The use of remote sensing to estimate changes of seagrass extent and biomass in Cockburn Sound, Western Australia

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Abstract. The extent of seagrasses in Cockburn Sound was examined using Nearmap images of year 2010, 2012, 2014, and 2016 to be compared to the last assessment in 1999. It was identified that the seagrass coverage has increased by 231 Ha since 1999, with most of the growth occurred in the southern part. While the water quality in Cockburn Sound has improved, it is believed that there are other pressures affecting the slow growth rate of the seagrasses. Seagrass biomass was also evaluated using Landsat images of year 1994, 1999, 2010, 2012, 2014, and 2016 in addition to a field survey data of leaf biomass in 2016. Despite its increasing extent, seagrass in Cockburn Sound indicated a declining biomass since 1994, which is believed due to the changing nutrient content.

1. Introduction
Seagrass meadows play an essential role in climate change for their high contribution of carbon sequestration and storage. Carbon stocks of seagrass (1-meter depth) ranges between 10 – 829 Mg/Ha, with a mean of approximately 108 Mg/Ha [1]. Meanwhile, another study shows that the global carbon burial rate of seagrass ranges between 48 – 112 Tg C per year [2]. These numbers are comparable to the temperate forest (53 Tg C per year), tropical forest (78.5 Tg C per year), and boreal forest (49.3 Tg C per year) [3]. Besides, the longevity of carbon sequestration in seagrass ecosystems are higher compared to terrestrial soils [3].

Despite their importance, however, seagrass meadows have encountered extensive loss and degradation globally. It is suggested that approximately 30% of global seagrass area has been deteriorated, with an accelerating loss of less than 0.9% per year in the 1970s to more than 7% per year since 2000 [4]. This number is relatively higher compared to the global loss rate of other vegetated coastal areas in the same time frame, e.g. mangroves (1 – 2% per year) and salt marshes (1 – 3% per year).

Cockburn Sound in Western Australia is one of many sites where extensive seagrass loss and degradation has been recorded. Based on a mapping study by Kendrick, there has been a decline of more than 77% seagrass coverage between 1967 and 1999, which happened due to poor water quality [5]. Cockburn Sound has been used for various activities, including industrial, recreational, commercial and cultural heritage use, which resulted in changing water quality [6]. Since then, the industrial and agricultural activities in Cockburn have been restricted to improve the water quality [6]. However, recent field surveys have reported no significant expansion of seagrass meadows despite the improving water quality [7].

As the loss of seagrass meadows can be ecologically and socioeconomically significant, monitoring is essential. There have been several reports about seagrass health and water quality in Cockburn
Sound to date, such as [8] and [9]. However, there has been no recent studies which analyze the whole study area to look at the change in the spatial extent of seagrass habitat.

Remote sensing and Geographic Information Systems (GIS) is one of many methods that can be used to monitor ecological features, including seagrasses. Despite the absence of a consensus on a standard approach, remote sensing and GIS allow the study to be more holistic and cheaper due to the less field survey needed. It also enables the acquisition of long term data which generate highly accurate results, such as the mapping of seagrasses in Moreton Bay between 2004 and 2013 [10].

This study was conducted to evaluate the long-term change in seagrass spatial extent after the last assessment of seagrass coverage in 1999, using the combination of satellite and field data, and relate this to the potential seagrass carbon biomass production and overall carbon storage capacity of Cockburn Sound. Remote sensing and GIS methods were used in this study and the outcome is expected to illustrate the feasibility of concurrent methods in the identification of seagrass feature and the estimation of biomass.

2. Methodology
This study relies on satellite imagery as the main data. Seagrass feature was classified using Nearmap imagery. Nearmap is a high-resolution image of up to 0.075 m resolution with three bands of Red, Green, and Blue available from the year 2007 to present time. In addition to its high resolution, Nearmap imagery was used due to the easily accessible nature of the data. Nearmap images were collected in parts (scenes) to maintain the same resolution of 0.2 m. This study utilized the Nearmap images of year 2010, 2012, 2014, and 2016. The classification of previous years was taken from the results of a study by [5]. Meanwhile, the estimated carbon biomass were derived from Landsat images. In the case of Landsat image, additional image from the year 1994 and 1999 was used because the carbon biomass has not been discussed in the previous study [5]. Similarly, the older years were not assessed due to the unavailable data. The images’ date acquisitions of both Nearmap and Landsat were varied from February to May in the same year depend on the quality and the availability of the images. These months were chosen as the occurrence of seagrass meadows are expected to be at their peak.

Field data of carbon biomass was used as the base of the statistical equation to derive the estimated above ground biomass. The field data was taken from a field survey, where seagrass samples from 12 sites were examined to acquire the shoot density, root biomass, rhizome biomass, leaf biomass, epiphytes, and productivity [7]. This study used the leaf and epiphytes biomass, as appear in table 1, to generate the above ground biomass of the study area. They were chosen as they represent the above ground biomass more than the root and rhizome biomass which are situated mostly below the ground.

| Site               | Leaf biomass (g m$^{-2}$) | Epiphytes biomass (g m$^{-2}$) | Mean (g m$^{-2}$) |
|--------------------|--------------------------|-------------------------------|-------------------|
| GI 2 m             | 241.3                    | 39.4                          | 140.35            |
| GI 3 m             | 88.9                     | 16.6                          | 52.75             |
| GI 5 m             | 188                      | 26.7                          | 107.35            |
| GI 7 m             | 104.7                    | 22.6                          | 63.65             |
| Jervois Bay        | 94.2                     | 37.5                          | 65.85             |
| Kwinana            | 133.9                    | 46.4                          | 90.15             |
| Owen Anchorage     | 162.5                    | 35.0                          | 98.75             |
| Woodman Point      | 154.5                    | 37.2                          | 95.85             |
| WS 2 m             | 58                       | 31.1                          | 44.55             |
| WS 3 m             | 24.7                     | 16.7                          | 20.7              |
| WS 5 m             | 105.8                    | 49.3                          | 77.55             |
| WS 7 m             | 89.9                     | 28.3                          | 59.1              |
2.1. Seagrass classification
Even though eight species (including A. antarctica, A. griffithii, P. australis, P. coriacea, P. sinuosa, H. ovalis, H. tasmanica and S. isoetifolium) could be identified in Cockburn Sound, it is difficult to differentiate each species in this study due to the necessity of examining the rhizome and structure of the seagrasses. Therefore, this study only classified the images into seagrass and non-seagrass class.

The identification of seagrass feature in this study was made using supervised classification method. The Fisher and MAXLIKE classifier in TerrSet software were utilized with the help of training sites consisting of seagrass and non-seagrass classes which were created manually. Fisher classifier was developed from a linear discriminant analysis similar to multivariate linear regression, where the equations maximize the variance between classes and minimize the variance within classes [11]. Meanwhile, the MAXLIKE classifier is based on the Bayesian probability theory, where it uses the mean and variance/covariance data of the signature to estimate the posterior probability that a pixel belongs to each class [11]. The maps of seagrass meadows each year would be presented as a result.

2.2. Biomass calculation
In this study, the carbon is represented by the above ground biomass. The approach to determine the seagrass’ above ground biomass was adopted from a study which integrate the reflectance index with the in-situ biomass data [12].

The blue band, green band and red band of the Landsat images were used in this study. They would later be compared to find the best result with the closest resemblance to the in-situ data. The reflectance index of each band was extracted with reference to the sample sites and combined with the field data of above ground biomass. Software R was then used to calculate the linear regression, resulting in the equation of each band. Each equation was then applied accordingly to the images in ArcGIS to acquire the biomass in the study area. The maps of biomass would be presented as a result.

2.3. Accuracy analysis
In order to verify the results of seagrass classification, the images from Google Earth were used in place of the ground-truth survey due to time and budget constraints. Based on another study, Google Earth can derive land cover information with high accuracy [13], thus using the information to verify the results might be acceptable. 100 random points were created and converted into kmz format using ArcGIS software. The random points were imported to Google Earth to be used as the observation points. Seagrass feature was examined by its presence or absence in both the Nearmap classification and Google Earth each year. The results were exported again to ArcGIS. Percent accuracy was calculated by comparing the number of seagrass and non-seagrass classification in the results of Nearmap (predicted) and Google Earth (observed) with the help of two-way tables. Also, Kappa analysis was used to measure the difference between the observed and predicted maps, following the formula below. Where $K$ is Kappa coefficient; Observed is the total number of correct observed sample; Expected is the total number of correct expected sample.

$$K = \frac{Observed - expected}{1 - expected}$$

The means difference between the results of biomass estimation and the in-situ biomass was also assessed using the pair-t-test in R software.

3. Results and Discussion

3.1. Results

3.1.1. Seagrass extent
Overall, the results show that the seagrass meadows in Cockburn Sound have been increasing from 688 Ha in 1994 to 918 Ha in 2016. The most significant increase occurred in the southern part, where
more than 30% new seagrass area was formed (figure 1). Although not as significant as the southern part, the western and eastern part had dynamic changes, where it decreased until 1999, increased in 2014 and decreased again in 2016 (table 2, figure 1).

In 2010 and 2012, only the southern part data was available. The results show that there was only 1% growth appeared between the two years. However, compared to the year 1999, there was a 15% increased of seagrass coverage in the southern part.

![Figure 1. Map of seagrass extent in year 1994 (a), 1999 (b), 2010 (c), 2012 (d), 2014 (e), and 2016 (f) in Cockburn Sound.](image)

| Year | Area of Seagrass (Ha) | Percentage of seagrass area |
|------|-----------------------|-----------------------------|
|      | West | East | South | Total   | West | East | South |
| 1994*| 374.32 | 25.74 | 288.21 | 688.27 | 29.97 | 0.80 | 51.21 |
| 1999*| 381.96 | 13.43 | 291.57 | 686.97 | 30.58 | 0.42 | 51.81 |
| 2010 | No data | No data | 376.79 | 376.79 | No data | No data | 66.96 |
| 2012 | No data | No data | 378.12 | 378.12 | No data | No data | 67.19 |
| 2014 | 421.41 | 42.05 | 395.35 | 858.81 | 33.74 | 1.31 | 70.26 |
| 2016 | 394.14 | 24.05 | 500.39 | 918.59 | 31.56 | 0.75 | 88.92 |

*Kendrick, et al (2002)*

A total of 858.8 Ha seagrasses was formed in 2014, with the most occurrence of 421 Ha in the western part, followed by the southern part with 395 Ha and the eastern part with 42 Ha. Compared to
the previous year assessed (the year 2012), there was an increase of approximately 3% in the southern part. Meanwhile, compared to the year 1999, there was a 0.7% increase of seagrass meadows in the eastern part, as well as a 3% increase in the western part.

In the year 2016, seagrasses occupied a total of 918.6 Ha of sandbanks in Cockburn Sound, which is the greatest amount compare to the other years. In 2016, the southern part area had the most coverage of seagrass with 88.92% coverage. Meanwhile, the eastern part had the least coverage of only 0.7%. Between 2014 and 2016, seagrass cover increased by approximately 60 Ha. The most significant growth can be seen in the southern part, where it rose almost 19%, from previously 70% coverage in the year 2014 to 88.9% in the year 2016.

The accuracy assessment derived a 93% accuracy for correctly classifying seagrass cover. Meanwhile, Kappa coefficient of 0.4 obtained from the calculation of the results shows a fair agreement between the observed and expected classification.

3.1.2. Above ground biomass
The estimated biomass was obtained from the calculation using reflectance value of the image and the in-situ biomass. The reflectance value ranges from 0 to 1. The reflectance value of the sample sites was collected and used to calculate linear regression. The linear regression of blue, green, and red band resulted in three equations with different coefficients, as appears in table 3. The equation was then applied to the entire image with reflectance value. Based on the results, the blue band has the least gap of maximum and minimum estimated biomass, which is represented by the p-value. Also, the blue band has better water penetration ability, which could result in a better representation of seagrass biomass. Therefore, the equation derived from the blue band was chosen for the other years, despite the fact that it has the highest RMSE that may result in a significant difference between the estimated and in-situ biomass.

| Band | R    | RMSE  | P-value | Intercept | Coefficient | Equations                |
|------|------|-------|---------|-----------|-------------|---------------------------|
| Blue | -0.099 | 61.97 | 0.94    | 114.44    | 232.41      | 114.44 + 232.41 BRI       |
| Green| -0.047 | 60.48 | 0.49    | 93.17     | 1460.29     | 93.17 + 1460.29 BRI       |
| Red  | 0.015 | 58.67 | 0.31    | 28.21     | 6328.47     | 28.21 + 6328.47 BRI       |

The results indicate a fluctuated carbon biomass between 1994 and 2016 (figure 2). Most of the highest biomass can be found in the Western and Eastern regions of Cockburn Sound. Meanwhile, the southern part in most years has the lowest biomass. The mean has decreased from 150 g/m² in the year 1994 to 145 g/m² in 1999 (table 4). However, the maximum biomass increased from 182 g/m² to 219 g/m², while the minimum value decreased from 145 g/m² to 140 g/m². The mean of biomass decreased in the year 2010, as well as the maximum and minimum value. It then increased again in 2012, where the mean was 154 g/m², the maximum value was 175 g/m², and the minimum value was 140 g/m². In 2014, the mean and minimum value decreased again, while the maximum value increased. Finally, all of them reduced and in the lowest state in 2016. The highest biomass identified was 219.3 g/m² in the year 1999, while the lowest was 118 g/m² in the year 2016. Meanwhile, the highest mean was identified in 2012, with 154.39 g/m². However, it has to be noted that the data available for seagrass classification in 2012 as well as 2010 was only covering the southern part. Therefore, it may not well-represent the whole study area.

The accuracy of the results was obtained from the comparison between the estimated and in-situ biomass presented in figure 3. Only year 2016 was assessed due to the data availability. The comparison shows a significant difference between the estimated and in-situ biomass. While the in-situ biomass ranges from below 100 g/m² to more than 200 g/m², the estimated biomass only has a range of 118 g/m² to 167 g/m².

The paired t-test shows that the mean of difference between the estimated and in-situ biomass are -32.81. With 95% confidence, the interval of the two is -61.12 to -4.49. Referring to the first step of the
calculation, these numbers are related to the RMSE of the linear regression. While most of the estimated biomass have a difference of less than 32.81 g/m² with the in-situ biomass, some of them also have up to 62 g/m² difference.

The linear distribution of in-situ and estimated biomass shows a negative relationship. It is supported by the results of Pearson’s correlation test between the two that show a correlation of -0.166 with a p-value of 0.72 and 95% confidence interval of -0.81 to 0.67.

Figure 2. Map of biomass of year 1994 (a), 1999 (b), 2010 (c), 2012 (d), 2014 (e), and 2016 (f) in Cockburn Sound.

Table 4. Detail results of above ground biomass calculation

| Year | Carbon biomass (g m⁻²) |
|------|------------------------|
|      | Mean | Maximum | Minimum |
| 1994 | 150.53 | 182.40 | 145.13 |
| 1999 | 145.12 | 219.30 | 140.42 |
| 2010 | 142.68 | 158.61 | 138.98 |
| 2012 | 154.39 | 175.09 | 140.04 |
| 2014 | 128.25 | 187.07 | 128.96 |
3.2. Discussion

This study has identified a general trend of increasing seagrass coverage from 1994 to 2016 in Cockburn Sound, which was found mostly in the southern part. The fact that most of the industries are located in the eastern part indicates the growth rate of seagrasses can be influenced by the distance from the pollution sources. It is implied by the results that show the least significant increase of seagrass meadows in the eastern part, where the sources are concentrated, compared to the southern and western part. This result is relevant to a study which suggests that the close distance between aquaculture ponds and the shore in NE Hainan has reduced the light penetration and affected the seagrass’ health [14]. It is also supported by another study that identified the contribution of *P. oceanica* in the evaluation of metal contaminations in Italy, where the rate of contamination was lower in the area further from the sources [15]. Based on previous assessments, the loss of seagrasses in the Southern Cockburn Sound was majorly due to the altered sediments impacted by the construction of causeways [16]. Thus the completion of the construction might be the main key in slowing down and even regenerate new seagrasses. On the other side, the seagrass meadows in the Western and Eastern Cockburn Sound have been depleted more because of the urchin overgrazing, shallower water, and nutrient enrichment [16], which would need more active management to improve the condition.

Aside from maintaining the water quality, several attempts of restorations, which have been concluded not practical, were expected to encourage seagrasses regeneration. A replantation was conducted in 2000, resulting in a survival of 40% plant units and confirmed that the Eastern and Western Cockburn Sound were the most suitable sites for rehabilitation using plug transplantation technique as the most efficient method [17]. Other transplant trials were conducted between 2004 and 2008 in the southern part of Cockburn Sound, which suggested a successful restoration, where a healthy meadow have grown and filled the gaps [18]. While it is possible for the successful replantation to keep expanding to date, which may explain the high growth rate in the southern part was beyond the influence of water quality, there has been no monitoring site in the southern part. Hence, no data recorded of the water quality which can provide a more detailed explanation of the reasons why the southern part has faster growth in comparison with the eastern and western part. However, similar to the previous restoration projects, the replantation was conducted on a small scale due to the expensive cost, intensive labor, and the possibility of severe impacts to the donor sites [18]. Furthermore, the re-colonization of *P. sinuosa* as the dominant species in Cockburn Sound is slow, due to the needs of modifications of C, N, and P content which may not fulfil the demand even one year after the transplantation [19]. While it has been more than 10 years since the replantation in the eastern and western part, the results of this study reflect an insignificant growth in the two areas. Thus, even though the replantation might have helped the Southern Cockburn Sound, it is not likely to be conducted on a large scale in the eastern and western part where the loss occupied a larger area due to
the inefficiency. Further assessment is necessary to indicate the reasons why the restoration might have worked more efficiently in the southern part and to identify the factors which interfere with the growth rate in the eastern and western part.

Meanwhile, the long-term assessment of seagrass’ above ground biomass shows a decreasing pattern between 1994 and 2016, which may be associated with the declining density shoot. As mentioned previously, the density shoot in Cockburn Sound has decreased despite the increasing extent of seagrass meadows estimated in this study. A spatial expansion of seagrass meadows does not necessarily lead to a higher seagrass biomass, as biomass is a reflection of the investment of its resources [20]. Thus it is possible to get contradicting results of the seagrass extent and biomass. On the other hand, it is suggested that the carbon accumulation rates are higher in the older meadows [21]. The restored seagrasses had almost the same rate of carbon accumulation as the naturally growing seagrasses [21]. Accordingly, the formation of new seagrasses with lower biomass in Cockburn Sound might have affected the average biomass.

The changes of nutrient in Cockburn Sound might also affect the decreasing biomass. Contrary to the conventional paradigm regarding the excessive nutrient’s detriment to the health of seagrass meadows, some studies, such as a reported positive correlation between seagrass biomass and nutrient availability [22]. The water movement was suggested to affect the seagrass biomass of tropical area in supplying the nutrients [20], which was in line with the findings for the temperate seagrasses. Similarly, seagrasses in Cockburn Sound also occupy a sheltered environment which preserves the meadows from the effect of storms [9]. The swell waves mainly come from the south - southwest in the summer and from the west – southwest in the winter [9]. While the water movement in Cockburn Sound is considerably low, occasional climatic events such as storm may influence the nutrient distribution, leading to a changing biomass despite the improving water quality.

This study also suggests the feasibility of using satellite data to properly assess the extent and the above ground biomass of seagrasses. While it has a high resolution with a relatively low cost compared to the other high-resolution images, Nearmap is rarely used to classify environmental features. It might be because it consists of only three bands (RGB), whereas many studies require more bands to identify particular features especially marine organisms like seagrasses. Therefore, this study could potentially be the first one using Nearmap image to determine the extent of seagrass meadows. However, the accuracy is still uncertain, given this study did not undertake a ground-truth survey. Although an accuracy percentage has been calculated with reference to expert annotation and Google Earth and resulted in an accuracy of more than 90%, field surveys are still necessary to obtain a more robust accuracy because the random points used in the assessment could appear in a stable area with not many changes. Thus they do not represent the accuracy of the more dynamics area. On the other side, Landsat images have been used in many studies to quantify the biomass of seagrasses which generate high accuracy results concurrent to the field verifications. While most of those studies assessed the seagrass biomass of recent years, it is difficult to conduct a long-term assessment like this study due to the limited in-situ data from the past. Thus, the results would be hard to be verified.

While remote sensing is an efficient method to assess an extensive area, the availability of the high-quality images also plays a major role in the results. The assessment of a particular event which may differ during a certain time of the year has to pay more attention to the date acquisition. The data, however, is not always proper for use on the preferred date. Hence, the results may not depict the condition very well. A thorough understanding of the mapping approaches is necessary to obtain a robust mapping result of inter-annual variation in seagrass distribution, as well as the impacts of episodic disturbance events [23].

4. Conclusion
This study has suggested the feasibility of using remote sensing in assessing seagrass extent. While the accuracy analysis showed the results have a high accuracy, field survey is still necessary. Nonetheless, the implications of this study are relevant for rehabilitation of seagrasses in Cockburn Sound. The seagrass extent has been expanding from the year 2010 to 2016, especially in the southern part,
although still far from the initial state. Therefore, more focus should be given to the western and eastern part with the least significant growth, in addition to observing the potential factors that have supported the growth in the southern part. While water quality has been the focus of most restoration projects, its relation with the increasing seagrass extent is still uncertain. Additionally, given the low growth rate amidst the improved water quality, the pressures of seagrass’ growth in Cockburn Sound remains unclear. Therefore, focusing on a more physical feature observation and restoration, such as transplantation, may be more effective despite it being inefficient. The absence of sample sites in the southern part has also made it difficult to compare the different growth rate spatially. Thus, adding a monitoring site in the southern part would enable the evaluation of the pressures in a diverse growing state.

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