Coastal carbon opportunities: using drones to measure mangrove above-ground biomass and carbon

SUMMARY REPORT

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1 Background

Coastal vegetated ecosystems such as seagrass beds, mangroves and saltmarshes are extremely efficient at capturing carbon dioxide from the atmosphere and are therefore considered a carbon 'sink' and a useful tool in combatting climate change (Figure 1). Compared to many terrestrial forests, coastal vegetation communities can take up carbon dioxide at faster rates and store it for longer periods (Mcleod et al. 2011). Carbon sequestered into coastal ecosystems is called 'blue carbon' and is predominantly stored below ground in the sediment, with a smaller proportion stored in the above-ground vegetation (referred to as biomass) (Nellemann and Corcoran 2009). Of the three main blue carbon ecosystems (seagrass, saltmarsh and mangrove), mangroves have the greatest **above-ground** biomass and carbon storage capacity, due to their larger, woody growth forms (Alongi 2014). However, the above-ground biomass and carbon pool of mangroves is generally poorly quantified, appears to be highly variable within and between species and also dependent on location (Owers et al. 2018) and there are no data on above-ground mangrove biomass and carbon storage for South Australian mangrove forests. We know that the climate and composition of coastal vegetation communities in South Australia differ from those in other states and countries, therefore it is likely that their productivity, biomass and blue carbon storage capacity are also different.

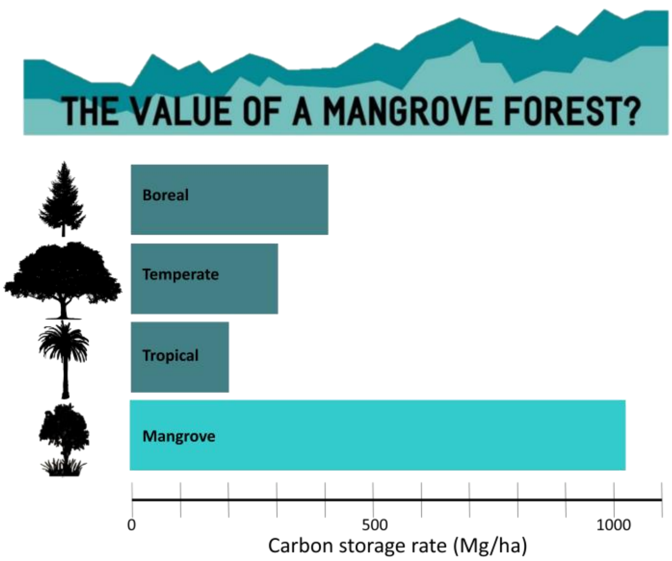

Figure 1. Global averages for carbon storage in four different forest types. Data from Donato et al (2012).

Our project, 'Coastal carbon opportunities' set out to collect and analyse new field data from coastal carbon ecosystems in South Australia (SA), to improve our understanding of the value of the state's coastal environments as carbon sinks. The proof-of-concept case study summarised in this report tested a new methodology for remotely estimating above-ground biomass and carbon stored in mangroves using drones. The outcomes can support development of novel tools for assessing coastal carbon sequestration and emissions abatement opportunities in SA and beyond.

For technical details of the study described in this summary report, please refer to:

Jones AR, Segaran RR, Clarke K, Waycott M, Goh WSH, Gillanders BM (in prep). *Demonstrating the use of drones for estimating mangrove tree biomass and carbon storage.*

1.1 Why do we need a new method for measuring mangrove biomass?

Measurement of mangrove biomass is traditionally done using field-based forestry techniques that involve the collection of physical measurements from trees within designated plots. The measurements collected include tree height, canopy/crown area and trunk diameter (often at the base of the tree and also at breast height, which is 130 cm up the trunk). These values are then used in allometric equations, which are used to estimate biomass based on established relationships between tree structure and overall tree biomass. These allometric equations allow tree biomass to be predicted from field based, non-destructive measurements from trees (Picard et al. 2012). The amount of carbon stored in the above-ground biomass of plants can then be calculated, as this is directly proportional to their biomass. This means that biomass values can simply be converted to estimates of carbon storage using multiplier values that assume a specified proportion of the tree's biomass represents organic carbon. The recommended multiplier values used for mangroves are usually between 0.46 and 0.5 (Kauffman and Donato 2012), with the Intergovernmental Panel on Climate Change (IPCC) recommending a value of 0.45 (IPCC 2014).

Collecting physical measurements from mangroves, can be problematic because it is time and resource demanding, as well as potentially hazardous for field staff (Figure 2). These constraints can lead to poor survey coverage and measurement errors due to limited access to dense mangrove stands. In areas where it is not safe, practical or affordable to collect physical measurements from mangroves, default carbon values (rather than site-based values) may be used to estimate mangrove above-ground carbon stocks (IPCC 2014). However, this introduces a large amount of uncertainty to the biomass and derived carbon estimates, which is penalised in carbon market schemes by lower payments (Gibbs et al. 2007, Howard et al. 2014, Kauffman and Donato 2012).

Figure 2. A field scientist working in a dense mangrove stand in SA (left) and the tightly intermingled canopies and multiple stems of the *Avicennia marina* mangroves in SA (right). Both illustrate the access difficulties in these environments and how this may prevent systematic surveys and the collection of accurate measurements from trees with which to estimate biomass.

1.2 How can drones help?

There is clearly a need for an easy-to-deploy, comparatively cheap method for collecting high-spatial resolution data on mangrove structural characteristics at a local scale, which could support site-level assessment and monitoring of mangrove biomass for carbon accounting and crediting purposes. The use of drones for ecological research and management has grown significantly in the last decade (Anderson and Gaston 2013), including applications for collection of structural measurements from plants, predominantly driven by forestry (e.g. Panagoitidis et al. 2017) and agriculture (Bendig et al. 2015). Drones have the potential to provide a relatively low-cost, low-risk and quick approach to surveying mangrove above-ground biomass when compared with on-the-ground forestry methods (Otero et al. 2018). In addition, they can collect much higher resolution data than most other remote sensing approaches, with the ability to generate cm-resolution, three-dimensional canopy models. This potentially makes them an ideal tool for site-based assessments of mangrove above-ground biomass and carbon stocks.

2 What we did

With support from Lendlease and the South Australian Department of Planning, Transport and Infrastructure, we were provided access to part of the Northern Connector road construction site close to North Arm Creek, where small areas of *Avicennia marina* (which is the only mangrove in South Australia) were permitted to be removed to make way for a road bridge.

When on site, we flew a drone with a mounted camera over ten individually marked trees (Figure 3) within the area to be felled (the selected trees were not on the edge of the canopy, in order to avoid edge effects), The drone collected photos that could be processed to form a 3D model of the tree canopy (using structure-from-motion photogrammetry) (Figure 4). The trees were then cut at ground level and delivered to us at a nearby facility owned by the South Australian Museum, where we took measurements and weights from them, as well as sub-samples for calculating the biomass of each tree (Figure 5).

The datasets we collected allowed us to estimate/measure above-ground biomass in three ways:

1) Modelled biomass based on structural measurements of the trees taken from the drone imagery
2) Estimated biomass using established forest inventory techniques, relying on physical measurements taken directly from the trees
3) Actual biomass measured directly from the felled trees

With the datasets we collected, we were able to compare the accuracy of mangrove biomass estimates from the drone image data with those from the traditional field-based techniques, as well as assessing the accuracy of both approaches by comparing the results to the actual measured biomass of each tree.

Figure 3. Photo of the drone flying over the marked trees

Figure 4. Three-dimensional structural information and derived imagery generated from multiple, overlapping images collected by a drone-mounted camera and processed in Pix4D Mapper Pro software. A) orthomosaic and B) structure from motion point cloud.

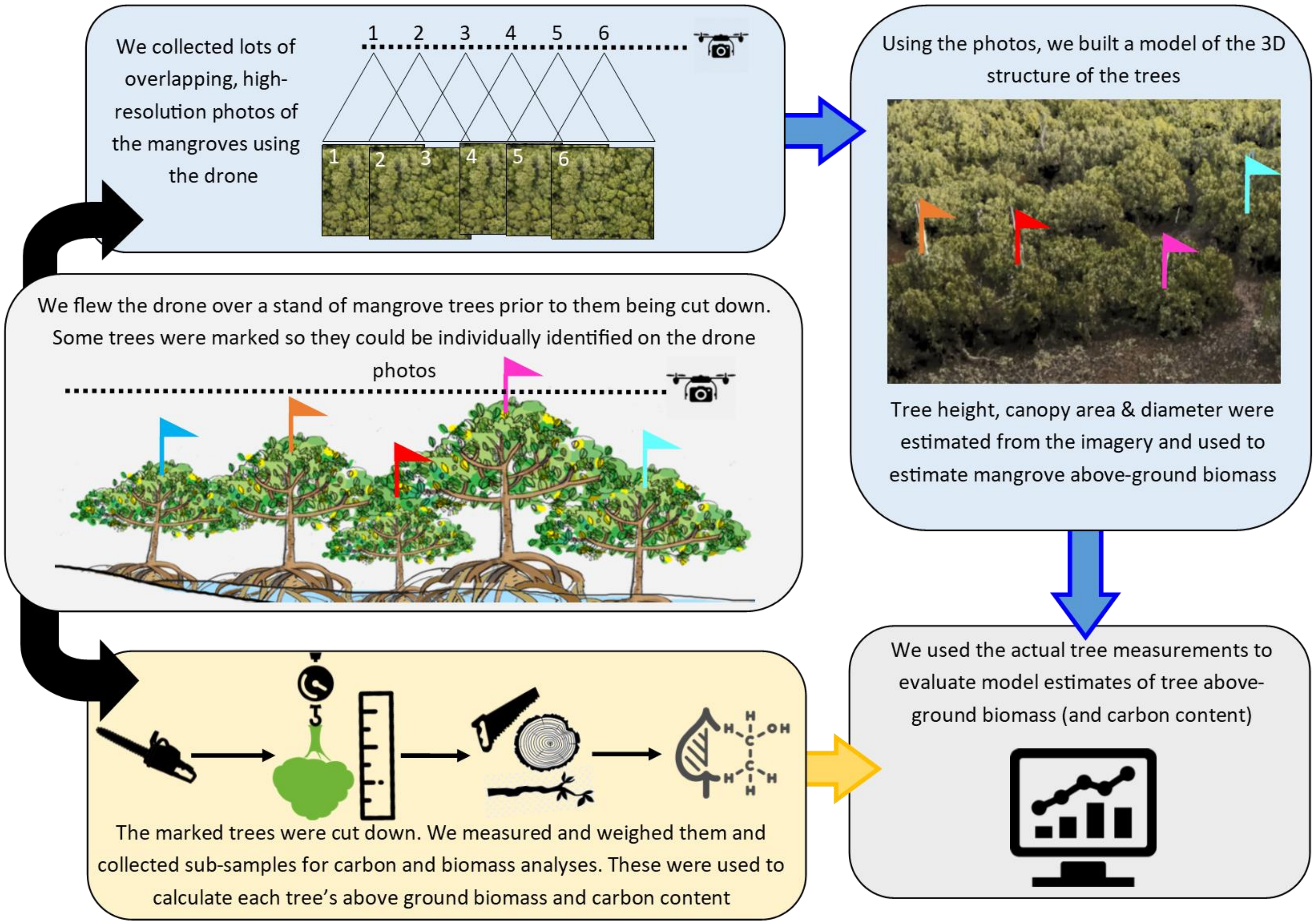

Figure 5. Schematic of the workflow used in our investigation into using drones-derived data to estimate the above-ground biomass of mangrove trees.

3 What we found

3.1 Modelled estimates of above-ground biomass from the drone image-based 3D canopy model

We found that the tree measurements from the drone imagery provided very accurate estimates of tree height, which could in turn be used to estimate the diameter of each tree at 30 cm and 130 cm from the base of the trunk; but with lower accuracy (Figure 6). The canopy size estimates from the drone-based 3D model were not useful for predicting the above-ground biomass of our study trees (we tested this using predictive model, but their prediction error was high). We used the tree structural variables estimated from the imagery to predict above-ground biomass of the trees but found that this approach led to fairly high prediction errors (Figure 7, box 'Drone model') compared to other approaches.

3.2 Estimated biomass using established forest inventory techniques that rely on physical measurements

We tested the accuracy of some previously published allometric equations for *Avicennia marina* (Clough et al. 1997, Comley and McGuinness 2005, Owers et al. 2018), using both measurements taken directly from the trees (height, diameter etc.) and estimates of the same structural variables derived from the drone based imagery. In addition, we built our own (new) allometric equation from data generated in the destructive sampling of trees in this study. We found that our new allometric equation, built using data from South Australian *Avicennia marina* trees, predicted tree biomass most accurately of all the equations tested (all the previously published equations for this species are based on trees from other states and countries). This result was consistent whether we used values of structural variables collected by physically measuring the trees, or we extracted these measurement values from the drone imagery (Figure 7, 'Jones' boxes). This result highlights that spatial variability in *Avicennia marina* growth form and other structural characteristics can affect the successful application of previously published allometric equations (based on trees from other regions/countries) that attempt to relate tree size measurements to their biomass. It is evident that it is important to undertake region-specific sampling and modelling to achieve the most reliable above-ground biomass estimates for mangroves. When undertaking these analyses, we discovered that the key variables for accurate estimation of above-ground biomass of *Avicennia marina* in South Australia were those that described the trunk diameter of the trees (diameter at 30 cm and 130 cm).

3.3 Comparison of above-ground biomass estimates from the drone data and the allometric techniques.

Ultimately, we found that above-ground tree biomass estimation was better (had lower prediction errors) when we used techniques that rely on taking direct measurements of structural characteristics from the trees in the field, as opposed to image based estimates of these characteristics from the drone (Figure 7). However, with further testing and model development, we aim to improve the accuracy of the drone-based method in order to provide robust estimates of mangrove above-ground biomass.

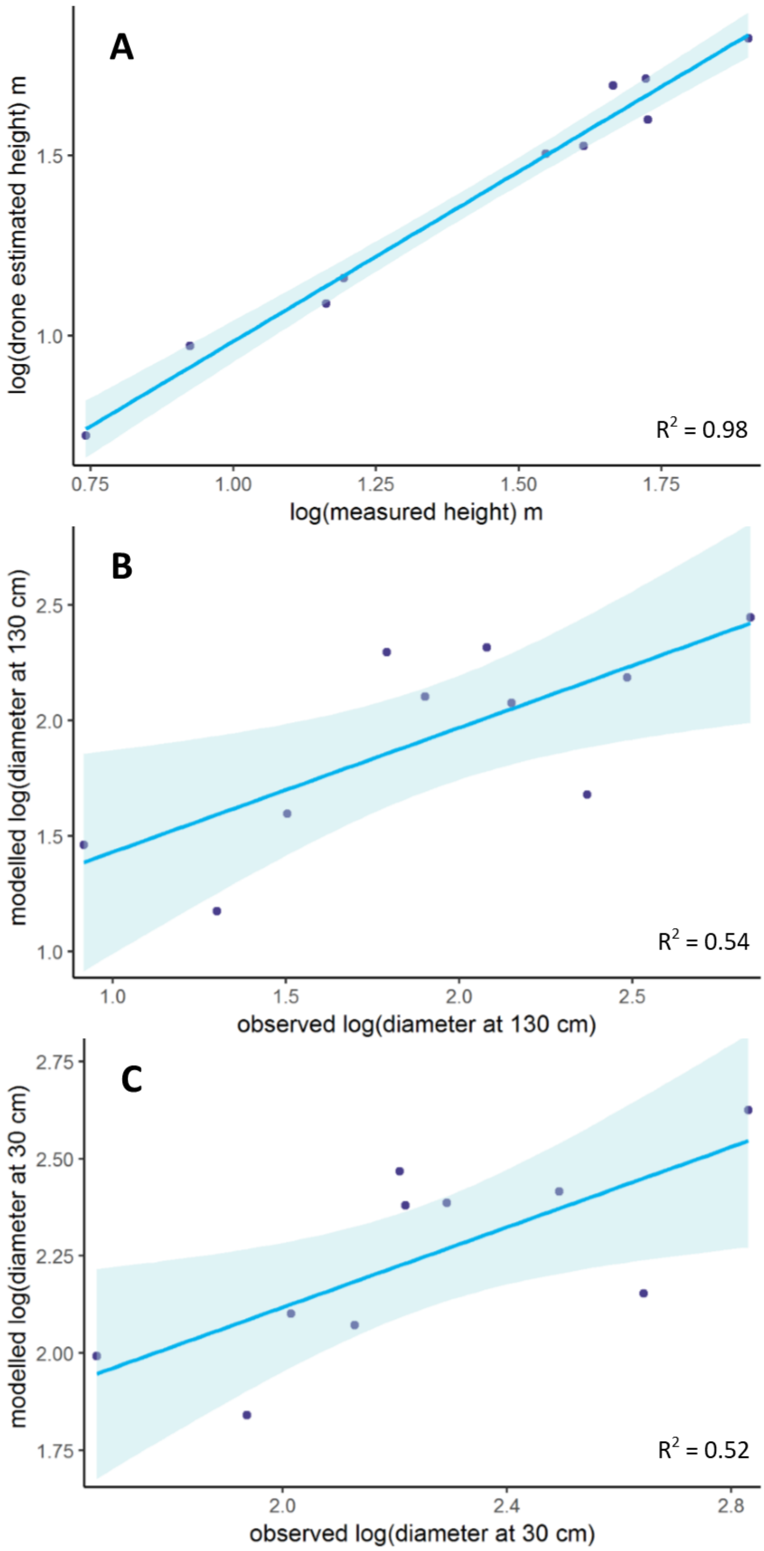

Figure 6. Plots of predicted values for tree structural characteristics from the drone 3D imagery, against the measured values from the felled trees. A) Logged estimates of tree height from the drone 3D canopy model and the logged measurements of tree height taken from the felled trees. Linear model predictions of B) log(diameter at 130 cm) based on drone-estimated tree height plotted against the log of measured diameter at 130 cm; and C) log(diameter at 30 cm) based on drone-estimated tree height and canopy area plotted against the log of measured tree diameter at 30 cm. Shading = 95 % confidence interval.

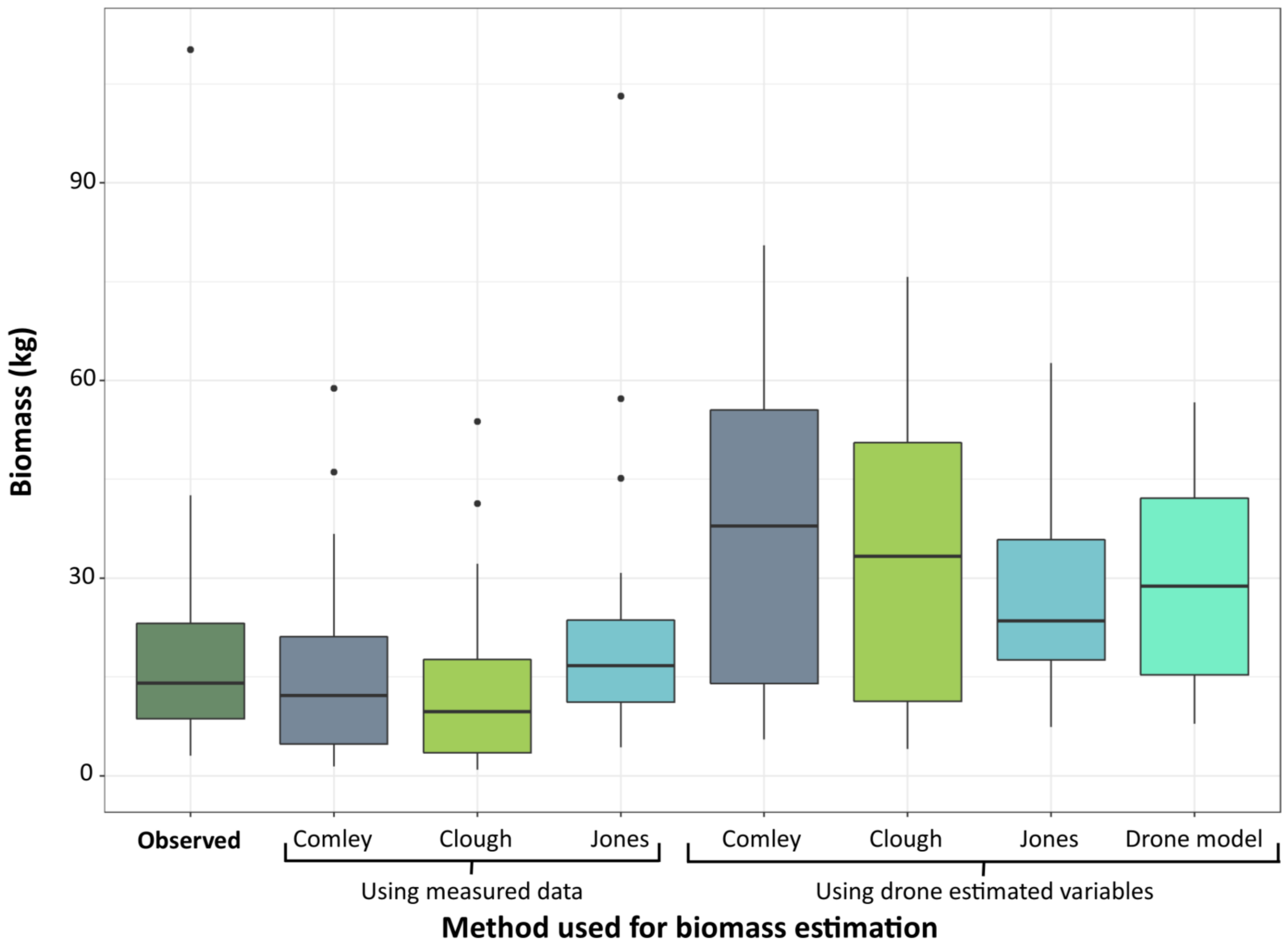

Figure 7. Boxplots showing the predictions of above-ground biomass (kg) based on tree structural characteristics (height, diameter, canopy area) that were either measured by hand (left side) or estimated from the drone imagery (right side). We tested two previously published allometric equations (Clough et al. 1997, Comley and McGuinness 2005, Owers et al. 2018) and a new allometric equation developed as part of this study ('Jones'). We also ran a model of biomass using only the estimates of tree structural variables that could be directly measured from the drone imagery (canopy area and tree height) which is shown on the plot as 'Drone model'. The horizontal dark line on each box shows the median, upper and lower box extents show the first and third quartiles respectively, whiskers extend to 1.5 times the interquartile range and black points indicate outliers. The actual biomass of the trees is shown in the far left box labelled 'observed'.

4 What this all means

Our project, 'Coastal carbon opportunities' aimed to generate data to fill critical knowledge gaps around carbon in coastal ecosystems, including the development of novel methods for measurement that can support the development of South Australian government climate strategies and policies.

This study produced a new allometric equation, which generates improved estimates of above-ground mangrove biomass for South Australian *Avicennia marina* trees compared to other published equations and should be used for future estimation of above-ground biomass in South Australian mangroves. The new allometric equation is given below for reference, where DBH is the measurement value for trunk diameter at breast height (in cm) and D_{30} is the measurement value for trunk diameter at 30 cm (in cm):

$$Biomass\ (Kg) = \exp\ (-2.3902 + 0.4771 * \ln(DBH) + 1.945 * \ln(D30))) * 1.179712$$

We also demonstrated proof-of-concept in that we show there is potential to use imagery collected by a drone to build structural models of mangroves and extract measurements from these models for estimation of above-ground biomass (which can be easily converted to carbon estimates using a multiplier). In particular, we found that the drone-based imagery can provide very accurate estimates of tree height. However, the estimates of tree biomass based on tree measurements extracted from the drone imagery were less accurate and this method is not yet ready for wider implementation. The results from our comparison of approaches for estimating above-ground mangrove biomass (field-based forestry methods vs remote sensing with drones) indicated that drone-estimated variables cannot currently provide the same power as on-the-ground measurements for biomass prediction. However, having identified that the critical predictors of biomass for South Australian mangroves are tree height and trunk diameter, it is now possible to move forwards with refining our ability to predict these from drone-based aerial imagery. Further study will require a greater sample size of individual trees. We also recommend further investigations to look at the potential for using area-based canopy structure (from the drone imagery), validated against on-the-ground surveys, to produce estimates of biomass and carbon storage per unit area, rather than per individual tree.

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