure for replacing missing transects/quadrats needs to be defined. This should include the process for gaining approvals from the CSMC to replace missing replicates.

Under the recent revision of the SOP, depth transects are required to have depth profiles established in order to accurately translate LDL transect lengths/distances to depth measurements. These depth profiles have not yet been constructed and need to be during the next sampling season. Possibly the best way to do this is to use a high resolution Lidar GIS layer which is available for the area, and was used by Mohring and Rule (2013b) to establish reliable depths for all of the sites used in this program.

Recommendation 6: That accurate depth profiles for each depth transect site are constructed.

At each depth transect site seagrass density is recorded every 2m along each transect. While the maximum depth of seagrass distribution is measured and changes in the depth of seagrass are now reported, no analyses or reporting of the density of seagrass along this transect is currently done. This is largely because of the confounding of seagrass density data as depth increases. Guidance is required as to how these additional data should be used, or if density data collection is still required at these sites.

Recommendation 7: That consideration be given to how the density data from the depth transect sites is used in the future.

5 References

Connolly, R., 2012. Seagrass, in: Poloczanska, E.S., Hobday, A.J., Richardson, A.J. (Eds.), A Marine Climate Change Impacts and Adaptation Report Card for Australia 2009, NCCARF Publication 05/09.

Duarte, C.M., Kirkman, H., 2001. Methods for the assessment of seagrass abundance and depth distribution. In: Short FT, Coles RG (eds), in: Short, F.T., Coles, R.G. (Eds.), Global Seagrass Research Methods. Elsevier Science B.V., p. p 141–153.

Environmental Protection Authority, 2014. Revised manual of standard operating procedures for environmental monitoring against the Cockburn Sound environmental quality criteria (2003-2004). A supporting document to the State Environmental (Cockburn Sound) Policy 2014. Environmental Protection Authority, Perth, Western Australia.

Environmental Protection Authority, 2013. Draft environmental quality criteria reference document for Cockburn Sound. A supporting document to the State Environmental (Cockburn Sound) Policy 2013 (No. Report 21). Perth, Western Australia.

Environmental Protection Authority, 2005. Environmental quality criteria reference document for Cockburn Sound (No. Report 21). Perth, Western Australia.

Environmental Protection Authority, 2004. Revised manual of standard operating procedures for environmental monitoring against the Cockburn Sound Environmental Quality Criteria (No. Report 21).

Heck, K.L., Hays, G., Orth, R.J., 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology Progress Series 253, 123–136.

Larkum, A.W.D., McComb, A.J., Shepard, S.A., 1989. Biology of seagrasses - a treatise on the biology of seagrasses with special reference to the Australian region. Elsevier, Amsterdam.

Lavery, P.S., 1994. Seagrass health in the Success Bank to Warnbro Sound Region., Department of Environmental Protection. Department of Environmental Management, Edith Cowan University, Perth.

Lavery, P.S., Gartner, A., 2008. A survey of selected seagrass meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound: Health and Status 2008 – (No. Report Number No. 2008-10), Report to the Cockburn Sound Management Council (Department of Environment and Conservation). Coastal Marine Ecosystems Research, Edith Cowan University.

Lavery, P.S., McMahon, K., 2011. Review of Cockburn Sound SEP Seagrass Monitoring Program (No. CMER 2011-04), Report to the Cockburn Sound Management Council. Edith Cowan University, Perth.

Mohring, M.B., Rule, M.J., 2014. A Survey of Selected Seagrass Meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound: data report (Prepared for the Cockburn Sound Management Council). Department of Parks and Wildlife, Perth.

Mohring, M.B., Rule, M.J., 2013a. A Survey of Selected Seagrass Meadows in Cockburn Sound, Owen Anchorage and Warnbro Sound: data report (Prepared for the Cockburn Sound Management Council). Department of Environment and Conservation, Perth.

Mohring, M.B., Rule, M.J., 2013b. Long term trends in the condition of seagrass meadows in Cockburn and Warnbro Sounds (Prepared for the Cockburn Sound Management Council). Department of Environment and Conservation, Perth.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck Jr, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., Williams, S.L., 2006. A global crisis for seagrass ecosystems. BioScience 56, 987–996.

Short, F.T., Neckles, H.A., 1999. The effects of global climate change on seagrasses. Aquatic Botany 63, 169–196. doi:10.1016/S0304-3770(98)00117-X

Walker, D.I., 1991. The effect of sea temperature on seagrasses and algae on the Western Australian coastline. Journal of the Royal Society of Western Australia 74, 71–77.

Wave Solutions, 2012. A survey of selected seagrass meadows in Cockburn Sound, Owen Anchorage and Warnboro Sound: data report 2012 (Report to the Cockburn Sound Management Council).

Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., Williams, S.L., 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences 106, 12377 –12381. doi:10.1073/pnas.0905620106