BENTHIC HABITAT MAPPING OF COCKBURN SOUND

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1. EXECUTIVE SUMMARY

Temperate seagrasses form an important component of shallow benthic habitats in Cockburn Sound, providing critical ecosystem functions and services. After concentrated coastal development along the eastern banks of Cockburn Sound, the spatial extent of seagrass coverage dramatically decreased between the late 1960s and early 1970s. Subsequent monitoring efforts have examined shoot densities at several long term sites, and have conducted infrequent mapping projects across Cockburn Sound, the last of which occurred in 2012. This document updates the distribution of seagrass in shallow (<10 m) areas of Cockburn Sound in 2017, and compares this to distributions from maps from 1999 and 2012. Seagrass covered a total of 9.65 km^2 (965 ha) of Cockburn Sound in 2017, comprising 22.6% of the total area of Cockburn Sound <10m in depth (42.78 km^2). The dominant species was *Posidonia sinuosa,* followed by *Posidonia australis.*

Total seagrass cover increased modestly between 2012 and 2017 (40 ha), mainly from an increase in seagrass cover in areas off the north-east coast of Garden Island. Seagrass cover has risen by 244 ha between 1999 and 2017, primarily as a result of increases in seagrass coverage in the eastern and southern regions of Cockburn Sound. This report also examined changes in seagrass coverage over smaller spatial scales in polygons selected in Woodman Point, Mangles Bay, Southern Flats and Eastern Banks. There were varying trends in benthic cover in these areas between 1999, 2012 and 2017, showing the potential for mapping using remote sensing for monitoring changes in seagrass coverage across different areas of Cockburn Sound.

This report updates the data on benthic habitats in Cockburn Sound, and can act as a valuable baseline to compare future mapping exercises to.

Acknowledgements

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2. INTRODUCTION

Temperate seagrass meadows constitute an important benthic habitat in Cockburn Sound. These seagrass meadows are foundation species in Cockburn Sound, providing critical ecosystem functions and services including providing habitat for important fisheries species. Seagrasses respond rapidly to changes in environmental conditions such as light or nutrient availability, making them good indicators of the state of the marine environment. There have been large losses of seagrass meadows in Cockburn Sound (Cambridge & McComb, 1984; Kendrick *et al.*, 2002). These losses were primarily driven by low light availability, caused by increased nutrient loads which led to increased epiphytic growth on leaves (Cambridge *et al.*, 1986). Between 1954 and 1978, industrial development led to decreases in seagrass cover from 4200 hectares to 900 hectares in Cockburn Sound (Kendrick *et al.* 2002). In response, management programs regulating inputs into Cockburn Sound have resulted in decreased inputs of nutrients into Cockburn Sound and an improvement in water quality, though seagrass density in some areas continues to decline (Fraser and Kendrick 2017).

The maintenance and recovery of seagrass meadows has been a key theme in the management of Cockburn Sound. Annual monitoring of seagrass shoot densities is undertaken by the Cockburn Sound Management Council at 21 sites in and around Cockburn Sound, including 11 'potential impact' sites in Cockburn Sound (Fraser *et al.* 2017). In addition, the lower depth limit of seagrasses is monitored at six sites, four of which are in Cockburn Sound. Such monitoring provides critical data on changes in the density of meadows within Cockburn Sound over time, with up to 15 years of shoot density data available at most sites. However, this regular monitoring does not reveal changes in the spatial extent of seagrass cover across the entirety of Cockburn Sound, and whether it is expanding or retreating over time. Larger-scale mapping is therefore required to fill this knowledge gap, and was a specific recommendation in the Review of Cockburn Sound SEP Seagrass Monitoring Program (Lavery and McMahon 2011).

Benthic habitat mapping has been undertaken at irregular intervals in Cockburn Sound predominately using aerial imagery, and has proven a useful tool in documenting changes in seagrass cover in the area. The first comprehensive mapping exercise was undertaken by Cambridge *et al*. (1986), and showed the extent of seagrass declines using aerial imagery taken annually since 1954, but concentrated on the eastern section of Cockburn Sound. This seminal work first revealed the extent of seagrass declines that had occurred since the 1950s in Cockburn Sound. This was revisited and updated in the late 1990s by Kendrick *et al.* (2002) as part of the D.A. Lord & Associates "Seagrass Mapping Owen Anchorage and Cockburn Sound 1999" project. Aerial photography and towed video was used to create maps comparing 1999 seagrass cover to historical imagery from 1967, 1972, 1981 and 1994, and 1999, revealing that seagrass cover had declined by 77% in Cockburn Sound between 1967 and 1999. The most recent mapping project was conducted in 2012 by UWA on behalf of 360 Environmental Pty Ltd (Hovey *et al.,* 2013). Digital aerial photography and video transects were used in this case to map benthic habitat cover in areas of Cockburn Sound shallower than 10 m (i.e. potential seagrass habitat), though no comparison to historical cover was made in this project. No comprehensive mapping project has been conducted in Cockburn Sound since 2012.

Remote sensing using satellite imagery is becoming an increasingly feasible method to map benthic habitats in coastal ecosystems. Satellite imagery is generally cheaper than commissioning aerial imagery for mapping projects, and represents a potential cost-effective method for regular monitoring of spatial changes in seagrass cover. Low resolution was previously a limitation with using satellite imagery for mapping changes in benthic habitats over small scales (e.g. 1-10m scale), but recent technological advances have increased this resolution, and there is now commercially available satellite imagery that offers various degrees of resolution each with different costs. For example, Landsat 8 is freely available satellite imagery and thus an economical monitoring tool, but it is of relatively low resolution (30 m pixels) which may not be conducive to detecting changes in seagrass distribution. Conversely, WorldView 3, which is a new satellite platform, has a higher resolution (>50 cm pixels), but incurs a cost (e.g. AUD $4415 for imagery in this project). It is important to determine the resolution required to accurately detect changes in seagrass extent, and compare this to the costs incurred, to identify whether satellite imagery represents an appropriate method for monitoring seagrass cover in Cockburn Sound.

The purpose of this project was to accurately map the distribution of benthic habitat in Cockburn Sound using remote sensing, with a specific focus on seagrass assemblages. We also conducted *in situ* towed video analysis of benthic habitats across Cockburn Sound to ground truth classifications determined by remote sensing. This project updates our understanding of the spatial extent of seagrass coverage in Cockburn Sound, complimenting existing shoot density data from the annual CSMC Seagrass Monitoring program. This project represents the first attempt at using satellite imagery to monitor seagrass cover in Cockburn Sound, thus helping to identify if this is a feasible method for future mapping exercises in the area. Finally, we compare the seagrass cover obtained in this study to historical seagrass mapping projects, to provide an update on the temporal and spatial changes to seagrass cover in Cockburn Sound.

3. METHODS

3.1 Imagery

Two satellite sensors differing in resolution were chosen to develop seagrass maps, allowing for comparison between different platform resolutions. The first platform used was Landsat 8, a freely available monitoring tool that has relatively low resolution (30 m pixels). The second platform used was WorldView 3, which has higher resolution (>50 cm pixels) but is more expensive as a commercial product. Images from both platforms were selected for minimal environmental components affecting the clarity of the sea surface, such as minimal cloud cover or wind and swell. Imagery from Landsat 8 and Worldview 3 taken in March 2017 was used for analysis, while additional Worldview 3 imagery from January and February 2017 was also downloaded to provide imagery in areas that were of low quality in March imagery due to poor conditions.

Image corrections were achieved using ENVI (Esri Australia), involving both geometric and radiometric operations. Geometric corrections were performed to enable the images to be overlaid with other spatial data, including bathymetry and the ground-truthing transect locations. Radiometric corrections were conducted to remove atmospheric, air–water interface and sun-angle effects on the water leaving a radiance signal in each pixel, which contained information from the benthos. A depth mask used in previous maps of the area (Kendrick *et al*., 2002) was applied to the image data to limit the seagrass mapping to areas where known seagrass species and cover differences would be detectable.

3.2 Unsupervised Classification Map

An iso-cluster unsupervised classification technique was performed on satellite imagery using Arc GIS to construct a first pass habitat map and to identify ground truthing sites to be verified during field surveys. Ground truthing sites were chosen as areas that were considered to be spectrally homogeneous suggesting a uniform habitat. They were further adjusted to ensure that all possible shallow water habitats were represented based on expert knowledge and bathymetry. Homogenous sites were used to define similar habitats and allow the collection of multiple field measurements within an area to obtain a 'best fit description' of the habitat for comparison with the image data (pixel data representing an area), giving the field data a unit of measure.

3.3 Field surveys

A towed video array was used to collect imagery of benthic habitats in Cockburn Sound conducted over three days in May 2017 (Fig. 1). The forward-facing towed video array consisted of a high definition GoPro camera in an underwater housing, which was used to obtain photographic records of the benthic communities and to enable identification of the species composition of the benthic communities within the homogenous areas selected from the unsupervised map. The camera array was towed behind the survey vessel, which travelled at 1.0 - 2.0 knots across selected areas. The camera position relative to the seabed was controlled manually to maintain a distance of approximately 1 m from the seabed. Dashware software was used to generate a time and GPS stamp on the images. Images were automatically taken every 5 seconds. Imagery was then downloaded, and images for analysis were randomly subsampled every 10 seconds (at least 5-10 m between each data point). Qualitative assessment of benthic communities 2-5 m in front of the camera was

then undertaken, with estimates of percent cover converted into Braun-Blanquet cover-abundance scale (Braun-Blanquet 1932, Fourqurean *et al.,* 2001).

Figure 1 Map of Cockburn Sound showing tracks used for towed video sampling.

3.4 Supervised Classification Map

Identification of seagrass was performed using a supervised maximum likelihood classification method in ENVI (Esri Australia). Several supervised classification methods have been trialled in other mapping studies, with the Maximum Likelihood Classifier (MLC) consistently achieving the highest separation between classes (e.g. Dekker *et al.,* 2005). The homogenous squares selected during the first pass map and ground truthed during the field survey (see above) were used as training data in the MLC method. There are a total of eight species known to be present in seagrass assemblages in Cockburn Sound, i.e. *Amphibolis antartica, Amphibolis griffithii, Posidonia australis, Posidonia coriacea, Posidonia sinuosa, Halophila ovalis, Heterozostera tasmanica,* and *Syringodium isoetifolium* (Kendrick et al., 2002). However, this project did not differentiate each species in the final classification across the entirety of Cockburn Sound, though species-level mapping was performed on the eastern shelf of Cockburn Sound. The classification was divided into three classes, i.e. seagrass, bare sand, and land, following the previous study by Kendrick *et*

al. (2002), for consistency when comparing to previous mapping studies. The accuracy of each platform and habitat classification was evaluated (and maps validated) based on the classification of towed video data points that had not been used in training of models.

3.5 Examining habitat changes

To examine how the benthic habitats may have changed temporally and spatially, the past and present habitat maps were compared using a number of methods. In ArcGIS (Esri Australia) the Create Random Points tool was used to generate 150 points across Cockburn Sound, stratified by depth. The habitat from historical and contemporary maps at each point were extracted and a cross comparison was made to examine changes in these locations. Four small rectangular polygons were created in different zones (Mangles Bay, Southern Flats, Woodman Point and Eastern Flats) to examine changes in seagrass area from 1999, 2012 and 2017. Finally, total seagrass area was also calculated and compared between time periods. These polygons were selected to sample a wide geographical area across Cockburn Sound, and encompassed long-term shoot density monitoring sites that have shown declining trends (Fraser *et al.*, 2017). Decision on locations of polygons in monitoring projects would ideally be based on management priorities.

4. RESULTS

4.1 Towed imagery analysis

A total of 677 georeferenced still images were analysed from the underwater towed video survey, which covered 25 km (linear) of benthic habitat (Appendix 1 for example imagery). Soft sediments were the most prevalent primary substrate (95%), and the ratio between hard and soft primary substrates was ~19:1. Seagrasses were the most prevalent benthic biota, and were the primary biota in 41% of images analysed. The dominant seagrass species was *Posidonia sinuosa*, which was the primary biota in 33% of images, and was present in 42% of all images. *Posidonia australis* was the next most prevalent seagrass species, being the primary biota in 5.7% of images and being present in 9.8% of images. *Amphibolis antarctica* and *Amphibolis grifitthi* were found in 1% and 0.6% of images respectively. No *Halophila ovalis* was recorded in any images, even in areas where it had previously been recorded (Appendix 2 for species-specific map from Dredge Spoil Area). Macroalgae was the primary biota in 10% of images; with *Sargassum* sp. being the major macroalgal species encountered (present in 7.7% of images). Benthic invertebrates were recorded in 3.7% of total images, with ascidians being the most prevalent invertebrate group (present in 2.7% of images). *Amphibolis* and *Posidonia* were not found in any areas deeper than 10 m.

4.2 Final classification of habitats

Two main benthic cover classes were clearly distinguishable in the satellite imagery; seagrass and sand, and used to create full coverage maps of Cockburn Sound (Fig. 3). None of the satellite platforms were capable of accurately distinguishing between different seagrass species or the presence/absence of microphytobenthos and turf algae seen in underwater video in sand dominated areas, though this would be a limitation of other methods of remote sensing such as using aerial imagery. All maps indicate that the shallow banks adjacent to Garden Island down to Mangles Bay are dominated by persistent seagrass stands, out to approximately 8m water depth. The eastern banks are primarily sand dominated, with pockets of persistent seagrass stands found along the edge of the deepwater basin that makes up over 60% of Cockburn Sound. Ephemeral seagrass cover, such as *Halophila* sp, maybe found throughout the eastern banks but has been found to be transient in time and space, and may not be distinguishable in satellite imagery or other forms of remote sensing unless in very high density.

The supervised map showed a total seagrass cover of 9.65 km^2 (965 ha) across Cockburn Sound, comprising 22.6% of the total area of Cockburn Sound <10m in depth (42.78 km^2). Extensive seagrass meadows were found in the western and southern regions of Cockburn Sound, with seagrass meadows representing the dominant benthic habitat off the eastern coast of Garden Island and in the Southern Flats region.

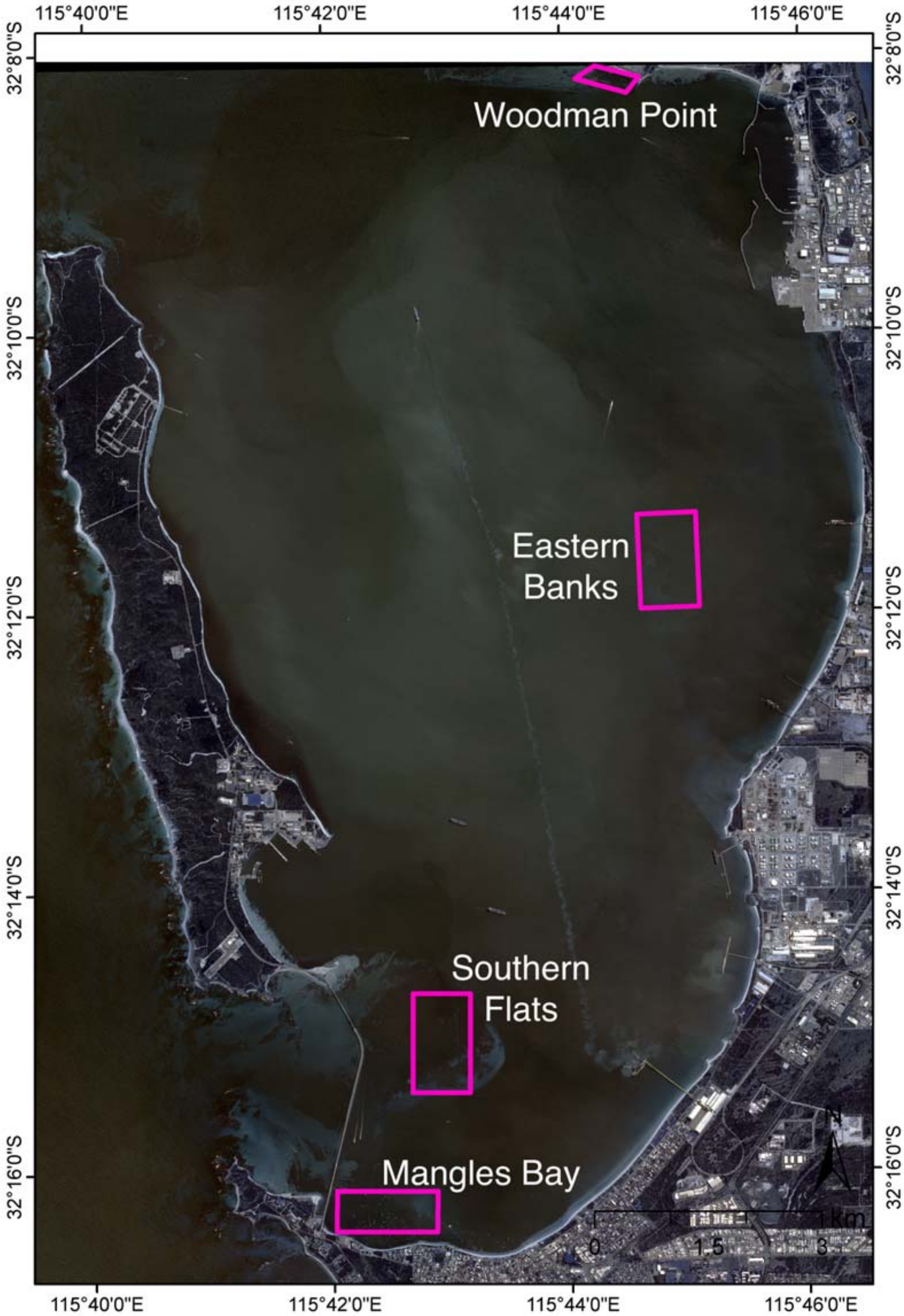

Figure 2 Map of Cockburn Sound showing polygons used for detailed mapping (see section 4.3).

4.3 Comparison to previous mapping

The total cover of seagrass has risen across Cockburn Sound between 1999, 2012 and 2017 (Fig. 4, Table 1). The total coverage of seagrass has risen from 7.21 km^2 in 1999 to 9.65 km^2 in 2017, representing a gain of 244 ha of seagrass. This increase is concentrated in the

eastern and southern regions of Cockburn Sound, with cover increasing in the Southern Flats region, as well as offshore areas in eastern Cockburn Sound (Fig. 4).

The total coverage of seagrass has risen from 9.25 km^2 in 2012 to 9.65km^2 in 2017, a gain of 40 ha (Table 1). The majority of this increase resulted from an increase in seagrass off the north-east coast of Garden Island, while there appears to be some loss of seagrass in the coastal regions of eastern Cockburn Sound, adjacent to Naval Base.

Specific polygons were identified across various sections of Cockburn Sound to examine temporal changes in seagrass cover over smaller spatial scales (Fig. 2, Appendices 3-6 for zoomed-in maps). The polygons identified across Cockburn Sound had differing patterns of seagrass area between 1999, 2012 and 2017 (Table 1). WorldView3 imagery and Landsat8 imagery produced maps with similar area coverage in Southern Flats, Mangles Bay and Eastern Banks, but varied greatly at Woodman Point (Table 1, Fig. 5). Due to the higher accuracy of maps produced using Worldview3 imagery (see section 4.4), only 2017 maps produced using the WorldView3 imagery are discussed hereafter.

Seagrass coverage increased across the entirety of Cockburn Sound between 1999, 2012 and 2017 (Table 1). However, only 2 of the 4 areas showed increases of seagrass area between 2012 and 2017. Woodman Pt (total polygon area = 0.15 km^2) showed an increase from 0.09 km^2 (60%) in 1999 to 0.11 km^2 (73.3%) in 2012, before decreasing to 0.09 km^2 (60%) in 2017. Seagrass coverage in Mangles Bay (total polygon area = 0.71 km^2) was relatively stable but followed a similar trend, increasing from 0.52 km^2 (73.2%) in 1999 to 0.59km^2 (83.1%) in 2012, before decreasing to 0.55 km^2 (77.5%) in 2017. Seagrass at Southern Flats (total polygon area = 0.98 km^2) showed consistent increases over time, increasing from 0.5 km^2 (51%) in 1999 to 0.84 km^2 (85.7%) in 2012 and to 0.86 km^2 (87.8%) in 2017. Similarly, seagrasses in the Eastern Banks polygon (total polygon area = 1.07 km^2) increased from 0.12 km^2 (11.2%) in 1999 to 0.17 km^2 (15.9%) in 2012 and 0.14 km^2 (13.1%) in 2017.

Table 1 Changes in seagrass cover across Cockburn Sound between 1967-2017. Potential habitats are classed as areas in Cockburn Sound <10m in depth (total polygon area for Cockburn Sound = 42.78km^2).

	Cockburn Sound		***Location specific seagrass area***			
Year	**Seagrass area (km^2)**	**% potential habitat**	**Woodman Point (km^2)**	**Southern Flats (km^2)**	**Mangles Bay (km^2)**	**Eastern Banks (km^2)**
2017 Worldview	9.65	22.6	0.09	0.86	0.55	0.14
2017 Landsat	7.52	17.6	0.04	0.87	0.55	0.12
2012[a]	9.25	21.6	0.11	0.84	0.59	0.17
1999[b]	7.21	16.9	0.09	0.5	0.52	0.12
1967[b]	29.3	79.9	-	-	-	-

[a] Hovey *et al*. 2013; [b] Kendrick *et al*. 2002

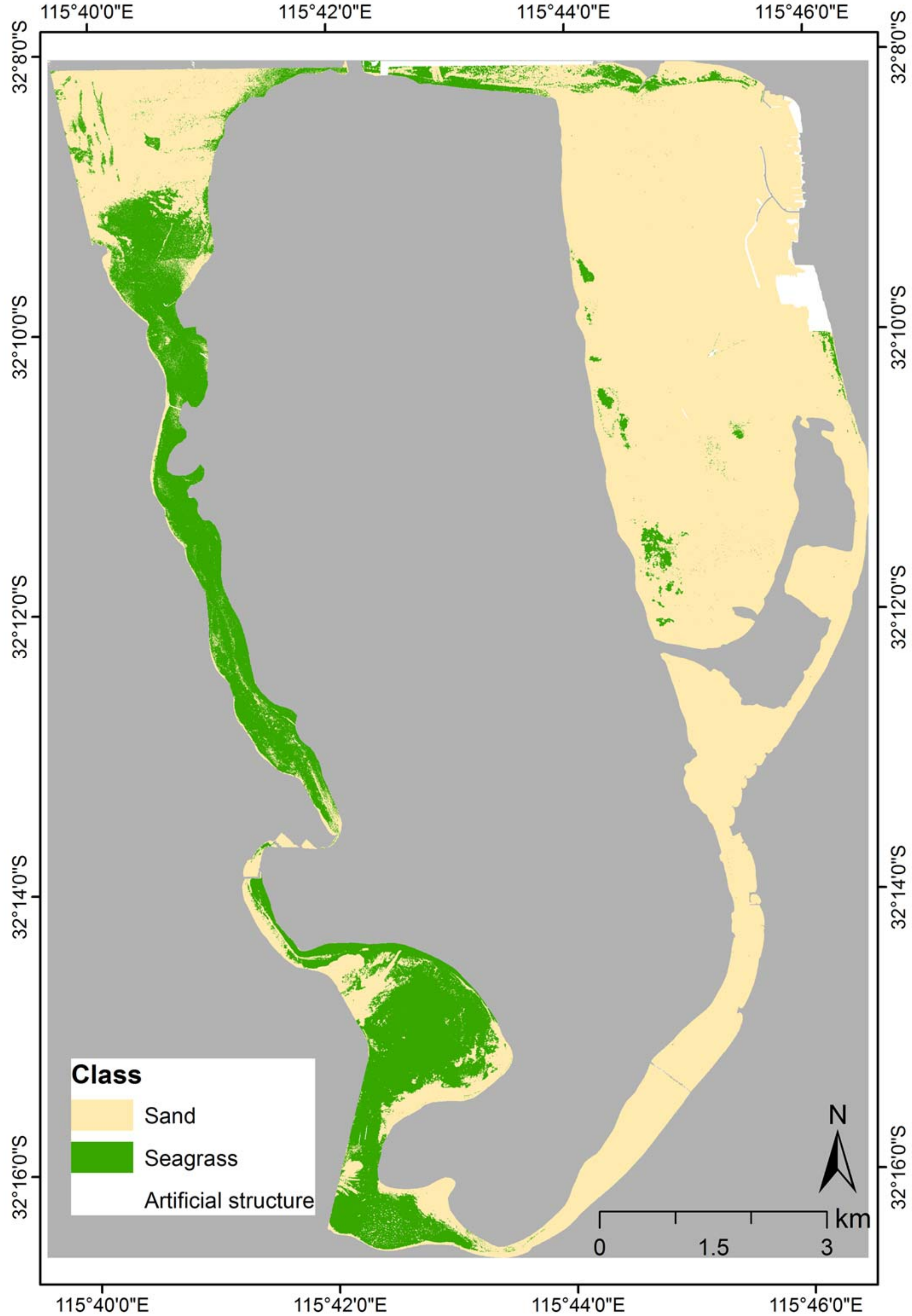

Figure 3 Distribution of seagrass across Cockburn Sound in 2017. Map generated using Worldview 3 imagery.

4.4 Accuracy comparison between remote sensing platforms

The overall mapping accuracy was calculated from error matrices (Tables 2 and 3) between ground truth and mapped data. The Worldview dataset had higher user and producer accuracy (and thus a higher overall accuracy) for all habitat classes. User accuracy is a measure of reliability (probability that a pixel class on the map represents the category on the ground; Czaplewski 2003) with both seagrass (88%) and sand (84%) having high reliability in the map created from WorldView imagery (Table 2). The reliability of Landsat imagery to distinguish seagrass (45%) and sand (62%) was considerably lower (Table 3). Producer accuracy defines how well a certain category can be classified (Czaplewski 2003), and was higher for the Worldview dataset than the Landsat dataset for sand (93% vs 77%) and seagrass (73% vs 28%). WorldView imagery resulted in much higher overall accuracy than Landsat 8 imagery (85% and 58% respectively; Tables 2 and 3, Fig. 5). The Kappa coefficient is a measure of agreement between the habitat map and ground-truthed data (Binaghi et al. 1999, Czaplewski 2003, McHugh 2012), and revealed 'good' agreement between maps and ground truthed data, with both platforms having similar coefficients (0.53 and 0.55).

Table 2 Accuracy assessment (error matrix) of Cockburn Sound Habitat map developed using 2017 Worldview satellite imagery. 'Predicted' describes the algorithm's prediction for habitat classification based on satellite imagery, while 'Ground-truthed' describes actual habitat class based on towed video imagery. Overall accuracy describes combination of user and producer accuracy.

	Ground-truthed			
Predicted	Seagrass	Sand	Total	**User Accuracy**
Seagrass	196	26	222	**88%**
Sand	73	373	446	**84%**
Total	269	399	668	
Producer Accuracy	**73%**	**93%**		
Overall Accuracy	**85%**			
Kappa	**0.53**			

Table 3 Accuracy assessment (error matrix) of Cockburn Sound Habitat map developed using 2017 Landsat 8 satellite imagery.

	Ground-truthed			
Predicted	Seagrass	Sand	Total	**User Accuracy**
Seagrass	75	91	166	**45%**
Sand	188	314	502	**62%**
Total	263	405	668	
Producer Accuracy	**28%**	**77%**		
Overall Accuracy	**58%**			
Kappa	**0.55**			

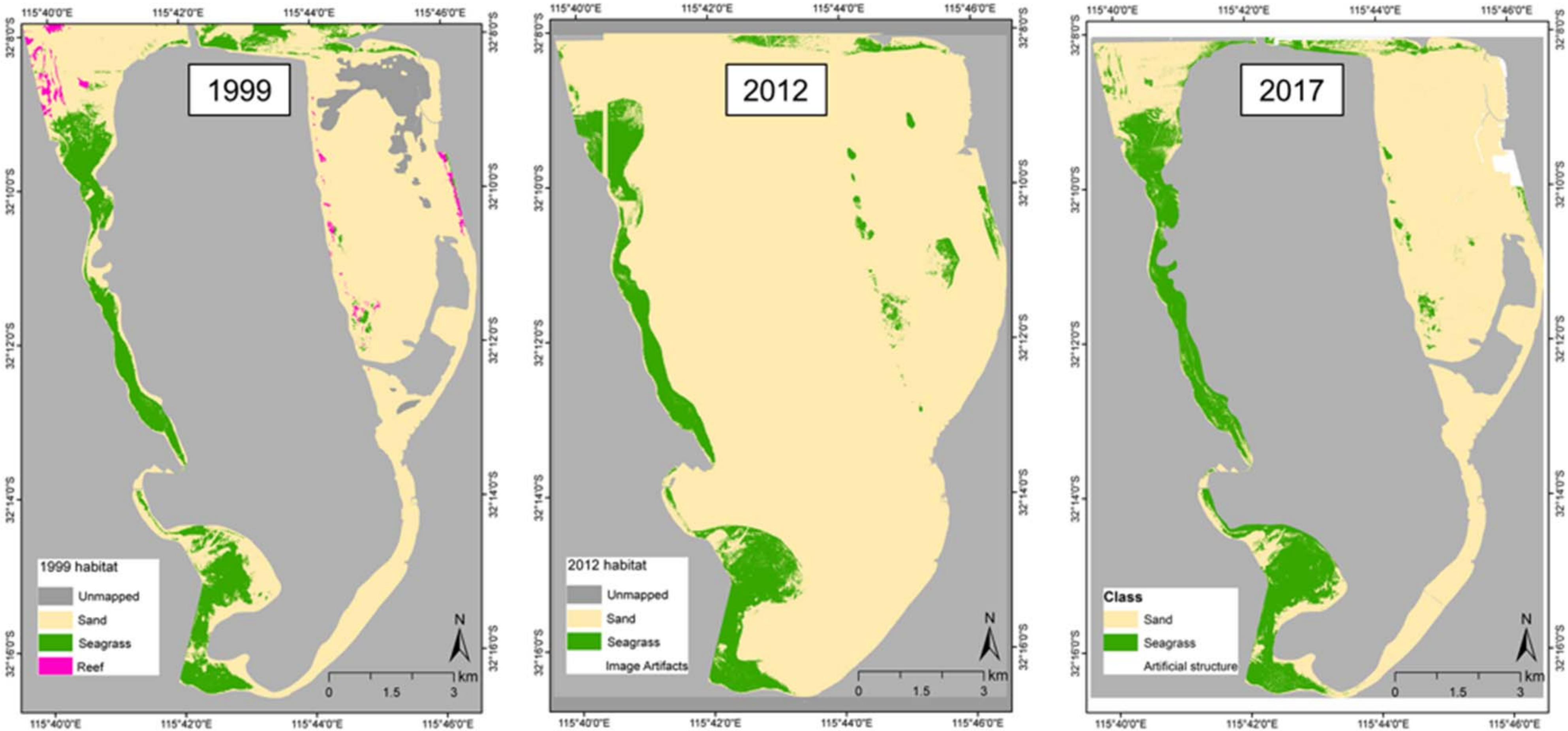

Figure 4 Distribution of seagrasses in Cockburn Sound in 1999 (from Kendrick *et al.*, 2002), 2012 (from Hovey *et al*., 2013), and in 2017 (this report). 2012 map is slightly cropped due to differences in areas of imagery collected in 2012.

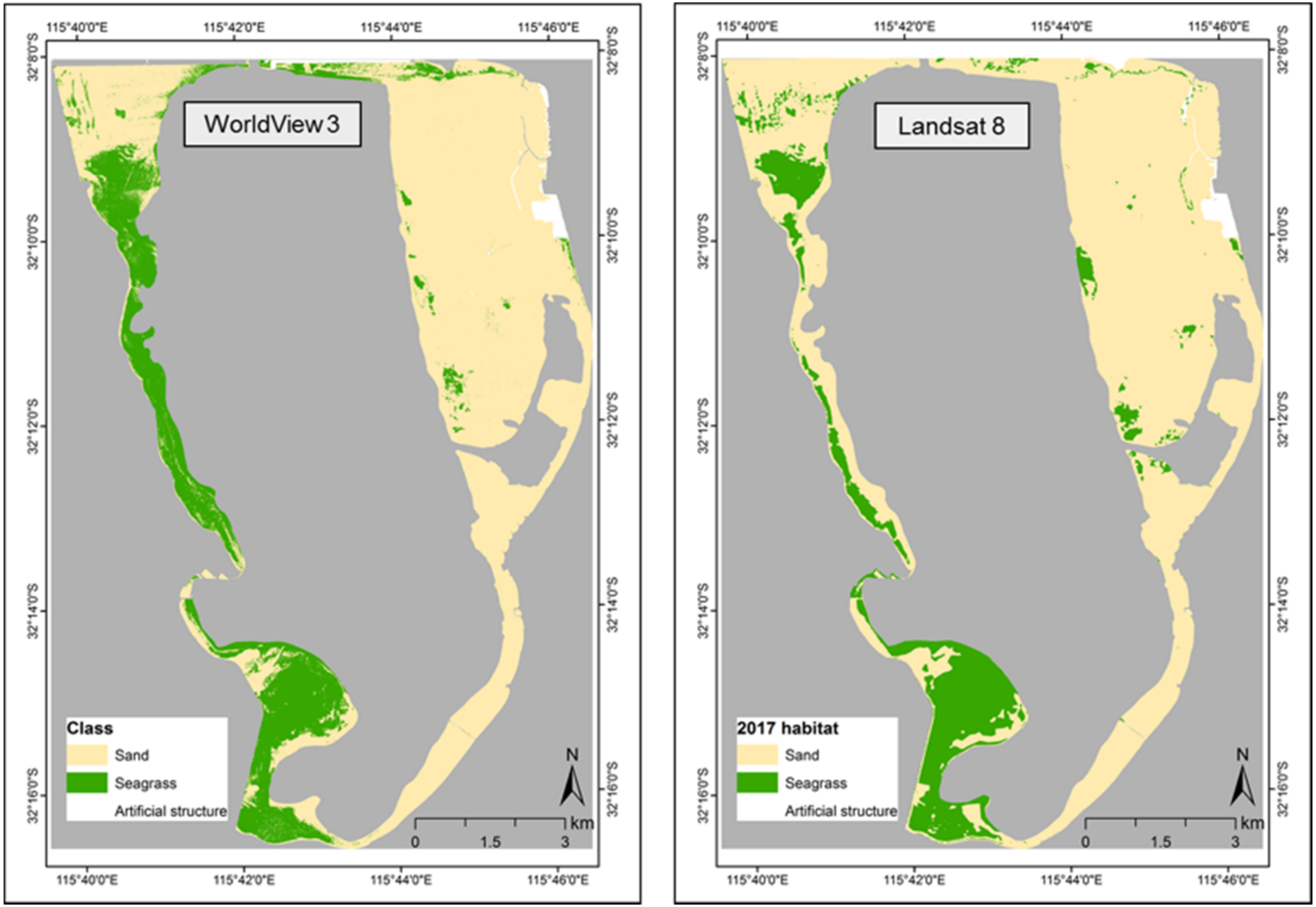

Figure 5 Comparison between 2017 maps generated with WorldView3 imagery (left) and Landsat8 imagery (right).

5. DISCUSSION

This study examined the distribution of seagrasses across Cockburn Sound using satellite imagery and towed video analysis. Full maps of benthic coverage in depths shallower than 10m were developed across Cockburn Sound, adding to a historical composite of changes in seagrass distribution that was previously mapped in 1999 and 2012. Seagrass coverage has remained relatively stable over the previous 5 years, showing modest gains since 2012. However, over the last 20 years total seagrass cover in Cockburn Sound has increased by over 200 ha, coinciding with improved water quality (Mohring and Rule, 2013). However, the present-day seagrass cover in Cockburn Sound is still far lower than earlier estimates of coverage of ~29.3km^2 prior to 1967 (Kendrick *et al*., 2002).

The largest continuous seagrass meadows are located in the southern and western areas of Cockburn Sound (Cambridge & McComb, 1984; Kendrick *et al.*, 2002). Historically, these sites were less impacted by terrestrial inputs that lead to eutrophication and light reduction on the Eastern Banks of Cockburn Sound (Cambridge *et al*. 1984, 1986). Despite the lack of continuous meadows on the Eastern Banks, seagrass cover approximately doubled in the Eastern Banks polygon between 1999 and 2017 (Table 1, Fig. 4). Cover in Southern Flats was also greatest in 2017, potentially indicating the lower disturbance rates in this area between 1999 and 2017. Polygons in Mangles Bay and Woodman Point showed slight decreases between 2012 and 2017. The differential responses of meadows across Cockburn Sound necessitates that future mapping projects identify changes in seagrass cover at specific locations in addition to total seagrass cover. This would provide information on areas of seagrass losses and gains over small spatial scales that could be linked to localised impacts, and be highly useful from a management perspective. Such an approach would require long-term areas of interest to be identified, where remote sensing could be used to examine changes in seagrass cover annually. The polygons used in this study represent potential areas that could be specifically examined in long-term mapping projects, as they encompass a wide spatial scale of Cockburn Sound that also show differing trends in seagrass cover. Such areas could also be examined individually using remote sensing in between system-wide mapping projects which may not be required each year, reducing costs.

Currently, annual monitoring of seagrass in Cockburn Sound is conducted through measurements of shoot density at 21 long-term monitoring sites (11 within Cockburn Sound). Shoot density has shown a significant declining trend at several of these sites over the last 11-15 years of sampling, suggesting continued declines of meadows in areas such as northern Garden Island, Kwinana (Eastern Banks) and Mangles Bay (Fraser *et al*., 2017). However, trends in mapping show an increased areal cover of seagrass across these areas, and Cockburn Sound as a whole. One explanation for this pattern may be that meadows are expanding at the edges, but thinning in other parts of the meadow. Indeed, significant thinning of meadows (~80%) would be required to detect impacts from remote sensing alone, justifying the continued collection of shoot density data in monitoring programs. Though the increase in total seagrass cover is positive, continued thinning of meadows could still lead to reduced resilience (Bell & Westoby, 1986) and potentially threaten some of the important ecosystem functions of the seagrasses in Cockburn Sound. A combined approach investigating changes in shoot densities over patch scales and changes in

seagrass cover over landscape scales is therefore valuable in determining the overall health of seagrass in Cockburn Sound.

This report updates the data on benthic habitats in Cockburn Sound, and can act as a valuable baseline to compare future mapping exercises to. In addition, this report also provides evidence of the use of remote sensing (specifically satellite imagery) for the future monitoring of seagrass in Cockburn Sound, and confirms that data collected in this way can be compared to historical imagery to provide a time series of changes in benthic cover in Cockburn Sound. Given the recent advances in remote sensing technology, platforms such as Worldview can provide imagery that can also allow specific areas of Cockburn Sound to be monitored over time at a resolution of 50 cm. Though such methods have costs associated with obtaining and analysing imagery, they can reduce costs associated with fieldwork by reducing sampling effort required. Imagery can also be obtained free of charge from the Landsat 8 platform, though the reliability and accuracy of maps obtained from Landsat 8 imagery is considerably lower than those from Worldview 3 (Table 2 and 3, Fig. 5), and would only be suitable for qualitative assessments. This study provides an accurate baseline of seagrass change between 1999 and 2017 for further monitoring and management of seagrasses in Cockburn Sound, and provides a template for future mapping projects in the Sound using remote sensing technologies. We recommend that periods of regular mapping using remote sensing imagery be conducted at specific areas of interest annually, and across Cockburn Sound every 5 years.

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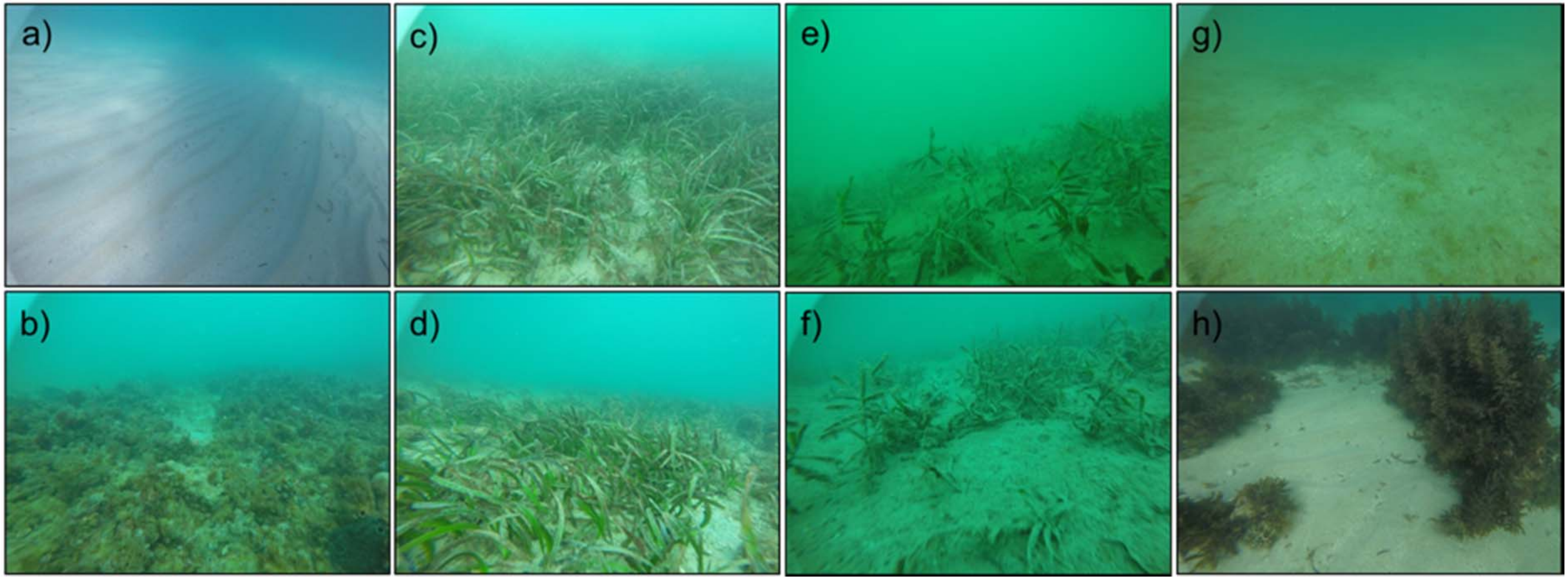
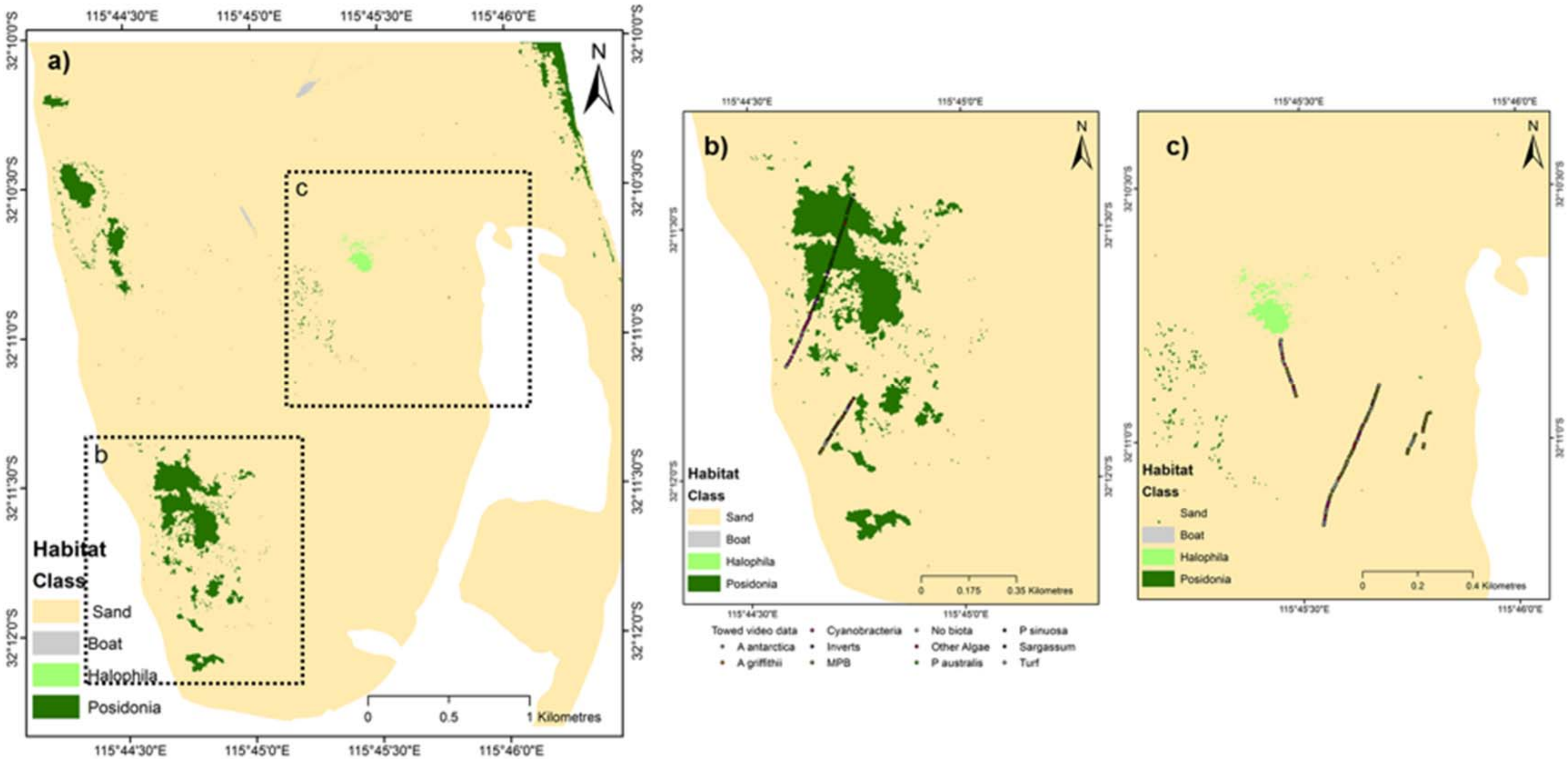
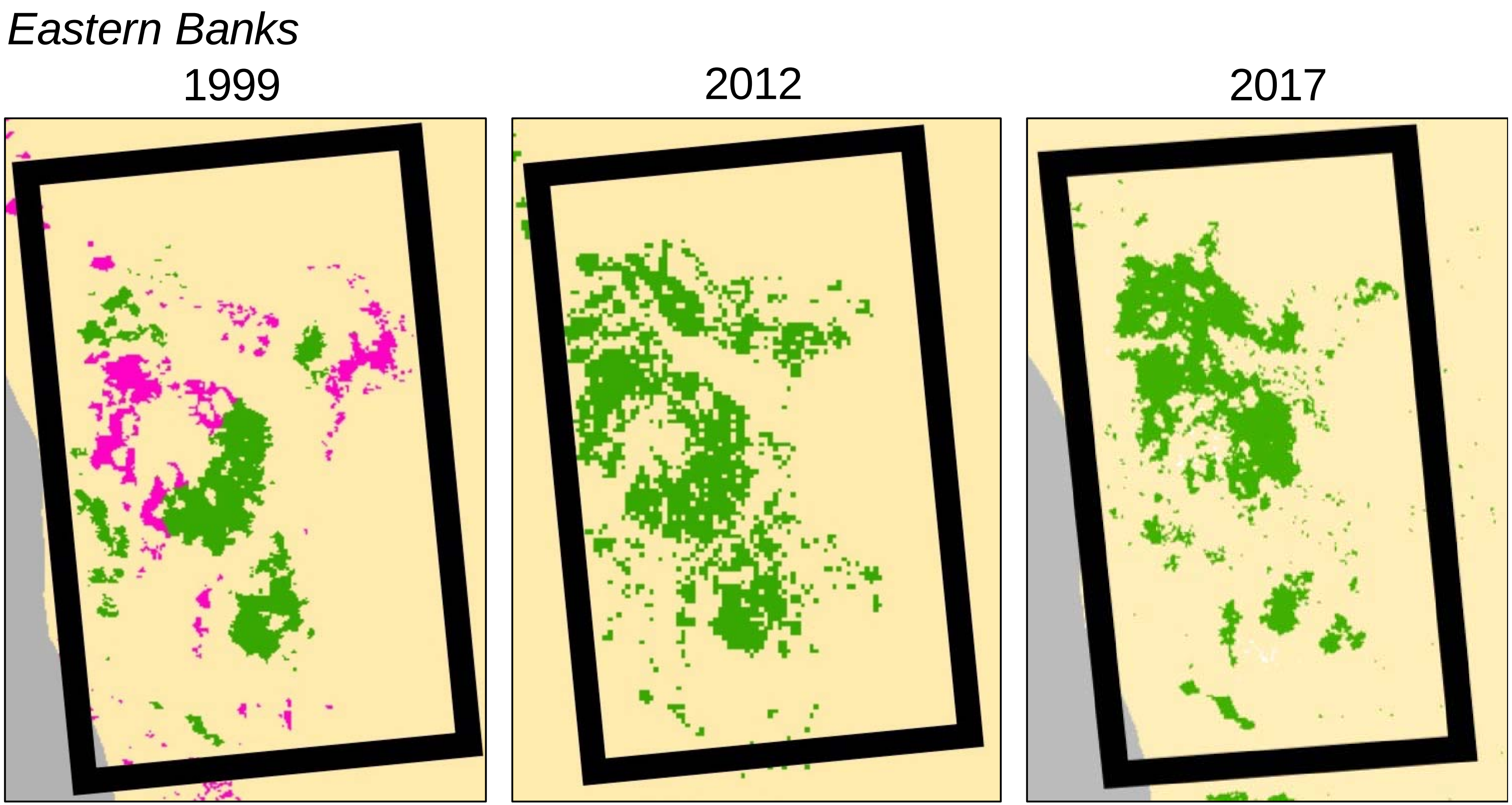


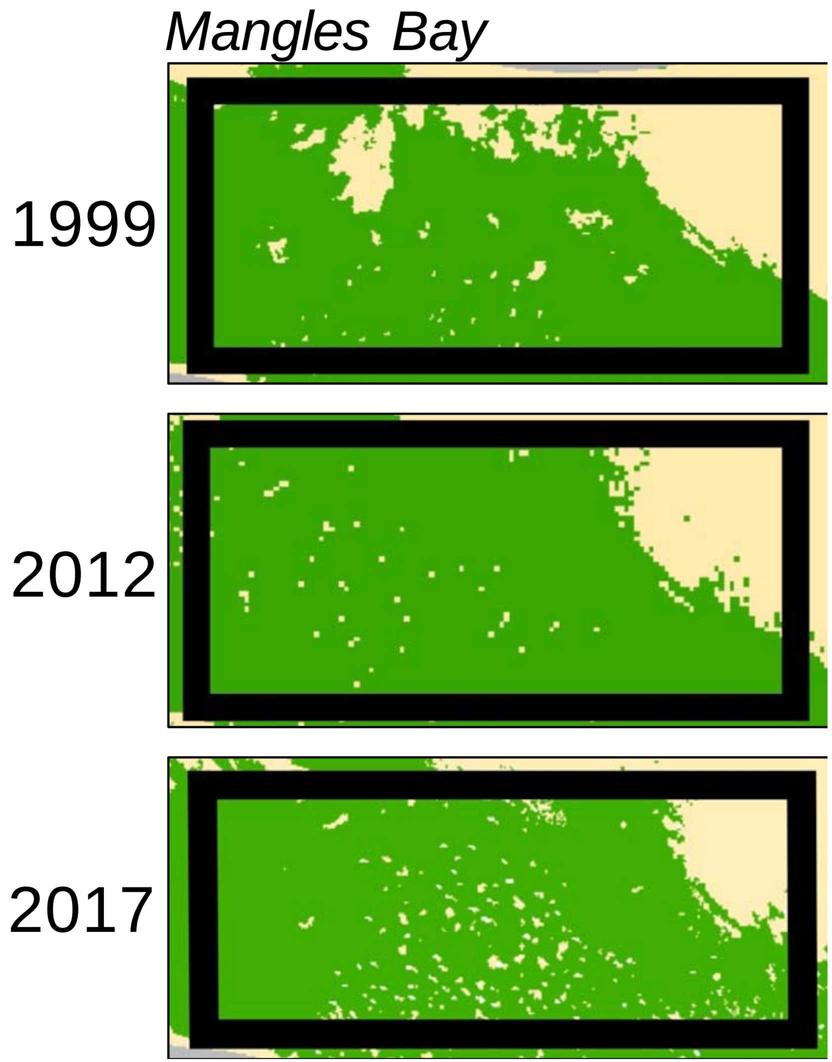
Appendix 1 Example imagery collected from towed video. a) soft sediments; b) reef/broken reef; c) *Posidonia sinuosa*; d) *Posidonia australis;* e/f) *Amphibolis grifithii;* g) microphytobenthos; h) *Sargassum sp.*



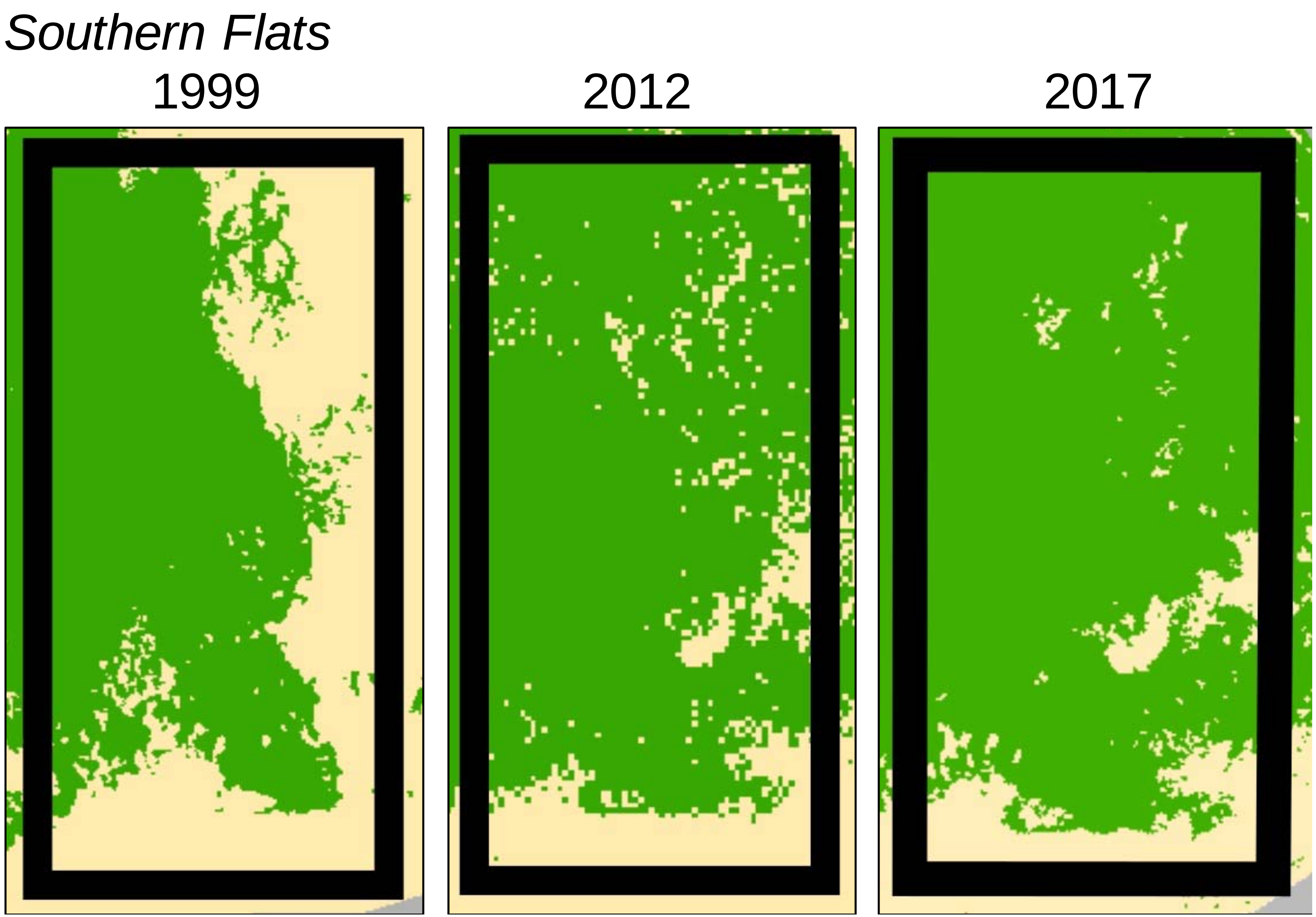
Appendix 2 a) Close up imagery of Dredge Spoil ground, with areas of predicted *Halophila ovalis* cover based on previous *H ovalis* cover recorded in Kendrick et al. (2002) and Hovey et al. (2013). b) and c) show areas of specific interest, along with tracks used for towed video sampling. c) shows area predicted to have *H. ovalis* cover, based on previous sampling, slight differences in spectral signatures on imagery, and expert knowledge. No *H. ovalis* was seen in towed video analysis during this project, likely due to time of sampling.



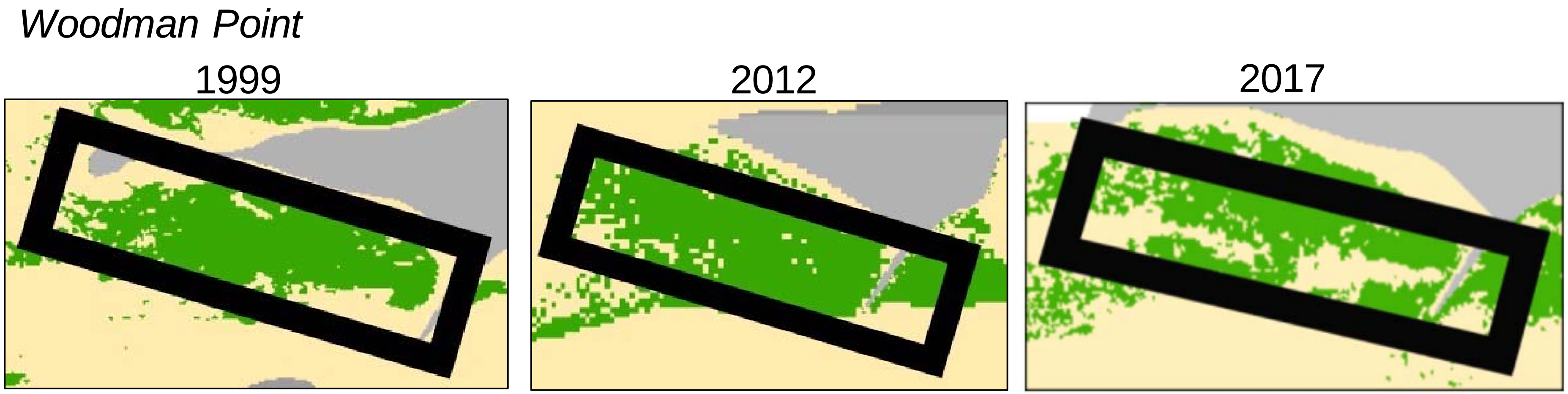
Appendix 3 Close up imagery of distribution of seagrasses in Eastern Banks polygon in 1999 (from Kendrick *et al.*, 2002), 2012 (from Hovey *et al.*, 2013), and in 2017 (this report). Green areas show seagrass, pink areas show reef, yellow areas show sand.



Appendix 4 Close up imagery of distribution of seagrasses in Mangles Bay polygon in 1999 (from Kendrick *et al.*, 2002), 2012 (from Hovey *et al.*, 2013), and in 2017 (this report).



Appendix 5 Close up imagery of distribution of seagrasses in Southern Flats polygon in 1999 (from Kendrick *et al.*, 2002), 2012 (from Hovey *et al.*, 2013), and in 2017 (this report).



Appendix 6 Close up imagery of distribution of seagrasses in Woodman Point polygon in 1999 (from Kendrick *et al.*, 2002), 2012 (from Hovey *et al.*, 2013), and in 2017 (this report).