Abstract: Coastal ecosystems, including saltmarsh, provide important ecosystem services, including blue carbon storage, nutrient cycling, and coastal protection. The loss or degradation of saltmarsh ecosystems may undermine their capacity to provide these services and drive carbon emission increases. The accurate mapping and monitoring of the aboveground carbon content in these ecosystems supports protection and rehabilitation activities. Previous studies have used medium resolution satellites (e.g., Landsat and Sentinel-2) to characterise saltmarsh communities; however, these platforms are not well suited to the fine-scale patchiness of the saltmarsh ecosystems found in Australia. Here we explore the potential of a very high spatial resolution (0.15 m), seven-band multispectral ArborCam airborne sensor and 3 m images captured by the PlanetScope satellite constellation for mapping and monitoring the aboveground carbon content of a saltmarsh ecosystem in Jervis Bay National Park, Australia. The Normalized Difference Vegetation Index (NDVI) derived from an ArborCam image was calibrated to aboveground carbon content using field survey data. Strong linear relationships between the ArborCam NDVI and aboveground carbon content were found when survey data were partitioned by species. The mean aboveground carbon content derived from the calibrated ArborCam image was 1.32 Mg C ha$^{-1}$ across the study area; however, this is likely to have been underestimated. A monthly NDVI time series derived from 12 PlanetScope images was analysed to investigate the short-term temporal variation in saltmarsh phenology, and significant intra-annual variation was found. An exploration of potential drivers for the variation found that local rainfall was a potential driver. The combination of the very high spatial resolution airborne ArborCam image and the regular 3 m capture by PlanetScope satellites was found to have potential for accurate mapping and monitoring of aboveground carbon in saltmarsh communities. Future work will focus on improving aboveground carbon estimates by including a very high spatial resolution species distribution map and investigating the influence of temporal variations in saltmarsh spectral response on these estimates.

Keywords: aboveground carbon content; saltmarsh; ArborCam; PlanetScope; Jervis Bay NSW
coastal and marine ‘blue carbon’ stores that provide a key climate regulating service. Large declines in the global extent of coastal ecosystems have occurred, principally due to land conversion for coastal development [5–7] and, in some cases, due to changes in climate factors (e.g., air temperature and precipitation) [8]. The impacts of future climate change on the extent and functioning of coastal ecosystems is an active area of investigation. For example, there is evidence that sea-level rise may drive increases in coastal carbon storage, possibly mitigating potential climate feedback effects [9,10], and increasing annual maximum temperatures may drive a landward shift and encroachment of mangroves into saltmarsh communities in Australia [11]. The accurate mapping and monitoring of coastal ecosystems, such as coastal saltmarsh, and their associated aboveground carbon content will aid in their protection and rehabilitation, which can be supported through adaptive coastal governance policies [2] and carbon accounting mechanisms such as REDD+ [12,13].

Australian coastal saltmarsh ecosystems are intertidal plant communities that occupy the high tidal zone, often behind mangroves in areas sheltered from wave energy, such as estuaries [14]. These saltmarsh ecosystems are often characterized by short, patchy vegetation that often displays species zonation along salinity, elevation and inundation frequency gradients and presents in predominantly monospecific patches [15]. The total saltmarsh area in Australia is estimated to be 13,825 km² [16], and it is listed as vulnerable under the national Environment Protection and Biodiversity Conservation Act 1999. In the Australian state of New South Wales (NSW), the total saltmarsh area is estimated at 72 km² [17], and saltmarsh communities are listed as an Endangered Ecological Community under the state Threatened Species Conservation Act 1995. Both federal and state legislatures reinforce the need for the comprehensive monitoring and management of these important saltmarsh communities.

Remote sensing has been used for decades as an effective tool for the environmental monitoring of large, vegetated areas due to reduced costs and the reduced need for extensive field-based sampling [18–20]. The applications of remote sensing to map and monitor saltmarsh vegetation have included the use of Landsat satellites to examine temporal trends [20–22] and the use of high spatial resolution airborne sensors and uncrewed aerial vehicles (UAVs) for mapping the saltmarsh vegetation structure [23–25]. In particular, multispectral remote sensing technology enables the quantification of aboveground biomass through the use of calibrated vegetation indices, such as the widely used Normalized Difference Vegetation Index (NDVI) [26,27].

Coastal ecosystems, including saltmarsh, have several characteristics that make them challenging to monitor remotely, including a high variation in vegetation cover across fine spatial scales due to steep salinity and inundation gradients [28] and high dynamicity over short time scales due to tidal influences [29]. Together these characteristics necessitate very high spatial resolution and fine-temporal scale monitoring approaches; however, there is often a trade-off between the spatial and temporal domains with remote sensing technologies [30]. Existing multispectral sensors onboard earth observation satellites such as Landsat-8 and Sentinel-2 have systematic, relatively short revisit intervals (16 and 5 days, respectively); however, they are limited by a relatively coarse spatial resolution (30 m and 10 m, respectively) that reduces their capacity to detect the fine spatial vegetation patterns typical of saltmarsh communities in NSW.

Airborne sensors and UAVs generally can achieve the much finer spatial resolution necessary to detect saltmarsh biomass changes (<3 m). The airborne ArborCam multispectral sensor captures seven adjustable narrow spectral bands across the visible to the near-infrared region with a spatial resolution as fine as 0.01 m, dependent on the altitude of the aircraft. In addition to the increased spatial resolution, crewed aircraft platforms are more scalable than many UAVs and enable the scheduling of acquisition and flight planning for optimal illumination and environmental conditions in saltmarsh environments (e.g., tide levels). However, fine-scale temporal observations of saltmarsh seasonal dynamics incur increased costs and human resource requirements associated with repeat airborne acquisitions [24,27].
New-generation CubeSat technologies may create new opportunities for the monitoring of the seasonal dynamics of saltmarsh ecosystems and the associated aboveground carbon content. CubeSats are miniature, lightweight satellites built to standard dimensions that can be customized with purpose-built sensors at relatively low cost. PlanetScope, an earth observation CubeSat sensor developed by Planet Labs Inc. (San Francisco, CA, USA), captures four-band visible to near-infrared images at a 3 m spatial resolution, and the PlanetScope constellation of 180+ CubeSats aims to image the entire earth daily [31]. These attributes are particularly advantageous for monitoring spatiotemporally dynamic landscapes such as saltmarsh at relatively fine scales and may allow for issues related to coastal ecosystem mapping and monitoring to be addressed in ways that were not previously possible.

The aim of this study was to evaluate the feasibility of ArborCam and the PlanetScope CubeSat constellation for the mapping and monitoring of the aboveground carbon content in saltmarsh landscapes at fine spatial and temporal scales. Our specific objectives were (1) to assess ArborCam for mapping fine-scale variations in the aboveground carbon potential of saltmarsh communities; and (2) to assess the PlanetScope constellation for analysing the intra-annual variation of the saltmarsh phenological response. Our study focused on a saltmarsh community located in Jervis Bay National Park, NSW, Australia. The outcomes of this research provide support for the use of ArborCam and PlanetScope to routinely map and monitor the aboveground carbon content in coastal saltmarsh ecosystems.

2. Materials and Methods

2.1. Site Description

Jervis Bay National Park is in the Australian state of New South Wales, 150 km east of Australia’s capital city, Canberra (Figure 1a). Jervis Bay National Park encompasses an area of 63 km² and includes a range of forest and coastal ecosystems [32]. The saltmarsh ecosystem studied here is located along the upper reaches of Cararma Inlet (Figure 1b), a small tidal creek that runs inland from the sheltered northern side of Jervis Bay and is situated between mangroves and Casuarina forest. The saltmarsh plain has no publicly accessible entryways and is relatively undisturbed. The saltmarsh vegetation is typically less than 1 m in height and grows in a mosaic of mostly monospecific patches. Common saltmarsh species found at the study site include: Sarcocornia quinqueflora, Samolus repens, Juncus kraussii, Sporobolus virginicus and Wilsonia backhousei, which is listed as a vulnerable species in NSW under the Biodiversity Conservation Act 2016 [33,34].

2.2. Field Sampling and Calculation of Aboveground Carbon Content

Field surveys of saltmarsh species presence and abundance were made on the 1st and 2nd December 2020 with permission from the NSW National Parks and Wildlife Service. Transects were chosen at the middle and upper tidal limit of Cararma Inlet (Figure 1c). Quadrats of 1 m² were placed at 25 m intervals along five transects. A total of 47 samples were collected. At each sample site, the sides of the quadrat were aligned north-south using a handheld compass. The location of the corner of each quadrat was recorded using a Trimble R10 real-time kinematic GPS system with <8 mm horizontal accuracy (Figure 2). The quadrat was divided into 10 × 10 cm squares; species presence and the number of squares with >50% vegetation cover were recorded. Quadrats were photographed from the four cardinal compass directions using a tripod-mounted Nikon D5300 digital SLR camera (24.1 MP) for later species identification and reference.
Figure 1. (a) Jervis Bay National Park is located 150 km east of Canberra; (b) The areal extent of the saltmarsh study located along the upper reaches of Cararma Inlet; (c) The 1 m² vegetation quadrats overlayed on the ArborCam true colour orthoimage.

Figure 2. A Trimble R10 real-time kinematic GPS (left) was used to measure the precise location of each quadrat. Each 1 m² quadrat was divided into 10 cm² sections and photographed to aid in species identification e.g., (right) patchy Sarcocornia quinqueflora.

The aboveground carbon content for each quadrat was calculated by multiplying the percentage of vegetation cover by the species-specific aboveground biomass and the
percentage of carbon content for the dominant species in the quadrat, using values from a published destructive sampling study carried out in Jervis Bay (Table 1) [35]. The published biomass and carbon content values for *Wilsonia backhousei*, a protected species, were not found in the literature; therefore, values for *Samolus repens*, another creeping herb species, were used as a proxy.

Table 1. Published values for aboveground biomass and carbon content for saltmarsh species in Jervis Bay [35].

| Saltmarsh Species          | Aboveground Biomass (Mg ha\(^{-1}\)) | Carbon Content (% C) |
|---------------------------|--------------------------------------|----------------------|
| *Sarcocornia quinqueflora* | 6.88                                 | 34.4                 |
| *Samolus repens*          | 5.51                                 | 42.5                 |
| *Sporobolus virginicus*   | 10.12                                | 38.0                 |
| *Juncus kraussii*         | 15.97                                | 42.9                 |

\(^1\) Used as a proxy in this study for *Wilsonia backhousei*.

The RTK GPS coordinates for the four corners of each quadrat were transferred into ArcGIS Pro in a .csv file format, where they were transformed into individual quadrat polygons and attributed with their calculated aboveground carbon content. The quadrat polygons were uploaded to Google Earth Engine (GEE) [36].

2.3. Acquisition of Remote Sensing Data

A very high spatial resolution (0.15 m) multispectral image of the study area was acquired on 15th October 2020 at low tide (0.4 m) by ArborCarbon using the airborne ArborCam sensor. The seven adjustable band placements of the ArborCam sensor were configured for vegetation measurement. The bands capture reflected solar irradiance in the red, green, blue, red-edge and near-infrared (NIR) regions of the electromagnetic spectrum (Table 2). ArborCarbon provided the image orthorectified (0.15 m RMSE) and calibrated to surface reflectance. ArborCarbon also provided a proprietary vegetation height product derived from the image.

Table 2. Band numbers, names, and regions of the ArborCam sensor and PlanetScope sensors [31].

| Number | ArborCam Bands | PlanetScope Bands |
|--------|----------------|-------------------|
|        | Name           | Centre (nm)       | Number | Name | Range (nm) |
| 1      | Blue           | 450               | 1      | Blue | 455–515    |
| 2      | Green-1        | 530               | 2      | Green| 500–590    |
| 3      | Green-2        | 570               |        |      |            |
| 4      | Red-1          | 655               | 3      | Red  | 590–670    |
| 5      | Red-2          | 680               |        |      |            |
| 6      | Red-edge       | 720               |        |      |            |
| 7      | NIR            | 780               | 4      | NIR  | 780–860    |

The PlanetScope sensor images at 3 m spatial resolution and has 4 bands that capture reflected solar irradiance in the red, green, blue and NIR regions of the electromagnetic spectrum [31]. The spatial resolution is coarser than the ArborCam sensor, and there are fewer bands, particularly in relation to red and red-edge wavelengths (Table 2). Twelve orthorectified (<10 m RMSE) PlanetScope surface reflectance images were selected; they were acquired at approximately monthly intervals from April 2020 to March 2021. The images were selected based on the absence of cloud cover and coincidence with low tides (Table 3) as tidal flooding of saltmarsh areas will significantly impact vegetation reflectance, resulting in a reduction in the NDVI [37].
Table 3. Monthly PlanetScope images used in this study with tide level (m) at time of acquisition.

| Acquisition (UTC) | Local Time         | PlanetScope Image ID                | Tide (m) |
|-------------------|--------------------|-------------------------------------|----------|
| 17 April 2020 23:40 | 18 April 2020 09:40 | 20200417_234006_101f               | 0.6      |
| 18 May 2020 23:39  | 19 May 2020 09:39   | 20200518_233928_1032               | 0.7      |
| 15 June 2020 23:00 | 16 June 2020 09:00  | 20200615_230004_0f46               | 0.7      |
| 13 July 2020 00:10 | 13 July 2020 10:10  | 20200713_001012_26_1064            | 0.7      |
| 25 August 2020 23:38 | 26 August 2020 09:38 | 20200825_233805_1009              | 0.6      |
| 27 September 2020 | 27 September 2020   | 20200927_001210_14_1061            | 0.7      |
| 00:12             | 10:12              | 20201022_223957_0f2a               | 0.8      |
| 22 October 2020 22:39 | 23 October 2020 09:39 | 20201125_234809_79_105c          | 0.8      |
| 25 November 2020  | 26 November 2020    | 20201125_234809_79_105c            | 0.8      |
| 23:48             | 10:48              | 20201224_001518_69_105d            | 0.7      |
| 24 December 2020 00:15 | 24 December 2020 11:15 | 20210121_000350_37_2416        | 0.8      |
| 21 January 2021 00:03 | 21 January 2021 11:03 | 20210220_001743_67_105d         | 0.7      |
| 20 February 2021 00:17 | 20 February 2021 11:17 | 20210324_001859_67_105e          | 0.6      |

The ArborCam image and 12 PlanetScope images were uploaded to GEE for analysis as described below.

2.4. Calculating the Normalized Difference Vegetation Index

The NDVI [26] is a widely used remote sensing index that exploits the characteristic contrast in reflectance between the red and NIR wavelengths by vegetation. The NDVI has been used to estimate the biophysical properties of vegetation, such as biomass or photosynthetic activity [38]; however, the NDVI can be impacted by sun-sensor geometry [39] and variations in soil background, particularly in low biomass environments [40]. The NDVI is calculated as the ratio between the difference and the sum of the NIR and red bands in an image (Equation (1)):

\[
\text{NDVI} = \frac{(\text{NIR} - \text{red})}{(\text{NIR} + \text{red})}
\]  

(1)

The NDVI was calculated from the ArborCam image using band 4 (Red-1) and band 7 (NIR). The NDVI was calculated for all 12 PlanetScope images using the red band 3 and NIR band 4. We used the ArborCam NDVI to explore the relationship with the aboveground carbon content derived for the quadrats. We used the PlanetScope NDVI to analyse the saltmarsh seasonal response (both described below).

2.5. Investigating the Relationship between ArborCam Normalized Band Differences and Aboveground Carbon Content

We undertook an initial exploratory analysis to understand the relationship between the aboveground carbon content for each quadrat and the ArborCam NDVI. The NDVI is sensitive to vegetation biomass [38], and because we calculated the aboveground carbon for each quadrat from established, species-specific fractions of vegetation biomass (Table 1), we therefore expected the NDVI to be positively correlated with aboveground carbon content. The mean ArborCam NDVI was calculated for each quadrat location using all pixels falling within or overlapping a quadrat polygon, with partial pixels given a fractional weighting. Pearson’s correlation coefficient (r) was used to explore the covariance between the mean ArborCam NDVI values and the aboveground carbon content for all quadrats. Our initial exploration found that quadrats dominated by a rush species, *Juncus kraussii*, were relatively high in aboveground carbon content but were correspondingly low in NDVI compared to other quadrats, resulting in a relatively poor correlation between the aboveground carbon content and NDVI \((r = 0.51, p < 0.01)\). Quadrats were therefore partitioned into two groups: the 6 outlier quadrats dominated by *J. kraussii*, and the remaining 41 quadrats representing all other saltmarsh species (herbs, grasses, and sedges).
Additional bands are available in the ArborCam image, particularly in the red-edge region, that may provide suitable normalized-difference (ND) band combinations in place of the red and NIR bands typically used in the NDVI. The ND between a pair of ArborCam bands was calculated as:

\[ ND = \frac{B2 - B1}{B2 + B1} \]  

An ND image was calculated from every possible band pair combination (21 in total), with B2 set as the longer wavelength band of the pair. The herbs, grasses, and sedges quadrat polygons were used to extract mean ND values from an ND image. Pearson’s correlation coefficient was then calculated between the mean ND values and the aboveground carbon content determined for each of the herbs, grasses, and sedges quadrat locations. This correlation analysis was repeated with each of the 21 ND images. The same correlation analysis between the aboveground carbon content derived for the six *J. kraussii* quadrats and each of the 21 ND images was also performed.

### 2.6. Mapping Aboveground Carbon Content in Saltmarsh Using ArborCam

Based on the ArborCam normalized band difference analysis, and given that most quadrats did not have *J. kraussii* present (suggesting that it is not dominant across the study site), simple linear regression between the normalized difference of ArborCam bands 4 and 7 (i.e., the standard NDVI) and the aboveground carbon content for the herbs, grasses, and sedges quadrats was used to calibrate the ArborCam image to aboveground carbon content. Non-saltmarsh areas were masked out from the final aboveground carbon content map using the height stratified vegetation cover data supplied by ArborCarbon. This allowed for a qualitative analysis of the fine-scale, spatial variation in the aboveground carbon across the study area.

Due to limited access to the field site due to COVID-19-related travel restrictions, further field sampling could not be carried out to validate the map of aboveground carbon. Therefore, leave-one-out cross-validation (LOOCV) was used to validate the linear regression model to predict aboveground carbon using the NDVI. Using the LOOCV method, one quadrat is removed at a time, and the remaining dataset is used to create a model to predict the value of the excluded quadrat. This process is repeated for each quadrat, and the mean absolute error (MAE) and root mean square error (RMSE) were calculated between the observed and predicted values from all model iterations [41].

The aboveground carbon map was also used to calculate an estimate of mean aboveground carbon content. The aboveground carbon content map was resampled to 1 m, and the mean aboveground carbon content was calculated as the sum of pixel values within the study areas divided by the saltmarsh area.

We also modelled the relationships between the ArborCam NDVI and the aboveground carbon for all 47 quadrats, and between the NDVI and the six outlier (*J. kraussii*) quadrats to understand the impact that the inclusion of the outlier quadrats would have had on the goodness-of-fit of the model used to map aboveground carbon.

### 2.7. Assessing PlanetScope NDVI for Capturing Saltmarsh Spectral Response

The NDVI derived from the PlanetScope image acquired on 23 October 2020, a week after the acquisition of the ArborCam image, was used to test the ability of PlanetScope to capture the saltmarsh spectral response with a coarser 3 m pixel scale (Figure 3). The aboveground carbon content map (described in Section 2.6) was resampled to 3 m spatial resolution. Pearson’s correlation (r) coefficient and simple linear regression analysis were used to compare the mapped aboveground carbon content pixels with the corresponding PlanetScope NDVI pixels extracted at each of the 47 quadrat locations. If these values were well correlated, then the 3 m NDVI images derived from PlanetScope could be considered reliable proxies for temporal variations in saltmarsh biomass and aboveground carbon content.
2.8. Analysis of Temporal Variation in Saltmarsh NDVI Using PlanetScope

To investigate the potential seasonal phenological response of saltmarsh, the mean NDVI values for all 47 quadrat locations were extracted from the 12 monthly PlanetScope images (April 2020 to March 2021). The significance of the mean NDVI variation between months was analysed using a one-way repeated measures ANOVA that detects differences between multiple related means [42]. For the herbs, grasses, and sedges quadrats, the monthly NDVI means met the assumption of sphericity using Mauchly’s test [43], and no correction factor was applied. For the J. kraussii quadrats, the monthly NDVI means violated the assumption of sphericity, and a Greenhouse–Geisser correction factor was applied [44].

Any observed seasonal variation in saltmarsh NDVI may be due to actual vegetation response or may potentially be caused by a confounding factor unrelated to the changing biophysical properties of the saltmarsh vegetation, such as variations in soil moisture or tidal water levels [45,46] or variations in sun/sensor geometry at the PlanetScope image acquisition times [47]. The seasonal variations in NDVI were compared to the monthly rainfall prior to and during the study period. Monthly rainfall data were acquired from the Australian Bureau of Meteorology [48]. Due to small gaps in the available data, mean monthly rainfalls from the three weather stations closest to the study area were used: Jervis Bay Airfield, Callala Treatment Plant and Point Perpendicular (Stations IDs 068264, 068245 and 068141, respectively). The relationship between the monthly rainfall and NDVI of the 47 sampled quadrats was tested using Pearson’s correlation coefficient. The tide level, sun elevation and view angle of the PlanetScope sensor were also qualitatively evaluated. Tide levels were sourced from a local tide forecast [49], and the sun elevation angle and sensor view angle were extracted from the PlanetScope metadata supplied with each image.

3. Results

3.1. Investigating the Relationship between ArborCam Normalized Band Differences and Aboveground Carbon Content

The relationship between each of the 21 normalized difference (ND) images derived from the ArborCam image and the aboveground carbon content for the herbs, grasses, and sedges quadrats was strongest with bands sensitive in the red, red-edge and NIR regions (Table 4). The correlation between the aboveground carbon content and the ND derived from bands four and six (Red-1 and Red-edge), bands five and six (Red-2 and Red-edge) and bands five and seven (Red-2 and NIR) were equally strong (r = 0.79, p < 0.01).

These same ND band combinations also had strong correlations with the aboveground carbon content derived from the six J. kraussii quadrats (Table 5; r = 0.85–0.89); however,
the strongest correlations were found with ND between bands two and six (Green-1 and Red-edge; \( r = 0.92 \)), bands two and seven (Green-1 and NIR; \( r = 0.95 \)), bands three and six (Green-2 and Red-edge; \( r = 0.96 \)) and bands three and seven (Green-2 and NIR; \( r = 0.96 \)).

Table 4. Correlation \((r)\) between aboveground carbon content of saltmarsh herbs, grasses, and sedges quadrats with each normalized difference (ND) ArborCam image (* \( p < 0.05 \); ** \( p < 0.01 \)).

|          | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 |
|----------|--------|--------|--------|--------|--------|--------|
| Band 2   | −0.19  |        |        |        |        |        |
| Band 3   | −0.23  | −0.27  |        |        |        |        |
| Band 4   | −0.46 **| −0.54 **| −0.57 **|        |        |        |
| Band 5   | −0.46 **| −0.53 **| −0.54 **| −0.10  |        |        |
| Band 6   | 0.38 * | 0.53 **| 0.64 **| 0.79 **| 0.79 **|        |
| Band 7   | 0.54 **| 0.64 **| 0.70 **| 0.79 **| 0.79 **| 0.76 **|

Table 5. Correlation \((r)\) between aboveground carbon content of *J. kraussii* quadrats with each normalized difference (ND) ArborCam image (* \( p < 0.05 \); ** \( p < 0.01 \)).

|          | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 |
|----------|--------|--------|--------|--------|--------|--------|
| Band 2   | −0.27  |        |        |        |        |        |
| Band 3   | −0.19  | −0.11  |        |        |        |        |
| Band 4   | −0.13  | −0.08  | −0.02  |        |        |        |
| Band 5   | 0.05   | 0.17   | 0.25   | 0.83   |        |        |
| Band 6   | 0.87 * | 0.92 **| 0.96 **| 0.89 * | 0.85 * |        |
| Band 7   | 0.94 **| 0.95 **| 0.96 **| 0.89 * | 0.87 * | 0.87 * |

3.2. Mapping Aboveground Carbon Content in Saltmarsh Using ArborCam

The simple linear regression model between the ArborCam NDVI (using bands four and seven) and the aboveground carbon derived from the 41 herbs, grasses, and sedges quadrats provided a better goodness-of-fit \( (R^2 = 0.62) \) than when all 47 quadrats were included \( (R^2 = 0.26; \) Figure 4). The six outlier quadrats dominated by the rush species *J. kraussii* had a relatively high carbon content (>600 g C m\(^{-2}\)) with correspondingly low NDVI values. However, a simple linear regression model using just the six *J. kraussii* quadrats had a very good fit \( (R^2 = 0.79) \).

The LOOCV analysis of the NDVI-calibrated carbon model for the herbs, grasses, and sedges group indicated that there was a relatively large uncertainty for predicted carbon content values \( (\text{MAE} = \pm 49.13 \text{ g C m}^{-2}; \text{RMSE} = \pm 78.16 \text{ g C m}^{-2}) \). The spatial distribution of the aboveground carbon content across the study site (Figure 5) derived from the calibrated ArborCam NDVI image showed that higher predicted carbon content occurred around the edges of the saltmarsh before the transition into *Casuarina* forest. The aboveground carbon content was particularly concentrated at the northernmost part of the saltmarsh, where Carama Inlet reached furthest inland. The estimated mean aboveground carbon content across the 124 ha saltmarsh study area was 1.32 Mg C ha\(^{-1}\).
Figure 4. Simple linear regression model between NDVI derived from the ArborCam image (bands four and seven) with aboveground carbon content for all 47 quadrats, and quadrats partitioned into two groups: herbs, grasses, and sedges (41 quadrats), and *J. kraussii* (6 quadrats).

Figure 5. Spatial distribution of aboveground carbon content in Saltmarsh derived from the ArborCam NDVI image calibrated using the herbs, grasses, and sedges simple linear regression model.
3.3. Assessing PlanetScope NDVI for Capturing Saltmarsh Spectral Response

There was a strong correlation \( r = 0.78; p < 0.001; \) Figure 6 \) between the aboveground carbon content extracted from the resampled 3 m map created using the ArborCam image and the NDVI extracted from the 3 m PlanetScope image captured 8 days later for the 47 quadrat locations. However, the extracted NDVI values were not directly comparable. The dynamic range of the extracted PlanetScope NDVI values (0.37–0.70) was reduced compared to the extracted ArborCam NDVI values (0.10–0.68). The large positive offset (0.401) in the linear model indicates a significant positive bias in the PlanetScope NDVI values compared to the ArborCam NDVI (see also Figure 3).

![Figure 6. Relationship between aboveground carbon content extracted from the resampled 3 m map derived from the ArborCam image and PlanetScope NDVI captured on 23 October 2020 for all 47 quadrat locations \( r = 0.78, p < 0.001 \).](image)

3.4. Analysis of Temporal Variation in Saltmarsh NDVI Using PlanetScope

The NDVI extracted from the 12 monthly PlanetScope images for the herbs, grasses, and sedges quadrats varied significantly between April 2020 and March 2021 based on the repeated measures ANOVA test with sphericity assumed \( (F_{11, 429} = 104.57, p < 0.001) \). Similarly, the NDVI extracted for the J. kraussii quadrats varied significantly across the study period, as indicated from a repeated measures ANOVA with a Greenhouse–Geisser correction \( (F_{2.70, 13.51} = 18.23, p < 0.001) \). For all quadrats, there was a large NDVI peak in May (late autumn) as well as a smaller peak October–November (mid–late spring), followed by steady increases during summer (Figure 7). The NDVI of the herbs, grasses, and sedges quadrats showed comparatively greater temporal variation in NDVI from July to September than the J. kraussii quadrats, where the NDVI remained relatively constant.
Sensor and environmental factors were investigated to determine if there was any single, clear driver of the observed temporal variation of the PlanetScope NDVI. The tide level at the time of image capture had very little variation between monthly images, ranging from 0.6 m to 0.8 m, compared to the maximum tide height of 2 m (Table 3). The sun elevation at the time of image acquisition did vary seasonally, as expected, and was lower in the October 2020 image due to an earlier acquisition time, but it did not qualitatively appear to be directly related to the measured saltmarsh NDVI (Figure 8). Furthermore, the view angle was small (≈5°) in all 12 images.

The monthly rainfall showed a large variation between January 2020 and March 2021 (Figure 9a). There were large peaks in rainfall in February and from July to August 2020, with a smaller peak in May 2020. After September 2020, there were gradual increases in monthly rainfall until March 2021, similar to the annual rainfall trend for the Jervis Bay area. Changes in NDVI appeared to track changes in monthly rainfall, except for the large rainfall peak in July–August. There was no relationship between the monthly rainfall and NDVI when all months were included in the correlation analysis between these two variables (r = 0.04; p = 0.90; Figure 9b). However, when high rainfall data points for July and August were removed, there was a strong correlation between monthly rainfall and NDVI (r = 0.66; p < 0.05).

Figure 7. Temporal variation in mean NDVI extracted at each quadrat location from the 12 PlanetScope images (April 2020 to March 2021). Error bars show ±1 standard error.

Figure 8. Potential drivers of the NDVI variation measured in saltmarsh: sun elevation and view angle at the time each PlanetScope image was acquired.
The monthly rainfall showed a large variation between January 2020 and March 2021 (Figure 9a). There were large peaks in rainfall in February and from July to August 2020, with a smaller peak in May 2020. After September 2020, there were gradual increases in monthly rainfall until March 2021, similar to the annual rainfall trend for the Jervis Bay area. Changes in NDVI appeared to track changes in monthly rainfall, except for the large rainfall peak in July–August. There was no relationship between the monthly rainfall and NDVI when all months were included in the correlation analysis between these two variables ($r = 0.04; p = 0.90$; Figure 9b). However, when high rainfall data points for July and August were removed, there was a strong correlation between monthly rainfall and NDVI ($r = 0.66; p < 0.05$).

**Figure 9.** (a) Local monthly rainfall from January 2020 to March 2021 and mean monthly rainfall from all available years (Bureau of Meteorology, 2021) overlaid with mean PlanetScope NDVI for all saltmarsh quadrats ($n = 47$). (b) Relationships between monthly rainfall (all months, and high rainfall outliers in July and August excluded) and PlanetScope NDVI for all saltmarsh quadrats ($n = 47$) from April 2020 to March 2021.

4. Discussion

The very high spatial resolution map of the aboveground carbon content in saltmarsh derived from the airborne ArborCam image provided important insights into the fine-scale spatial distribution of aboveground carbon. The aboveground carbon content was found to be higher at the boundaries between saltmarsh and *Casuarina* forest and between saltmarsh and mangroves. The importance of these saltmarsh boundaries has been highlighted in previous research into the impacts of climate on blue carbon ecosystems, with a particular focus on the changing boundaries between saltmarsh and the surrounding mangroves [10,11,50,51]. Saltmarsh boundaries remain a key consideration in monitoring and predicting the potential impacts of climate change on blue carbon ecosystems, and our results support the importance of saltmarsh boundaries as particularly crucial areas of relatively high aboveground carbon storage.

Species-specific relationships were found between the ArborCam NDVI and the aboveground carbon content of saltmarsh vegetation, with much stronger correlations when quadrats were partitioned into two species groups (herbs, grasses, and sedges; and rushes). This partitioning corresponds with the species groups adopted in other saltmarsh studies conducted in south-east Australia [24,35]. Quadrats with the dominant rush species,
J. kraussii, had far greater aboveground carbon content than the other species with similar NDVI values. This may be due to its greater height, yellow/brown coloration, or higher proportion of non-photosynthetic components. J. kraussii has been identified by other saltmarsh studies as a dominant saltmarsh species with a high carbon content [35,50,52].

The estimated mean aboveground carbon content of the study area (1.32 Mg C ha⁻¹) was derived using the model based on the ArborCam NDVI extracted for the herbs, grasses, and sedges quadrats only, and it is therefore likely to have been underestimated by excluding the J. kraussii quadrats with a higher aboveground carbon content. More accurately estimating the aboveground carbon content contributed by J. kraussii is important, and the presence of species-specific relationships between NDVI and aboveground carbon content indicates that one model cannot be generalized across all saltmarsh species. A species distribution map is therefore a prerequisite for more accurate maps of the spatial distribution of the aboveground carbon content in saltmarsh vegetation and for estimating the total aboveground carbon content across a saltmarsh ecosystem using the optical remote sensing techniques employed here. Possible areas of tidal inundation of saltmarsh vegetation could also have resulted in an underestimate of the spatial distribution and mean aboveground carbon content. Tidal inundation can significantly impact the reflectance of saltmarsh vegetation, resulting in a decrease in the NDVI [37]; however, the ArborCam image was captured at low tide to reduce the potential confounding effects of tidal inundation on our results.

The relationships between aboveground carbon and all the potential normalized difference band combinations derived from the ArborCam image highlighted potential species- and wavelength-dependent improvements for estimating aboveground carbon. For herbs, grasses, and sedges, a combination of red or red-edge, and red-edge or NIR produced the strongest correlation, while for J. kraussii it was the combination of green or red and red-edge or NIR. Therefore, there is the potential to exploit the greater sensitivity of the ArborCam sensor across the green to NIR range to produce species-specific indices to more accurately model and predict the total aboveground carbon in saltmarsh ecosystems.

Seasonal variations in saltmarsh vegetation have been recorded in many locations globally [27,53], including western Australia [54]. However, Clarke & Jacoby [33], using quarterly biomass harvests across 2 years, concluded that the saltmarsh at Jervis Bay showed no seasonal variation despite finding significant variation within an annual timescale. No other studies have since addressed the possibility of seasonality or intra-annual variations of saltmarsh in south-eastern Australia. Studies on the aboveground carbon content in saltmarsh in south-east Australia have worked under the assumption that seasonal variation does not occur [35]. In contrast, this study provides preliminary, limited evidence that there is a significant seasonal variation in saltmarsh spectral response in Jervis Bay on an intra-annual scale as captured by the PlanetScope constellation. Multiple peaks and troughs in the saltmarsh PlanetScope NDVI were observed over the one-year study period, which did not appear to be related to sensor-derived confounding factors. The possibility of tidal inundation of saltmarsh in the study area may have contributed to the variability in the PlanetScope NDVI [37]; however, the PlanetScope images were captured at similar low tides, and it is therefore unlikely to be a significant contributing factor to the observed seasonality. The NDVI timeseries for the partitioned quadrat groups behaved similarly, indicating that a direct or indirect environmental driver may have been acting on the wider saltmarsh landscape. Therefore, care should be taken when estimating carbon using remote sensing images from a single discrete time, and improved estimates may be achieved by incorporating a temporal analysis of the saltmarsh phenological response to include intra-annual fluctuations.

While the temporal variation in NDVI observed was not characteristic of a seasonal trend, there is a large variation that requires greater understanding for accurate carbon monitoring. In line with existing saltmarsh ecology studies [22,55,56], our results suggest that the observed temporal variation in NDVI may be indirectly driven by local rainfall (which may have affected saltmarsh extent and biomass), although outlier monthly rainfall
in the winter months (July and August) suggests that rainfall is only part of a more complex set of direct or indirect environmental drivers. Given the importance of salinity and inundation gradients for saltmarsh vegetation [28], consideration should be given to other environmental factors, including groundwater level and nutrient fluxes from runoff. There is substantial evidence that longer-term trends in saltmarsh biomass and extent are driven by rainfall [22,50,51,55], including evidence of a rainfall-driven hysteresis effect that drives the change of saltmarsh into mangrove and vice versa [56]. However, the shorter-term dynamics between rainfall and saltmarsh structure, physiology and condition need to be better understood in order to distinguish shorter-term fluctuations from longer-term trends in saltmarsh spectral response and vegetation indices and to understand the potential impact this may have on aboveground carbon estimates using optical remote sensing.

The differences in vegetation reflectance derived from the ArborCam and PlanetScope sensors were indicated by the higher dynamic range of NDVI values extracted from the ArborCam image and the PlanetScope image captured 8 days later, which may be due to differences in the absolute calibration of the images to surface reflectance. For PlanetScope, NDVI values calculated for areas containing mostly bare soil were unexpectedly high (>0.37). However, evidence suggests that for partially vegetated landscapes with dark soil backgrounds (such as those occurring in the study area), the spatial resolution has an important impact on NDVI. Therefore, NDVI at different spatial scales, such as between ArborCam and PlanetScope, may not be directly comparable [57], as was the case here.

Despite the difference in the dynamic range of NDVI values between the sensors, the strong linear relationship between the PlanetScope NDVI and the ArborCam NDVI provides confidence for the use of the PlanetScope constellation to capture seasonal trends in saltmarsh vegetation. The airborne ArborCam sensor was found to be capable of capturing the fine-scale patchiness of saltmarsh. The two sensors in combination have the potential to improve the mapping and monitoring of coastal saltmarsh and blue carbon storage potential.

5. Conclusions

We found a strong and complementary potential for both the ArborCam airborne sensor and the PlanetScope constellation for mapping and estimating the total aboveground carbon content and the intra-annual dynamics of a saltmarsh ecosystem. We found the potential to improve the accuracy of aboveground carbon estimates by developing species-specific calibration models reliant on accurate saltmarsh species distribution maps. Total carbon estimates in saltmarsh must also consider the temporal dynamics of saltmarsh over longer time periods (possibly up to one year) to account for seasonal and intra-annual variations in the spectral response recorded by satellites over saltmarsh ecosystems. Future research will focus on improving our understanding of the drivers of intra-annual variations in the spectral response of saltmarsh vegetation, in particular the roles of rainfall and groundwater, and on better distinguishing short-term fluctuations in vegetation spectral response from longer-term trends. An improved understanding of the spatiotemporal dynamics of saltmarsh ecosystems is critical to achieving more accurate monitoring and estimates of blue carbon using optical remote sensing.

Author Contributions: Conceptualization, E.W.-C. and K.P.D.; methodology, E.W.-C., K.P.D. and E.B.; formal analysis, E.W.-C., K.P.D., P.B. and N.H.; investigation, E.W.-C. and K.P.D.; resources, K.P.D., P.B., N.H. and E.B.; writing—original draft preparation, E.W.-C. and K.P.D.; writing—review and editing, E.W.-C., K.P.D., P.B., N.H. and E.B.; visualization, E.W.-C.; supervision, K.P.D. and E.B.; project administration, K.P.D. and E.B.; funding acquisition, E.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Australian Research Council, grant number IC170100023.

Acknowledgments: We would like to thank the NSW National Parks and Wildlife Service for providing permission to access the field site.
Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results. PB and NH are employees of ArborCarbon.

References

1. Davidson, N.C.; van Dam, A.A.; Finlayson, C.M.; McInnes, R.J. Worth of wetlands: Revised global monetary values of coastal and inland wetland ecosystem services. *Mar. Freshw. Res.* 2019, 70, 1189–1194. [CrossRef]

2. McKinley, E.; Ballinger, R.C.; Beaumont, N.J. Saltmarshes, ecosystem services, and an evolving policy landscape: A case study of Wales, UK. *Mar. Policy* 2018, 91, 1–10. [CrossRef]

3. Mcleod, E.; Chmura, G.L.; Bouillon, S.; Salm, R.; Björk, M.; Duarte, C.M.; Lovelock, C.E.; Schlesinger, W.H.; Silliman, B.R. A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO2. *Front. Ecol. Environ.* 2011, 9, 552–560. [CrossRef]

4. Alongi, D.M. Carbon Balance in Salt Marsh and Mangrove Ecosystems: A Global Synthesis. *J. Mar. Sci. Eng.* 2020, 8, 767. [CrossRef]

5. Li, Y.; Qiu, J.; Li, Z.; Li, Y. Assessment of Blue Carbon Storage Loss in Coastal Wetlands under Rapid Reclamation. *Sustainability* 2018, 10, 2818. [CrossRef]

6. Pendleton, L.; Donato, D.C.; Murray, B.C.; Crooks, S.; Jenkins, W.A.; Sifleet, S.; Craft, C.; Fourquarean, J.W.; Kauffman, J.B.; Marb, N.; et al. Estimating Global “Blue Carbon” Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. *PLoS ONE* 2012, 7, e43542. [CrossRef] [PubMed]

7. Saintilan, N.; Williams, R.J. Short Note: The Decline of Saltmarsh in Southeast Australia: Results of Recent Surveys. *Wetl. Aust.* 2000, 18, 49–54. [CrossRef]

8. Hickey, S.M.; Radford, B.; Callow, J.N.; Phinn, S.R.; Duarte, C.M.; Lovelock, C.E. ENSO Feedback Drives Variations in Dieback at a Marginal Mangrove Site. *Sci. Rep.* 2021, 11, 8130. [CrossRef]

9. Rogers, K.; Kelleway, J.J.; Saintilan, N.; Megonigal, J.P.; Adams, J.B.; Holmquist, J.R.; Lu, M.; Schile-Beers, L.; Zawadzki, A.; Mazumder, D.; et al. Wetland Carbon Storage Controlled by Millennial-Scale Variation in Relative Sea-Level Rise. *Nature* 2019, 567, 91–95. [CrossRef]

10. Kelleway, J.J.; Saintilan, N.; Macreadie, P.I.; Skillbeck, C.G.; Zawadzki, A.; Ralph, P.J. Seventy Years of Continuous Encroachment Substantially Increases ‘Blue Carbon’ Capacity as Mangroves Replace Intertidal Salt Marshes. *Glob. Chang. Biol.* 2016, 22, 1097–1109. [CrossRef]

11. Whitt, A.A.; Coleman, R., Lovelock, C.E.; Gillies, C.; Ierodiaconou, D.; Liyanapathirana, M.; Macreadie, P.I. March of the Mangroves: Drivers of Encroachment into Southern Temperate Saltmarsh. *Estuar. Coast. Shelf Sci.* 2020, 240, 106776. [CrossRef]

12. Ullman, R.; Bilbao-Bastida, V.; Grimsditch, G. Including Blue Carbon in Climate Market Mechanisms. *Ocean Coast. Manag.* 2013, 83, 15–18. [CrossRef]

13. Radabaugh, K.R.; Moyer, R.P.; Chappel, A.R.; Powell, C.E.; Bociu, I.; Clark, B.C.; Smaok, J.M. Coastal Blue Carbon Assessment of Mangroves, Salt Marshes, and Salt Barrens in Tampa Bay, Florida, USA. *Estuaries Coasts* 2018, 41, 1496–1510. [CrossRef]

14. Daly, T. *Coastal Saltmarsh*: Primefact; NSW Department of Primary Industries: Orange, Australia, 2013; p. 16.

15. Laegdsgaard, P. Ecology, Disturbance and Restoration of Coastal Saltmarsh in Australia: A Review. *Remote Sens.* 2022, 14, 1782. [CrossRef]

16. ABARES. *Australia’s State of the Forests Report 2013*; Australian Bureau of Agricultural and Resource Economics and Sciences: Canberra, Australia, 2013.

17. Russell, K. *NSW Northern Rivers Estuary Habitat Mapping—Final Analysis Report*; NSW Department of Primary Industries: Port Stephens, Australia, 2005.

18. Dong, J.; Kaufmann, R.K.; Myneni, R.B.; Tucker, C.J.; Kauppi, P.E.; Liski, J.; Buermann, W.; Alexeyev, V.; Hughes, M.K. Remote Sensing Estimates of Boreal and Temperate Forest Woody Biomass: Carbon Pools, Sources, and Sinks. *Remote Sens. Environ.* 2003, 84, 393–410. [CrossRef]

19. Patenaude, G.; Hill, R.A.; Milne, R.; Gaveau, D.L.A.; Briggs, B.B.J.; Dawson, T.P. Quantifying Forest above Ground Carbon Content Using LiDAR Remote Sensing. *Remote Sens. Environ.* 2004, 93, 368–380. [CrossRef]

20. Navarro, A.; Young, M.; Macreadie, P.I.; Nicholson, E.; Ierodiaconou, D. Mangrove and Saltmarsh Distribution Mapping and Land Cover Change Assessment for South-Eastern Australia from 1991 to 2015. *Remote Sens.* 2021, 13, 1450. [CrossRef]

21. Johnston, R.M.; Barson, M.M. Remote Sensing of Australian Wetlands: An Evaluation of Landsat TM Data for Inventory and Classification. *Mar. Freshw. Res.* 1993, 44, 235–252. [CrossRef]

22. O’Donnell, J.P.R.; Schalles, J.F. Examination of Abiotic Drivers and Their Influence on Spartina Alterniflora Biomass over a Twenty-Eight Year Period Using Landsat 5 TM Satellite Imagery of the Central Georgia Coast. *Remote Sens.* 2016, 8, 477. [CrossRef]

23. Wang, C.; Menenti, M.; Stoll, M.-P.; Belluco, E.; Marani, M. Mapping Mixed Vegetation Communities in Salt Marshes Using Airborne Spectral Data. *Remote Sens. Environ.* 2007, 107, 559–570. [CrossRef]

24. Owers, C.J.; Rogers, K.; Woodroffe, C.D. Identifying Spatial Variability and Complexity in Wetland Vegetation Using an Object-Based Approach. *Int. J. Remote Sens.* 2016, 37, 4296–4316. [CrossRef]

25. Kalacska, M.; Chmura, G.L.; Lucanus, O.; Bérubé, D.; Arroyo-Mora, J.P. Structure from Motion Will Revolutionize Analyses of Tidal Wetland Landscapes. *Remote Sens. Environ.* 2017, 199, 14–24. [CrossRef]
26. Rouse, J.; Haas, R.H.; Schell, J.A.; Deering, D. Monitoring Vegetation Systems in the Great Plains with ERTS. In *Third Earth Resources Technology Satellite Symposium*; Goddard Space Flight Centre: Washington, DC, USA, 1973; pp. 309–317.
27. Doughty, C.L.; Cavanaugh, K.C. Mapping Coastal Wetland Biomass from High Resolution Unmanned Aerial Vehicle (UAV) Imagery. *Remote Sens.* 2019, 11, 540. [CrossRef]
28. Hickey, D.; Bruce, E. Examining Tidal Inundation and Salt Marsh Vegetation Distribution Patterns Using Spatial Analysis (Botany Bay, Australia). *J. Coast. Res.* 2010, 26, 94–102. [CrossRef]
29. Gallant, A.L. The Challenges of Remote Monitoring of Wetlands. *Remote Sens.* 2015, 7, 10938–10950. [CrossRef]
30. Woodcock, C.E.; Strahler, A.H. The Factor of Scale in Remote Sensing. *Remote Sens. Environ.* 1987, 21, 311–332. [CrossRef]
31. Planet Labs Inc. PlanetScope. Available online: https://developers.planet.com/docs/data/planetscope/ (accessed on 10 September 2021).
32. NSW National Parks & Wildlife Service Jervis Bay National Park. Available online: https://www.nationalparks.nsw.gov.au/visit-a-park/parks/jervis-bay-national-park (accessed on 10 September 2021).
33. Clarke, P.J.; Jacoby, C.A. Biomass and Above-Ground Productivity of Salt-Marsh Plants in South-Eastern Australia. *Mar. Freshw. Res.* 1994, 45, 1521–1528. [CrossRef]
34. Clarke, P.J. Mangrove, Saltmarsh and Peripheral Mapping of Jervis Bay. *Cunninghamia* 1993, 3, 231–253.
35. NSW National Parks & Wildlife Service Jervis Bay National Park. Available online: https://a-park/parks/jervis-bay-national-park (accessed on 10 September 2021).
36. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-Scale Geospatial Analysis for Everyone. *Remote Sens. Environ.* 2017, 202, 18–27. [CrossRef]
37. Mauchly, J.W. Significance Test for Sphericity of a Normal N-Variate Distribution. *Ann. Math. Stat.* 1940, 11, 204–209. [CrossRef]
38. Myneni, R.B.; Tucker, C.J.; Asrar, G.; Keeling, C.D. Interannual Variations in Satellite-Sensed Vegetation Index Data from 1981 to 1991. *J. Geophys. Res. Atmos.* 1998, 103, 6145–6160. [CrossRef]
39. Epiphanio, J.C.N.; Huete, A.R. Dependence of NDVI and SAVI on sun/sensor geometry and its effect on fAPAR relationships in Alfalfa. *Remote Sens. Environ.* 1995, 51, 351–360. [CrossRef]
40. Baret, F.; Goutot, G. Potentials and limits of vegetation indices for LAI and APAR assessment. *Remote Sens. Environ.* 1991, 35, 161–173. [CrossRef]
41. Gollob, H.F. Cross-Validation Using Samples of Size One. In Proceedings of the American Psychological Association Meeting, Washington, DC, USA, 1–5 September 1967.
42. Girden, E.R. Cross-Validation Using Samples of Size One. In Proceedings of the American Psychological Association Meeting, Washington, DC, USA, 1–5 September 1967.
43. Greenhouse, S.W.; Geisser, S. On Methods in the Analysis of Profile Data. *Psychometrika* 1959, 24, 95–112. [CrossRef]
44. Greenhouse, S.W.; Geisser, S. On Methods in the Analysis of Profile Data. *Ann. Math. Stat.* 1950, 21, 204–209. [CrossRef]
45. Huete, A.R. A Soil-Adjusted Vegetation Index (SAVI). *Remote Sens. Environ.* 1988, 25, 295–309. [CrossRef]
46. Kearney, M.S.; Stutzer, D.; Turpie, K.; Stevenson, J.C. The Effects of Tidal Inundation on the Reflectance Characteristics of Coastal Marsh Vegetation. *J. Coast. Res.* 2009, 25, 1177–1186. [CrossRef]
47. Morton, D.C.; Nagol, J.; Carabajal, C.C.; Rosette, J.; Palace, M.; Cook, B.D.; Vermote, E.F.; Harding, D.J.; North, P.R.J. Amazon Forests Maintain Consistent Canopy Structure and Greenness during the Dry Season. *Nature* 2014, 506, 221–224. [CrossRef]
48. Australian Bureau of Meteorology. Climate Data Online. Available online: http://www.bom.gov.au/climate/data/index.shtml (accessed on 15 August 2021).
49. Jervis Bay Tide Times, NSW 2540. Available online: https://tides.willyweather.com.au/nsw/illawarra/jervis-bay.html (accessed on 15 August 2021).
50. Morton, D.C.; Nagol, J.; Carabajal, C.C.; Rosette, J.; Palace, M.; Cook, B.D.; Vermote, E.F.; Harding, D.J.; North, P.R.J. Amazon Forests Maintain Consistent Canopy Structure and Greenness during the Dry Season. *Nature* 2014, 506, 221–224. [CrossRef]
51. Eslami-Andargoli, L.; Dale, P.; Sipe, N.; Chaseling, J. Mangrove Expansion and Rainfall Patterns in Moreton Bay, Southeast Queensland, Australia. *Estuar. Coast. Shelf Sci.* 2009, 85, 292–298. [CrossRef]
52. Saintilan, N.; Rogers, K.; Mazumder, D.; Woodroffe, C. Allochthonous and Autochthonous Contributions to Carbon Accumulation and Carbon Store in Southeastern Australian Coastal Wetlands. *Estuar. Coast. Shelf Sci.* 2013, 128, 84–92. [CrossRef]
53. Gao, Z.G.; Zhang, L.Q. Multi-Seasonal Spectral Characteristics Analysis of Coastal Salt Marsh Vegetation in Shanghai, China. *Estuar. Coast. Shelf Sci.* 2006, 69, 217–224. [CrossRef]
54. Congdon, R.A.; McComb, A.J. Productivity and Nutrient Content of *Juncus kraussii* in an Estuarine Marsh in South-Western Australia. *Aust. J. Ecol.* 1980, 5, 221–234. [CrossRef]
55. Duke, N.C.; Field, C.; Mackenzie, J.R.; Meynecke, J.-O.; Wood, A.L. Rainfall and Its Possible Hysteresis Effect on the Proportional Cover of Tropical Tidal-Wetland Mangroves and Saltmarsh–Saltlans. *Mar. Freshw. Res.* 2019, 70, 1047–1055. [CrossRef]
56. Duke, N.C.; Field, C.; Mackenzie, J.R.; Meynecke, J.-O.; Wood, A.L. Rainfall and Its Possible Hysteresis Effect on the Proportional Cover of Tropical Tidal-Wetland Mangroves and Saltmarsh–Saltlans. *Mar. Freshw. Res.* 2019, 70, 1047–1055. [CrossRef]
57. Jiang, Z.; Chen, Y.; Li, J.; Dou, W. The Impact of Spatial Resolution on NDVI over Heterogeneous Surface. In Proceedings of the 2005 IEEE International Geoscience and Remote Sensing Symposium, Seoul, Korea, 29 July 2005; Volume 2, pp. 1310–1313, ISBN 978-0-7803-9050-4.