Work Package 2: Technological Innovation for Sustainable Development

Deliverable T2.2.1: Project report

Drone Surveying for Seaweed Resource Assessment: A Practical Guide

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SUSTAINABLE RESILIENT COASTS

Project Partners

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Executive Summary

The ability for innovative technologies, such as drones, to support local authorities and promote sustainable development of coastal regions have gained in popularity but have thus far been underutilised. This report provides a practical guidance on seaweed surveying that will suit the experience and skill levels of most coastal managers and will detail survey methods and results conducted in the case study of Clew Bay, County Mayo, Ireland. The report has been produced as part of the EU-funded Sustainable Resilient Coasts (COAST) project, a collaboration between partners from Iceland, Finland, Ireland, and Northern Ireland focusing on the future challenges and development of coastal areas in Europe's Northern Periphery and Arctic (NPA) region. The project seeks to deliver practical guidance for coastal local authorities to support resilience building and coastal sustainability. This document is therefore intended to enable local authorities with limited experience but a desire to understand and use drone technology for the assessment and survey of coastal resources.

Following on from a review of coastal applications of drone technology (Kandrot and Holloway, 2020; Kandrot *et al.,* 2021) and an overview drone surveying for the protection of natural and built heritage sites (Giannoumis, 2021), this report details the methods and findings of a seaweed assessment case study in Clew Bay. The survey sought to demonstrate the effectiveness of drone-based seaweed mapping, while also assessing how variations in tidal height and drone survey height influence the ability to accurately map the extent of seaweed coverage. To achieve this, three primary sites were chosen to conduct the surveys, ranging from approximately 62,000 m^2 up to 97,000m^2, where a range of flight height and tidal conditions were assessed. One larger survey site, >350,00 m^2, was also included where just the highest elevation flights were used at high and low tide. The overall results suggest that for every additional meter in tidal height, the seaweed coverage that can be mapped by drone is reduced by 18.7%, while every additional 10 m in the drone flight height increases the mapped seaweed coverage by 2.5%. Weather conditions were also found to play a less significant, but still important role in drone-based seaweed surveys.

In addition to the survey results, this report also provides practical guidance on other elements related to survey activity, such as flight planning, software, hardware, processing and analysis approaches. Other survey methods are also briefly described here, ranging from simple visual inspection of drone imagery to more advanced sensors and analysis methods. Some ancillary considerations are also explored, such as General Data Protection Regulations (GDPR), licensing, clearly identifying yourself and the survey area, and interacting with concerned members of the public during survey operations.

Overall, this report highlights two primary recommendations for seaweed surveying by drone:

1. Perform surveys at the lowest tide level possible. This will ensure the maximum seaweed coverage is visible and will decrease the coverage variability compared to higher tide levels.
2. Perform the surveys from a high elevation. This will allow the survey to be performed quickly, minimising within survey tidal variation and with little to no negative impact on the survey accuracy.

Acknowledgements

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Acronyms and Abbreviations

AGP	ArcGIS Pro
A. nodosum	Ascophyllum nodosum
CMOS	Complementary Metal Oxide Semiconductor
COAST	Sustainable Resilient Coasts
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EASA	European Union Aviation Safety Agency
GCP	Ground Control Point
GDPR	General Data Protection Regulations
GeoTIFF	Tagged Image File Format (Geo = containing georeferencing information)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAA	Irish Aviation Authority
ITM	Irish Transverse Mercator
MP2	DJI Mavic Pro 2
NPA	Northern Periphery and Arctic
SD	Standard Deviation
SOP	Standard Operating Procedure
UCC	University College Cork
UAV	Uncrewed Aerial Vehicles
VLOS	Visual Line of Site
WGS	World Geodetic System

1 Introduction

Drone technology, or uncrewed aerial vehicles (UAVs), have potential to promote sustainable development in coastal regions (Kandrot *et al.,* 2021). These innovative technologies are cost-effective and enable the assessment of marine resources that otherwise may be difficult to reach and/or in inaccessible sites while at the same time causing little to no disturbance to the environment. Natural marine resources, such as seaweed, seagrasses, mangroves, etc., provide direct benefits for the coastal communities and their livelihoods as well as indirect benefits for the wellbeing and health of the environment. There is a need to effectively monitor and assess these resources to ensure the longevity and the benefits that marine resources create. This report has developed a cost-effective methodological approach to mapping seaweed coverage using off-the-shelf drone technology and simple, established processing and analysis methods. This approach could also be used with other marine resources, such as those described in Kandrot *et al.,* (2021).

Quantitative, fine-scale information about the extent and volume of seaweed is required for the sustainable management of the resource. However, field measurement is laborious and time consuming. Given the global growth in commercial demand for seaweed from, for example, the biotechnology and pharmaceutical sectors, as well as renewed focus on their ability to store carbon and maintain biodiversity (Kelly *et al.,* 2001; Xiao *et al.,* 2020) work on how to efficiently collect such data is timely.

This document aims to provide local authorities with practical guidance in how to assess seaweed resources using drone technology. Mayo County Council and University College Cork (UCC) collaborated to implement and test the six-step methodology (Figure 1) to use drone surveys to assess seaweed resources (further details on drone survey methods can be found in Tmušić *et al.,* 2020).

- Firstly, the historical and contemporary relationship between Clew Bay, Co. Mayo, Ireland, and its seaweed resources are described – providing a foundation for the study purpose. This leads to a description of the site selection and criteria employed.
- The survey plan is presented next, with details on the flight heights and tidal conditions assessed. This also includes a brief description flight planning software followed by an explanation of the drone model selected for this survey.
- Next, various practical considerations regarding drone licensing and flight planning/preparation are addressed. This includes a pre-flight check list.
- In-flight awareness is next, discussing elements such as pilot visibility and local privacy concerns.
- Following this, the processing and analysis of the drone imagery are described in a step by step fashion.
- Finally, the results are presented and key recommendations are made.

This report was produced as part of the Sustainable Resilient Coasts (COAST) project, a collaboration between the Agricultural University of Iceland, Oulu University of Applied Sciences, Mayo County Council, University College Cork, and the Causeway Coast and Glens Heritage Trust. This collaborative project focuses on the future challenges and sustainable development of coastal areas. Information from this repot will be integrated into our Sustainable Resilient Coasts Toolbox for local authorities, an online resource focusing on SMART Blue Growth.

For more information see: http://coast.interreg-npa.eu/.

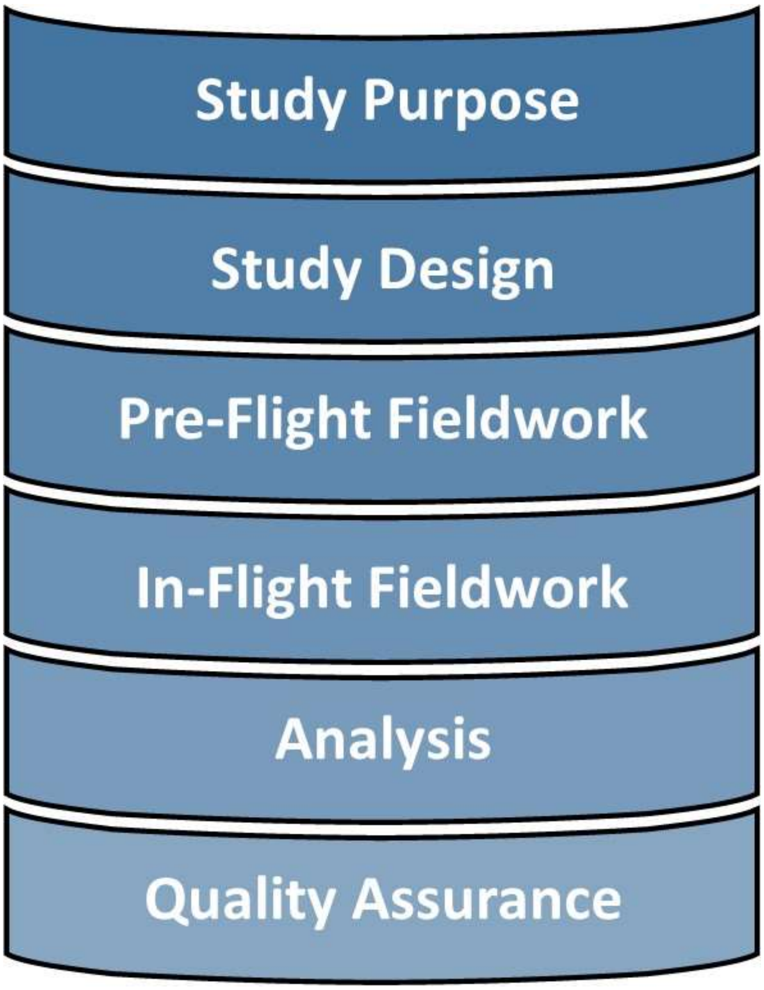


Figure 1: Basic drone study workflow

2 Clew Bay

Clew Bay is situated in Co. Mayo, in the northwest of Ireland (**Error! Reference source not found.**). It c onsists of 141 sunken drumlin islands (Cusack, 2016), formed as sea level rise inundated the region, turning the drumlin hills into a bay full of small islands (Figure 3)**.** Spread over an area of approximately 110 km^2, the region is home to various forms of aquaculture, such as salmon and oyster farming. Seaweed, primarily Ascophyllum nodosum, referred to hereafter as *A. nodosum* (Figure 4), has also been harvested in this region for hundreds of years, and commercially harvested for over 40 years (Fennelly, 2015). Seaweed has been used for dietary purposes for centuries along the west coast, changing to kelp ash for glass production and iodine extraction in the 18th century, to more recent uses as animal feeds, agricultural inputs and cosmetics (Arramara, 2021). Despite this, *A. nodosum* is considered to be underexploited along the west coast of Ireland (Hession, 1998).

A survey carried out by BioAtlantis in 2013 (Guinan *et al.,* 2014), as part of an application to secure exclusive harvesting rights in Clew Bay, noted the potential influence of local hand harvesting methods on maintaining a commercially viable and sustainable stock of *A. nodosum*. The authors noted two distinct harvesting methods at their test sites. The first leaves enough of the plant for regrowth to occur in a sustainable manner (which typically takes three to five years), and the other cuts near the base, close to the holdfast. The latter appears to leave much less than the usual 150-180 mm standard, running the risk of over exploiting, slowing regrowth and allowing for invasive species, such as Fucus spiralis, to increase in coverage (Kelly *et al.,* 2001). This may bring detrimental effects to local biodiversity levels and future harvesting volumes.

With a confluence of anticipated growth in demand for seaweed products worldwide, competing interests and harvesting methods, ensuring sustainable development of the *A. nodosum* resources in Clew Bay is paramount. Demonstrating the utility of drone-based survey methods can be an important step in this process. For example, regular drone surveys producing high resolution seaweed maps may allow for better estimates of local regrowth rates. This can result is improved forecasts of harvesting volume while highlighting regions where regrowth is slower than anticipated, potentially linking back to the influence of harvesting methods and other factors. This makes the region ideally placed for carrying out the case study.

Figure 2: Map showing Clew Bay and the four test sites plus an inset map of Ireland showing Clew Bay study area

Figure 3: Image of Clew Bay taken in June 2021 with the DJI Air 2s

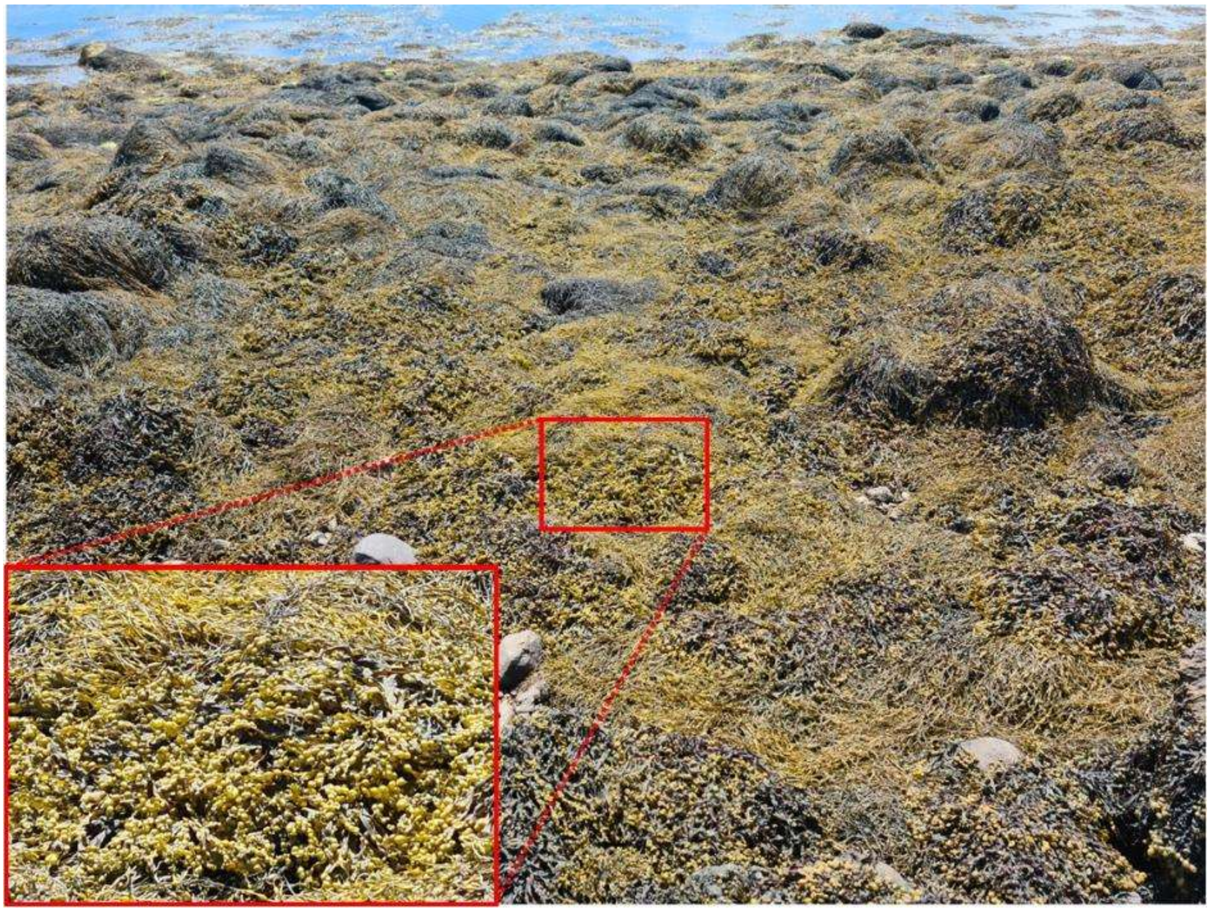


Figure 4: Close up of the Ascophyllum nodosum in Clew Bay

2.1 Study Design

There are numerous ways drones can be used for seaweed surveying, from very simple subjective assessments to surveys using expensive or custom build drones and advanced processing and analysis tools (Kandrot *et al.,* 2021), too many to list here. However, an example of a simple approach is visual analysis of drone photos and videos. As most drones provide a clear live feed from their cameras to the control pad or phone that is controlling them, it may be possible for local seaweed harvesters, with good knowledge of the area, to easily estimate the quality, quantity and ease of access to seaweed visually and in real time. This method would require little or no training or expertise in drone technology, eliminating the need to perform any further processing or analysis. This could also be performed on videos and pictures captured in-flight and viewed afterwards. This approach could still be much more cost effective and efficient than performing surveys from land or by boat.

There are numerous technologies that can be used to improve seaweed detection. For example, cameras that capture light from wavelengths outside of those visible to the human eye, such as Near Infrared, may be able to better detect submerged seaweed, to differentiate between seaweed species (Rossiter et al., 2020) that otherwise look similar in visual imagery and even provide information of the health and maturity of the seaweed (Mahajan et al., 2016). These methods have been used for decades in satellite based remote sensing and have recently become more common in drone based platforms, as both the cost of the sensors have dropped and the quality, power and flight time of the drones have increased. Furthermore, analysis methods using advanced machine learning, deep learning (Bhatnagar et al., 2020) and big data analysis (Lipsett, 2019) are rapidly developing and likely to become increasingly accessible to general users in the coming years. Furthermore, accurately surveyed known and stable objects in the study area using professional grade survey equipment can provide additional improvements to the locational accuracy of the maps and models generated at later processing stages.

This case study will aim to find a middle-ground, by using a combination of an inexpensive off-the-shelf drone to generate a quantitative measure of seaweed coverage while also assessing some of the main influences on the ability to detect and map seaweed (flight and tidal height). This will be achieved using standard software and established methods. This can highlight some of the quantitative potential of drone surveying while also using a workflow that is accessible to non-experts.

2.2 Survey Sites

Several criteria were employed to find the ideal sites. They needed:

1. to have at least some seaweed
2. contain a range of island sizes and numbers
3. to be sparsely populated (as few dwellings as possible)
4. be small enough that the tide changes little during a single survey

While most of the islands of Clew Bay appear to have some seaweed cover, Appendix 2 of the BioAtlantis seaweed harvesting application (Guinan *et al.,* 2014) entitled “Maps of harvesting area” were used to narrow down the test sites. These also showed the islands in detail and so could be used to pick regions with differing coverage of water, land and shoreline length.

While certain drone licenses allow the pilot to fly near individual homes so long as it’s not a built-up area, it was decided to choose areas with as low a population density as possible to respect the privacy of local residents. This involved using Google Earth (https://earth.google.com/web/) firstly for a brief inspection, and then a site visit to decide on an ideal flight path that could avoid passing over homes while still capturing the necessary data.

Finally, the sites needed to be small enough that the tide did not change significantly during a single survey, allowing surveys to be clearly categorised based on tidal conditions. For the most part, this meant a survey area of under 150,000 m^2.

With these considerations accounted for, three primary sites were chosen, stretching from the north to the south of Clew Bay (**Error! Reference source not found.**). One additional site was also chosen, c overing a larger area that would be used for high-elevation surveys only. This additional site comprised primarily of very shallow water seaweed, that was mostly submerged at high tide and re-emerges at low tide. This had the potential to demonstrate a more pronounced example of tidal height influencing seaweed variability.

2.2.1 Site 1

Site 1 is situated in the northeast corner of Clew Bay, covering an area of 96,589 km^2 (for the largest overlapping area across all surveys). It consists of a coastline to the north, a large island to the south with smaller islands either side, all of which are visible regardless of tide height (Figure 5). The water in this site tends to be deeper and more turbid than the other sites, owing to the Burrishoole River which enters the site from the northwest.

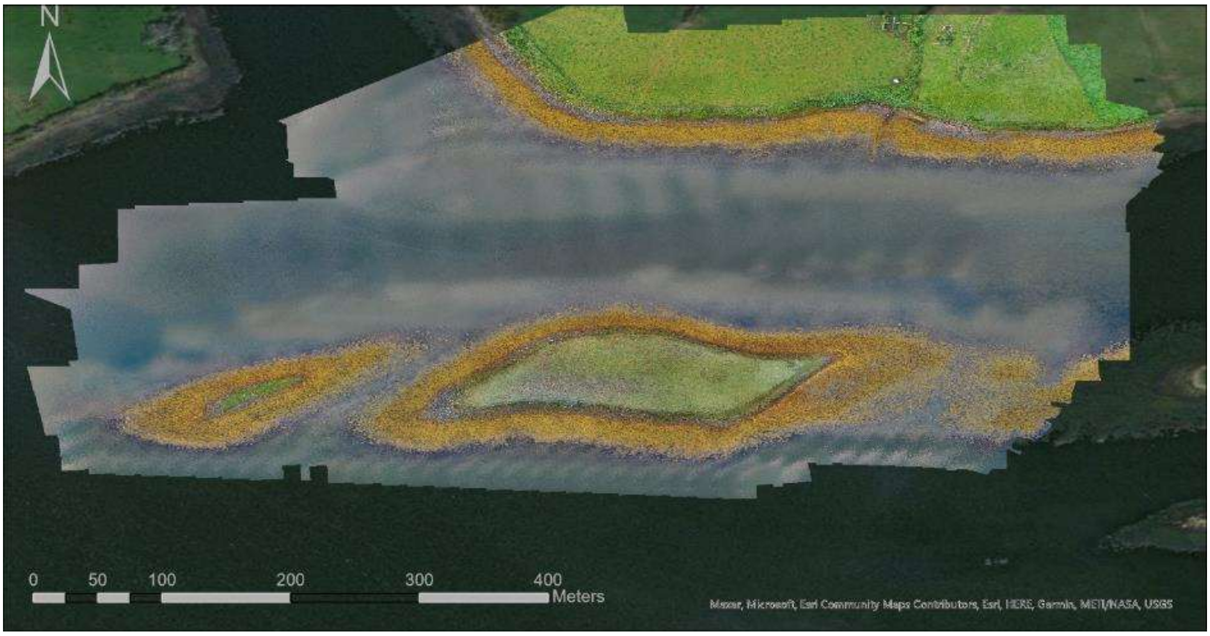


Figure 5: Orthomosaic of Site 1

2.2.2 Site 2

Site 2 is the most southerly located survey site, situated about 13 km west of Westport town. The total overlapping survey area is 85,436 km^2. The site appears quite shallow and the water clear, as the number of islands varies based on the tide and the sea floor is mostly visible regardless of tidal conditions (Figure 6).

Figure 6: Orthomosaic of Site 2

2.2.3 Site 3

Site 3 is located towards the middle of Clew Bay, just west of a road that connects the island of Inishnakillew with the mainland. This survey site has an area of 61,827 km^2 and consists one moderate sized island in the middle. The water in this area also appears quite shallow with features, such as vehicle tracks that are created at low tide, easily visible at high tide (Figure 7).

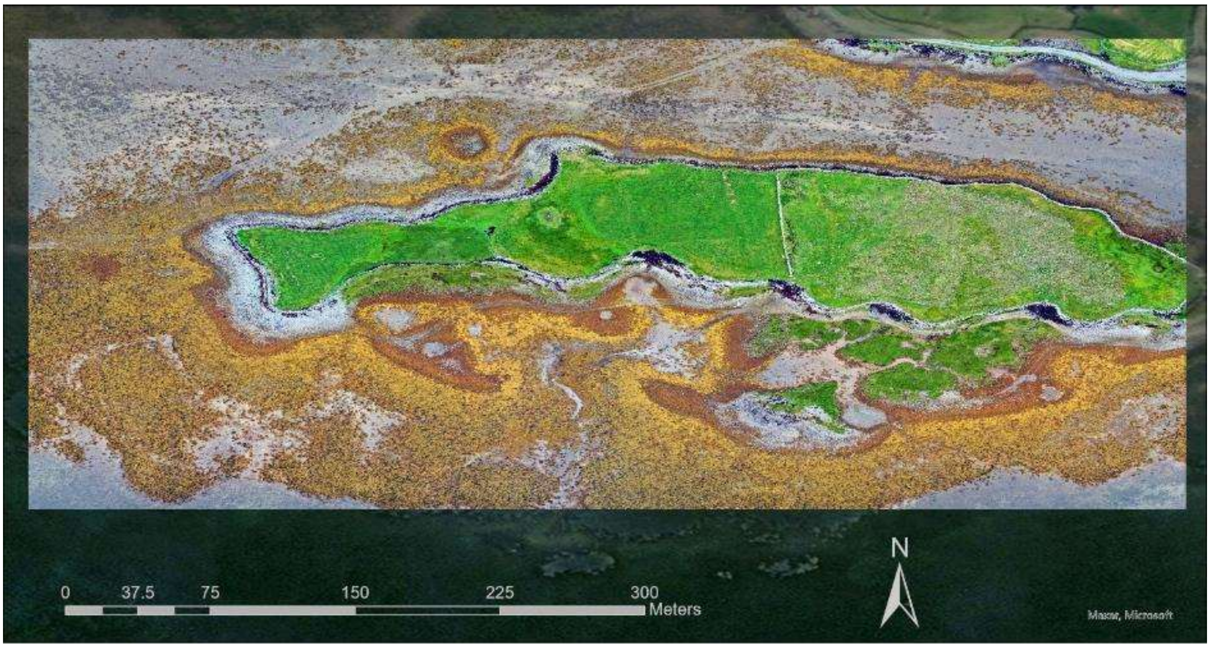


Figure 7: Orthomosaic of Site 3

2.2.4 Site 4

Site 4 is the final and largest of the survey sites, located just 2 km south of Site 3. It is situated between the mainland and Collanmore Island, covering an area of 386,891 km^2. The region again appears to have clear and shallow water, with many sea floor features visible even at high tide (Figure 8).

Figure 8: Orthomosaic of Site 4

3 Survey Planning and In-Flight Considerations

In addition to more details on the Clew Bay surveys, this section will describe some of the software, hardware and practical elements involved in planning and conducting drone-based seaweed surveys. A more comprehensive overview of drone survey methods is provided in another COAST report by Giannoumis (2021).

3.1 Flight Elevation and Tidal Conditions

Table 1 contains the details of the surveys carried out on the four test sites in Clew Bay. The initial plan was to conduct flights across three tidal levels (low, mid and high) and five drone flight heights (30 m, 45 m, 60 m, 90 m and 120 m) in three sites. This would allow a strong analysis of the influence of both tide and flight height on the ability to map *A. nodosum*, and from across a range of distinct sites. Time and weather constraints meant that the full survey complement was carried out in site 3 all but one of the full survey complement on site 2, while site 1 is missing the mid-tide surveys. Site 4 was added to compare both low and high across a much larger site, meaning only the 120 m flight elevation was used. Overall, 41 individual surveys were included in the analysis (Table 1).

Table 1: Surveys carried out at the 4 test sites. L, M and H refer to Low, Medium and High tide respectively

Flight Height	**Site 1**	**Site 2**	**Site 3**	**Site 4**
30 m	L, H	L, M, H	L, M, H	
45 m	L, H	L, M, H	L, M, H	
60 m	L, H	L, M, H	L, M, H	
90 m	L, H	L, M	L, M, H	
120 m	L, H	L, M, H	L, M, H	L, H

Flight planning software was used to partially automate the flights for each survey. These programs allow the user to input their chosen flight parameters such as geographical region to survey, flight height, ground resolution and overlap in images suitable to their desired task. Image overlap, both side to side and front to back (Figure 9), is an important consideration for drone surveying as it allows the images to be stitched together into a single large image. The software can then produce an optimal flight path, control the drone speed and rate of photo capture, while also providing an estimate of the time requirement, number of photos, total area covered and total distanced travelled, all tailored to the specifications of the drone in use. This data can be saved and used again for accurate repeat surveys. However, not all drones are compatible with flight planning software, so it's important consideration when choosing a drone. For the seaweed case studies described, the DJI Pilot PE flight planner was used (https://www.dji.com/ie/downloads/djiapp/dji-pilot-pe). Several other options also exist, such as Litchi (https://flylitchi.com/) or Pix4Dcapture, which is better suited to 3D surveys (https://www.pix4d.com/product/pix4dcapture).

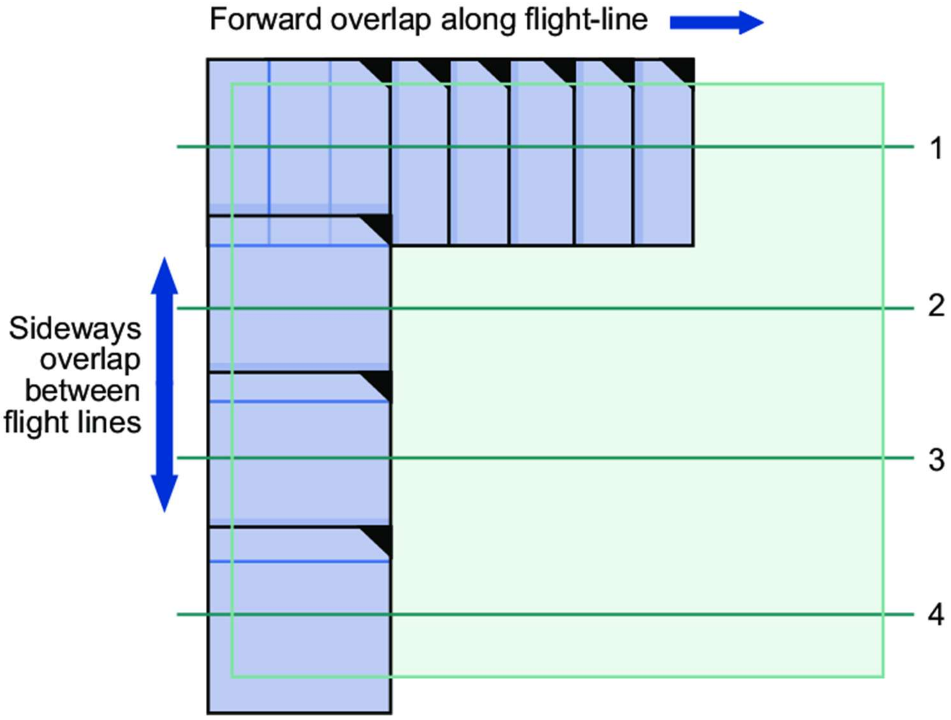


Figure 9: An example from side and front (forward) overlap in aerial images (Tempfli et al., 2009)

3.2 Drone Choice

Drone technology is currently in a stage of rapid development, with the types of drones and use applications growing drastically (Giones & Brem, 2017). At the lower price ranges (<€250) these systems may not contain positioning data (GPS/GNSS – Global Positioning System/Global Navigation Satellite system) or have cameras of suitable quality and resolution for surveying activities. Alternatively, the mid and higher end price ranges (>€2,500) will often be of a size that's more difficult to transport, too costly to be accessible, more difficult to fly and with sensors and other features that may not be required. In order to have a balance of both affordability, ease of use and quality, the DJI Mavic Pro 2 (MP2) was chosen for this project (https://www.dji.com/ie/mavic-2). It is small enough to fit in a backpack making transport simple, with a high quality 20 MP 1" CMOS Sensor, a flight time of close to 30 minutes, multi-directional obstacle avoidance, good quality positioning data, the ability to pre-program flight paths and for only €1,500 for the standard model (Figure 10). This made the MP2 an ideal combination of quality, affordability and ease of use. Further information on drone types and options can be found in Kandrot *et al.,* (2021).

Figure 10: DJI Mavic 2 Pro in flight over a stretch of seaweed

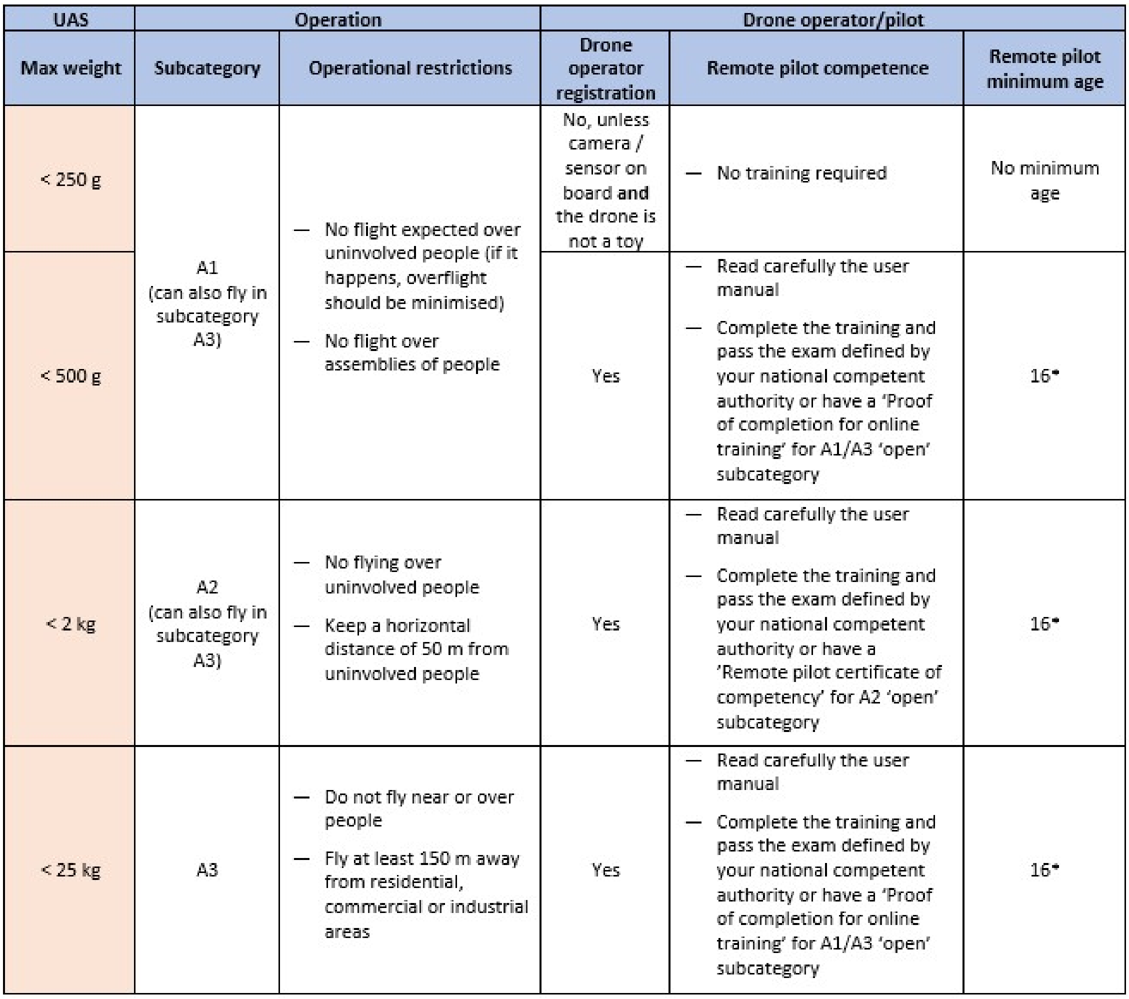
3.3 Licensing and Flight Regulations

Drone regulations in the EU do not differentiate between commercial and leisure activities. However, any drone that is not classified as a toy (under 250g and without a camera) requires the user to register and obtain an appropriate license. Many drone activities will be low-risk and fall under the purview of the open category licensing. Current regulations split them into three sections (details in Figure 11):

- A1: Can fly over people but not large groups
- A2: Can fly near people
- A3: Must fly far from people

The main factor that determines what open category license is required is the drone's weight. For example, the seaweed surveys required low risk flights and the MP2 has a take-off weight of 907g, meaning it requires either an A2 or A3 license. As the flights were anticipated to occur far from residential areas and with little risk of flying over uninvolved people, an A3 license was suitable for the work. Once the drone was registered with the Irish Aviation Authority (IAA), operator and flyer IDs obtained, the A1/A3 license test complete and all fees paid, the survey could commence in a legal manner.

For drone operations that carry more risk, such as flying above the 120 m elevation limit, out of visual line of site (VLOS), over urban area or near airfields, to name some risk factors, more advanced licenses are required. This may be a specific category license, for activities that fall outside of the open category, or certified category licenses, for the highest risk activities. More details on these licenses and their requirements can be found in Giannoumis (2021) and at EASA (2021b).



UAS	**Operation**		**Drone operator/pilot**		
Max weight	**Subcategory**	**Operational restrictions**	**Drone operator registration**	**Remote pilot competence**	**Remote pilot minimum age**
< 250 g	A1 (can also fly in subcategory A3)	— No flight expected over uninvolved people (if it happens, overflight should be minimised) — No flight over assemblies of people	No, unless camera / sensor on board and the drone is not a toy	— No training required	No minimum age
< 500 g			Yes	— Read carefully the user manual — Complete the training and pass the exam defined by your national competent authority or have a 'Proof of completion for online training' for A1/A3 'open' subcategory	16*
< 2 kg	A2 (can also fly in subcategory A3)	— No flying over uninvolved people — Keep a horizontal distance of 50 m from uninvolved people	Yes	— Read carefully the user manual — Complete the training and pass the exam defined by your national competent authority or have a 'Remote pilot certificate of competency' for A2 'open' subcategory	16*
< 25 kg	A3	— Do not fly near or over people — Fly at least 150 m away from residential, commercial or industrial areas	Yes	— Read carefully the user manual — Complete the training and pass the exam defined by your national competent authority or have a 'Proof of completion for online training' for A1/A3 'open' subcategory	16*

Figure 11: Current open category license requirements and regulations from EASA (2021a)

3.4 Practical Considerations

3.4.1 Battery Life, Drone Condition & Pre-Flight Checks

The manufacturer will indicate the maximum flight time that can be achieved with a particular drone. The time given is in ideal conditions, and doesn't include the effect of wind, temperature, flight speed, camera use or other factors that can drain the battery. In addition, the battery capacity will reduce over time and with repeated use. It can therefore be useful to keep a log of flights, battery charges and discharges to minimise the risk of battery issues compromising flight safety.

Before travelling to the survey site, it is useful to check for any firmware or software updates while you have a Wi-Fi connection. These can fix bugs, improve stability or allow for better battery management and so will keep your drone running smoothly and reliably. Make certain that the SD cards used (or on-board storage) is sufficient to cover the survey requirements. It is worth inspecting the condition of the drone before each flight. Remove any safety coverings for the gimbal, check that the propellors are securely fitted, all openings (such as USB or memory card) are properly closed, make sure your operator ID is securely attached and inspect for any defects or damage that may have occurred in transit. It is also worth wiping the camera lens clean regularly to ensure the best quality images are captured.

Before conducting a survey, it is important to visit the site and take note of any potential risk factors. For example, make note of any buildings, roads, parks or objects that might present privacy concerns or obscure your view of the drone in flight. Make note of the tallest object in the survey area so the return to home feature (if required) has clearance over any potential obstructions. Check if there are any restrictions on flights in the area and choose a location to safely take off and land, where you can ensure VLOS is maintained throughout the flight.

As the weather in coastal regions can often be highly changeable, with only short time periods with particular tidal conditions, it is useful to carefully monitor weather forecasts several days in advance of planned survey activity. This will allow the pilots to find the suitable combination of weather and tide height and to make contingency plans if needed. Very few drones are water resistant, and the wind tolerance varies depending on the model used. For the most part, the stronger the wind and colder the air temperature, the faster your battery will drain. With sudden heavy rainfall or increased winds, the drone could become damaged or control could be lost. As such, in changeable conditions with heavy or squally showers it pays to be very mindful of the risks and plan accordingly.

3.4.2 Public Consideration and In-flight Checks

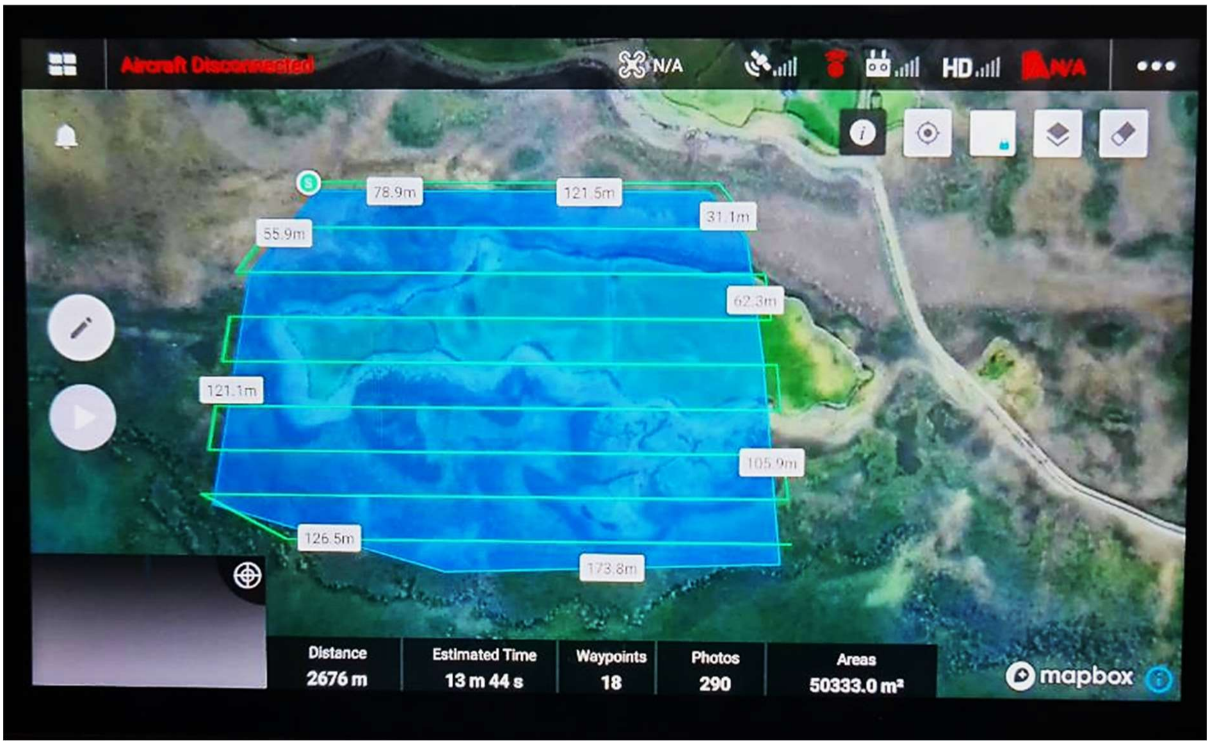
When conducting a drone survey, it is important to make yourself and your take-off/landing area clearly visible. In rural areas people can be suspicious of drone use, both over invasion of privacy and concerns regarding thieves looking for equipment to steal. Wearing a high-vis, branded jacket allows the pilot to be easily identified and reassures concerned members of the public that there is no attempt to hide the surveying activities. In addition, cones marking out the take-off/landing zone and a sign indicating that surveying is taking place can also help with both visibility and safety.

If flight planning software is being used to partially automate the flight, the flight route can be shown to local property owners to allay concerns about flights over their homes. The apps will usually display the drone flight path with a base map underneath (Figure 12), making it clear that the flight path does not infringe on their privacy. In the event of any people, vehicles or homes being captured in the survey, steps should be taken to ensure they are not identifiable in any published material, by removing or blurring sections of the photos. This will also help to ensure compliance with General Data Protection Regulations (GDPR).

It is worth taking note of the start and end time of surveys, any camera settings used and flight parameters (height, speed, etc). Describe the weather conditions at the time of flight, such as wind, cloud cover, sun angle and any other factors that could potentially contribute to variance in the image quality or characteristics.

Once a survey is complete it’s worth doing a quick check of the camera and body of the drone, re-attach the gimbal protector and any other protective coverings and put the drone into a secure container. It is good practise to back up the data as soon as possible, on an external hard drive, cloud-based storage or another safe option.

The essential pre- and in-flight survey checks are included in Figure 13.



Distance 2676 m

Estimated Time 13 m 44 s

Waypoints 18

Photos 290

Areas 50333.0 m²

Figure 12: Screen shot of the DJI Pilot application and a flight route over Site 3.

Flight Check List

- Batteries & Controllers Fully Charged ☐
- Firmware & Software Fully Up to Date ☐
- Adequate Storage for Survey Data ☐
- Propellors Securely Fit ☐
- Damage Free & Gimbal Protector Removed ☐
- Operator ID Visible ☐
- Adequate Backup & Storage for Survey Data ☐
- Pilot in High-vis Clothing ☐
- Take off/Landing Area Clearly Demarcated ☐
- No Obstacles Obscuring VLOS ☐
- Flight & Weather Details Recorded ☐

Notes

Figure 13: Some essential pre- and in-flight checks when conducting drone surveys

4 Data Processing and Results

This section will describe how the photos captured in each survey were converted into one single large image called an orthomosaic. It will then go through the process of classifying different surfaces available, isolating the seaweed information and then comparing across the different surveys. Finally, the main influences on survey results will be discussed. For each step details will be provided, and some alternative approaches highlighted, including software options.

4.1 Creating an Orthomosaic

4.1.1 Software Options

When a survey consisting of individual images (or frames extracted form a video) contains sufficient overlap, then software can be used to seamlessly blend the images into a single whole, where distortions are minimised and the colour is balanced across the image. A front overlap of 75% and side overlap of 60% is considered a general minimum for this task [Pix4D., n.d.] but will vary depending on the purpose of the survey and the landscape. Numerous photogrammetry packages can be employed to complete the orthomosaicing task. Some examples include ESRI’s Drone2Map (https://www.esri.com/en-us/arcgis/products/arcgis-drone2map/overview), Pix4D (https://www.pix4d.com/) or free, open source software such as Open Drone Map (https://www.opendronemap.org/). The workflow involved will vary between the different programmes, but the underlying principles will be largely the same. Agisoft Metashape (https://www.agisoft.com/), was the software chosen for this case study. Metashape is widely used in processing aerial imagery. As such, it contains detailed guides for creating different data sets, a dedicated forum for customer support and there’s a large global community creating countless written and video guides to aid in learning the software. The following section will describe a basic workflow for creating an orthomosaic using Metashape. Further details for all steps, and steps not included here, can be found in the guides and tutorials provided by agisoft (https://agisoft.freshdesk.com/support/solutions) and within the help contents page of the software itself.

4.1.2 Orthomosaic Processing

4.1.2.1 Upload and Quality Check

The first step in creating an Orthomosaic in Agisoft Metashape is to upload the image dataset from a single survey. This can be achieved by choosing “Add Photos” from the Workflow dropdown menu, or right-clicking “Chunk 1” in the “Workspace” pane, clicking “Add” and then “Add Photos”. For the seaweed test sites the number of images in single surveys ranged from as little as 67 up to 575.

An estimation of the image quality can be generated by highlighting all images in the “Photos” pane and selecting “Estimate Image Quality”. Once complete, choose “View Details” and image quality estimates are provided. Inspect the images with low values, especially under 0.5. Any that are excessively blurry or distorted may need to be removed as they can introduce errors in later steps and reduce the overall quality of the orthomosaic.

4.1.2.2 Photo Alignment

From the “Workflow” dropdown, select “Align Photos”. From the resulting dialogue box, choose the “high” accuracy setting and leave the other settings on default. This process estimates the camera (drone) positions and orientations, and produces a sparse point-cloud containing XYZ data from points that clearly match across multiple images regardless of scale, orientation, or lighting (Figure 14). When the process is complete, the computed camera positions can be checked. Those that are poorly aligned or failed to align can be realigned. If necessary, markers can be added to common points across aligned and non-aligned images to aid in the alignment process. In regions where there are large stretches of open water and the flight elevation is low, many images consist entirely of near featureless water. This can make it difficult for the alignment process to detect objects that occur across multiple images, resulting in data gaps and later holes in the orthomosaics. This can be partially compensated for by performing high elevation flights in addition to the low elevation flight. This allows high elevation photos to contain both land features, which are easier to find matching objects on, and open water areas, thus increasing the chances of the photos being aligned and reducing the size and number of gaps in the point cloud and final orthomosaics.

Once a sparse point cloud has been generated, there is the option to add ground control points (GCPs). These are markers distributed across the site and surveyed using professional grade equipment to provide millimeter positioning accuracy. These can be added at this stage to improve the georeferencing accuracy of the final orthomosaic. While these weren't included in the case study, the process to add them is described in the guide here: https://www.agisoft.com/pdf/PS_1.3%20-Tutorial%20(BL)%20-%20Orthophoto,%20DEM%20(GCPs).pdf.

The bounding box can also be resized to fit around the survey area, by choosing "Resize Region" from the "Move Region" dropdown menu. Clearly erroneous points can also be deleted. These steps ensure subsequent processing only occurs in the area of interest, reducing the computational load and errors.

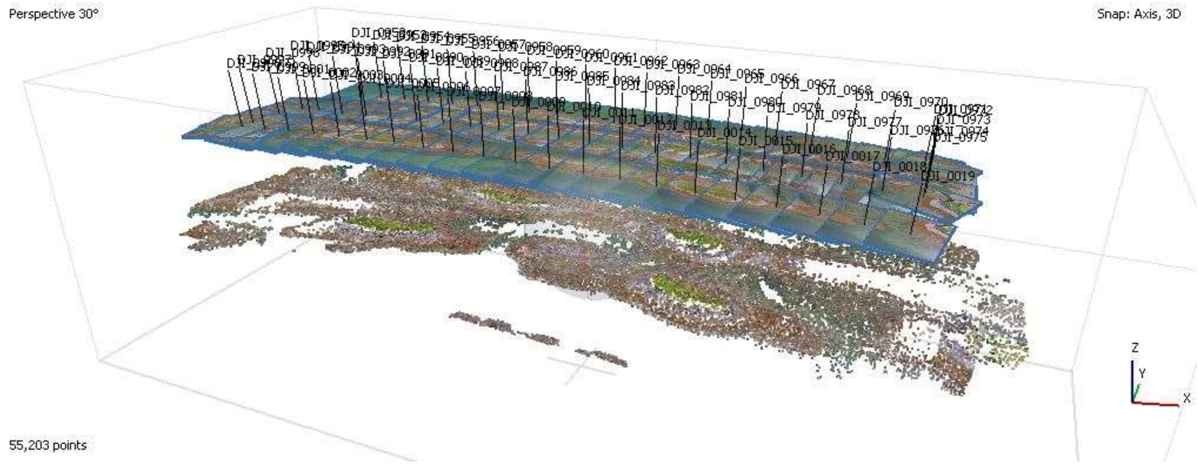


Figure 14: Sparse point cloud and camera positions from the 120 m, mid-tide survey of Site 2

4.1.2.3 Optimise and Build Dense Cloud

The next step is to optimise the camera alignment to improve the alignment results and reduce errors. This involves highlighting the photos in the reference pane, selecting the "Optimise Cameras" button and selecting the parameters to optimise. Details on what parameters to optimise depends on the survey approach and cameras settings, but details can be found in the guides and the help section of the software.

Following camera alignment, from the "Workflow" dropdown menu, select "Build Dense Cloud". This is one of the most computationally intensive steps and can take anywhere from under an hour to several days to complete, depending of the computer specifications, number of images, quality of images and settings selected. The dialogue box allows you to choose among different quality settings and depth filtering. Higher quality options will add significant time to the process, so a balance may need to be struck. Depth filtering can be set to aggressive where there are few complex and fine scale geometrical structures in the survey (such as in a landscape orthomosaic) but is usually set to mild where more complex 3D structures are present. The resulting point cloud (Figure 15) can be several hundred MB to several GB in size, containing potentially billions of points. Once complete, clearly erroneous point should be deleted before the next step in the process.

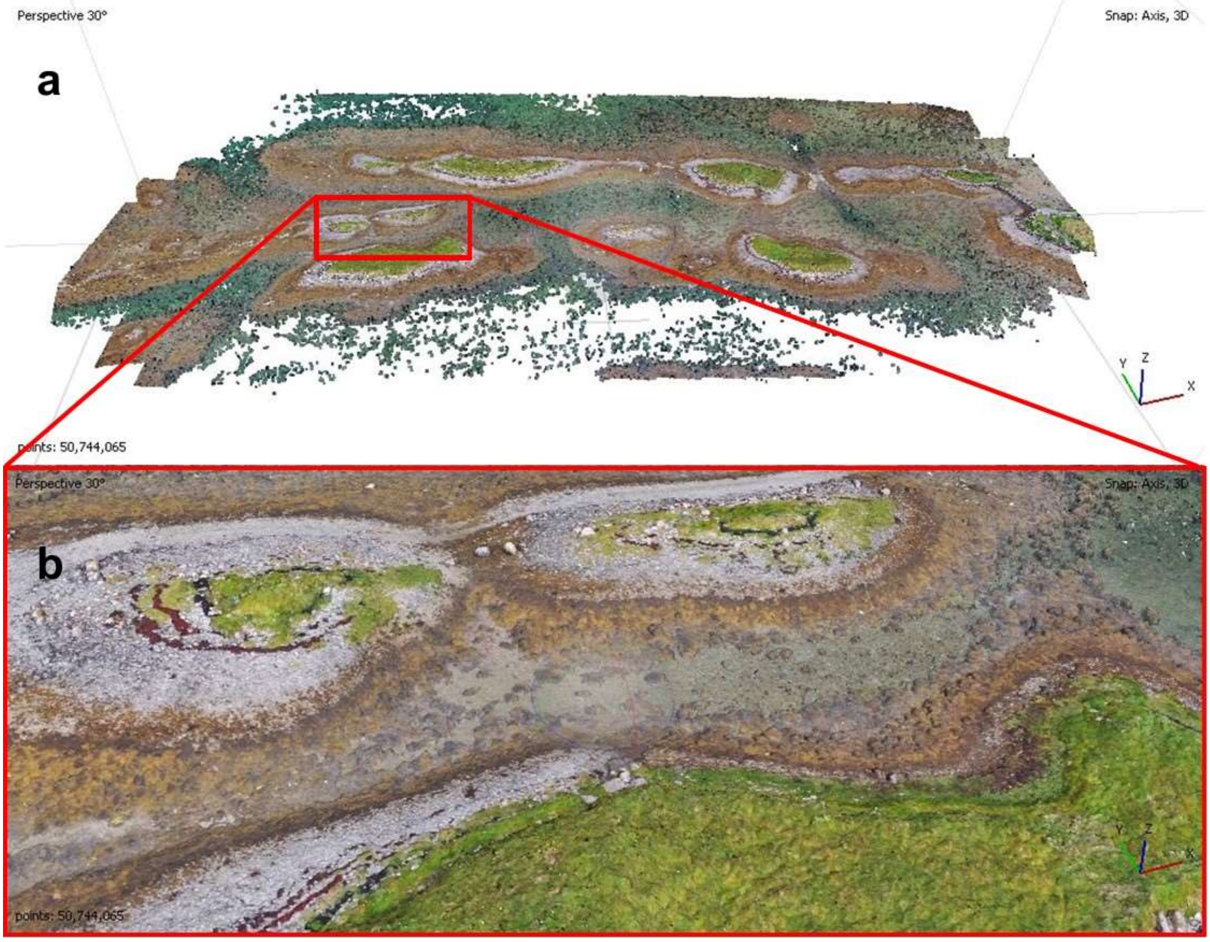


Figure 15: Example dense point cloud from mid-tide, 120 m survey of site 2 (a) and a close up of the section highlighted in red (b).

4.1.2.4 Build Digital Elevation Model (DEM) and Orthomosaic

From the “Workflow” dropdown menu once more, choose the “Build DEM” option. On the dialogue box select the source data that will be used to construct the DEM – the dense cloud in this instance. Enable interpolation to fill in any small gaps. The projection type and resolution of the DEM output can also be adjusted if required. The process converts the point cloud elevation values into a 2.5D model comprised of elevation data (Figure 16a). Digital Terrain Models (DTMs), which model just the bare Earth elevation can be created here, but require additional steps that are described in the guides and tutorials site (https://agisoft.freshdesk.com/support/solutions) and the help contents.

Finally, to build the orthomosaic, select “Build Orthomosaic” from the “Workflow” dropdown menu. In the dialogue box, chose “DEM” as the surface. This is the surface upon which the original images will be overlain, blended together and transformed into the required geographic projection system. A mesh can also be selected here, if one has been created earlier, but it’s more computationally demanding and not typically necessary for orthomosaics. The blending options determine how the seams connecting the images are blended together. Mosaic, the default, normally works best but other options can be used if the results are not adequate. The remaining options can normally remain on default but, as always, the help section provides details on all other options.

The resulting orthomosaic (example in Figure 16b) is a 2D image, combining the original photos and using the DEM and blending methods to create a single image with the pixel size dependent on the ground sampling resolution - a combination of survey height, camera quality and resolution. The orthomosaic can then be exported for analysis in other programs by right clicking the mosaic in the workspace pane and selecting “Export Orthomosaic” and then the required format, such as a GeoTIFF – an image with georeferencing information embedded within it.

To summarise, the process is: Upload photos > estimate quality > align photos > build dense cloud > build DEM > build orthomosaic > export orthomosaic.

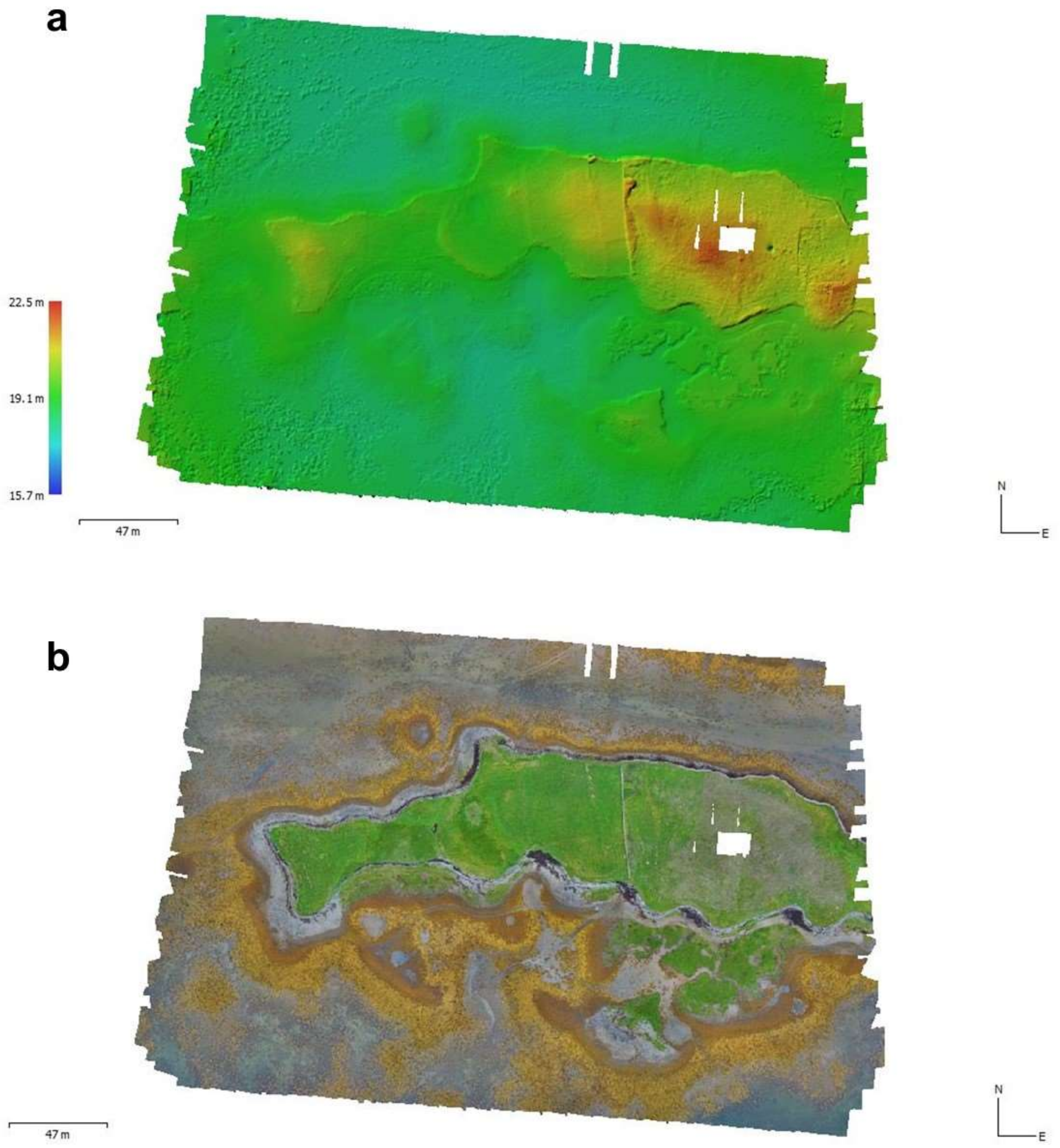


Figure 16: An example of both a DEM (a) and a resulting orthomosaic (b) from a 30 m elevation, mid-tide survey of site 3

4.2 Creating Classified Maps

For this section, ESRI's ArcGIS Pro (AGP) was employed for the analysis of the orthomosaics (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview). Free and open source options are also available that can carry out the same tasks, such as QGIS (https://www.qgis.org/en/site/).

4.2.1 Import Orthomosaics and Change Projection

The first step to working with the orthomosaics in AGP is to import them into a geodatabase through the "Raster to Geodatabase" tool. This is done as a separate geodatabase for each site to keep the data organised and the database sizes manageable.

Once complete, orthomosaics are converted from World Geographical System 1984 (WGS 84) coordinate system, which uses angular measurement units (degrees), to the Irish Transverse Mercator (ITM) projection, which uses linear units (meters). This makes it easier to calculate the areal coverage values of the *A. nodosum* later and compare between surveys.

4.2.2 Co-registration

The absolute positional accuracy of the orthomosaics may differ from each other by up to 10 m due to limitations in the GNSS positioning in the drone, and errors and noise introduced at different stages of the processing involved in creating the orthomosaic. It is therefore necessary to align the orthomosaics as closely to each other as possible. This was achieved using the "Georeference" tool under the imagery tab in AGP. This allows you to select one data set as a source (to be registered) and another as the reference (which the source is registered to). Using common points marked in each data set, the source data is altered to more accurately match the reference data set. There are a range of transformation methods that can be selected for this task. For the orthomosaics from each site, the 30 m meter elevation survey was chosen as the reference data set from each tide height group and all other elevations within that tide group was altered using a first order polynomial transformation. This requires and minimum of three common points to function, but between 6 and 10 points, evenly distributed across the survey sites, were used to ensure good coverage and accuracy.

4.2.3 Clipping to Equal Areas and Removing Land

Each orthomosaic covers a slightly different area to the others, owing to the different flight heights (and thus camera footprints), changes in conditions that alter the distribution of tie points used in the sparse cloud creation and more. In addition, submerged *A. nodosum* and dried grass can both appear as dull light brown colours. This means that classifying them as distinct features can be problematic and introduce errors. However, as *A. nodosum* is predominantly in the shallow waters, beaches and intertidal zones generally, the grassy land surfaces could be largely removed from the images. This improves both the processing time and classification accuracy.

To begin with, polygons are created to outline the maximum overlapping areas for each survey site (Figure 17a). This is done by right-clicking on your geodatabase and selecting "New" and then "Feature Class", and then follow the steps and select the options required. Once created, the common overlapping area can be traced out. Next, a separate polygon feature class is created for the land and islands (Figure 17b), following the same process for the outline polygon. Using the "Erase" tool in AGP, the land polygons are then removed from the outline polygon, leaving a polygon that covers mainly the beaches, seaweed and water (Figure 17c). Finally, the "Extract by Mask" tool is used to remove the undesired parts from the orthmosaics themselves, leaving only the overlapping areas and with land and islands removed (Figure 17d).

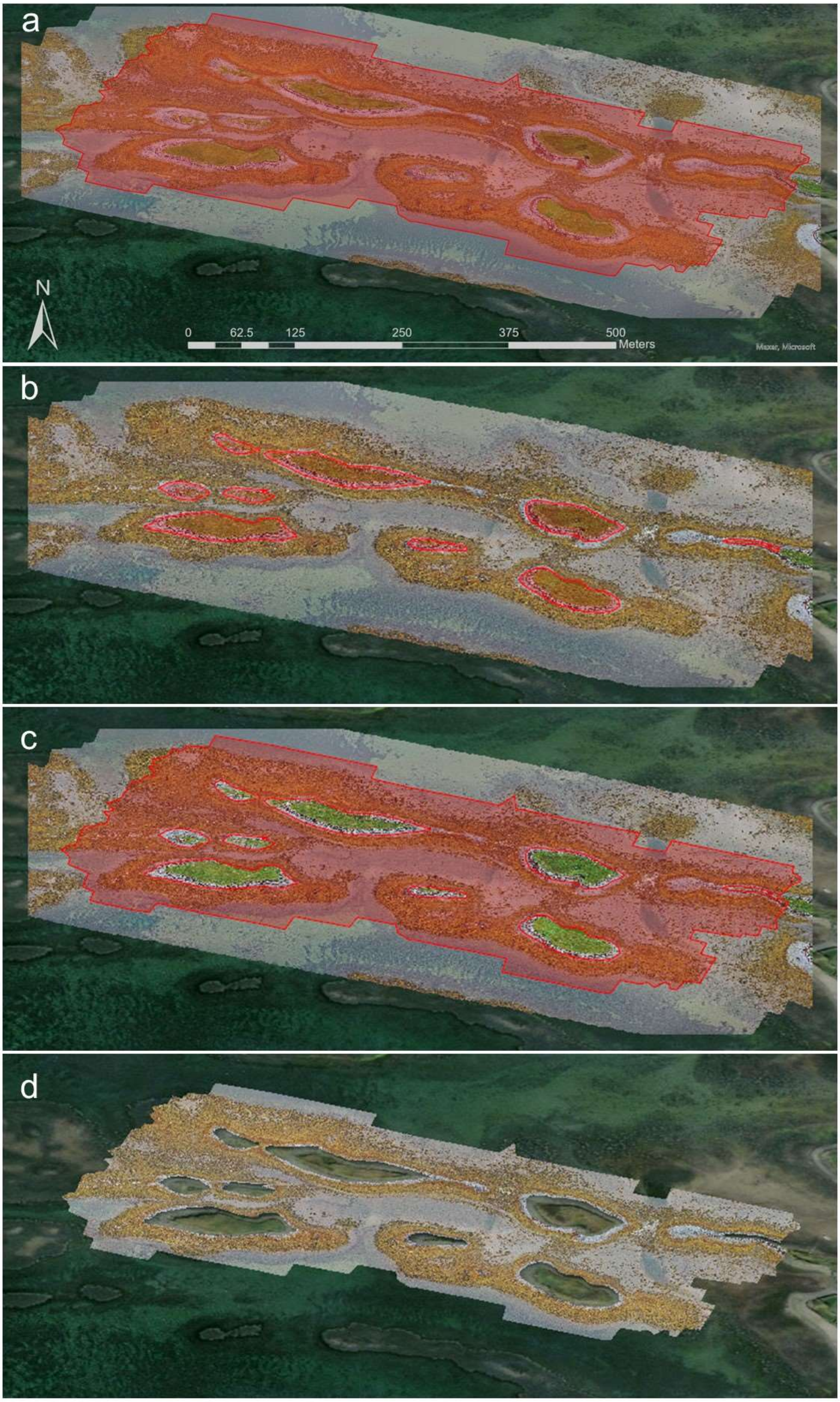


Figure 17: The maximum overlapping area of the low tide in Site 2 (a), the land area polygons (b), the land area subtracted from the overlapping area (c) and the final extracted orthomosaic (d)

With comparable areas created for each site and the land area removed, just a few more steps are required to extract quantitative data on the spatial coverage of seaweed. This involves classification of the remaining data and then extracting the seaweed class as a polygon.

4.2.4 Classification Method

Maximum likelihood was chosen as the classification method for the remaining data. While there are many classification options available, this classification technique has been widely used for seaweed mapping, both from satellite platforms (Pratama & Albasri, 2021; Webster *et al*., 2020) and drones (Rossiter *et al*., 2020), and is thus an established and accessible method.

The first step in maximum likelihood classification is the creation of training samples. These are regions within an image that the user defines as belonging to a particular class. For the test sites, four different classes were used: seaweed, water, vegetation and rocks. For each of these classes, numerous polygons are created to represent as much variation in each class as possible across the image. For example, the colour of the *A. nodosum* seaweed in site 2 ranges from a dull and greyish brown when slightly submerged to a bright orange or wine colour in exposed sections. The full range of colours visible should be captured to successfully differentiate the *A. nodosum* from other features during the classification process. The same holds true for all other classes. These training samples are used to create a unique spectral signature for each class, which is then used to place every other pixel in the image into one of the classes. AGP provides instructions on creating training samples through the “Classification Tools” dropdown menu in the “Imagery” tab.

Once the training samples have been created then classification can be executed (Figure 18).

Figure 18: Original clipped raster (a) and classifiedraster (b)

4.2.5 Extracting Seaweed Coverage

The final step in a quantitative measure of seaweed coverage involves extracting the seaweed class and converting it to a polygon. Within AGP, this can be achieved by opening the attribute table of the classified image and highlighting the seaweed class. Then use the “Raster to Polygon” tool to create a new polygon containing only seaweed (Figure 19). Open the attribute table of the new seaweed polygon and the area column will contain the seaweed coverage in squared meters. This value can be extracted from all surveys and added to databases or spreadsheets for further analysis.

Figure 19: Close-up comparison of a section of the orthomosaic (left) and the seaweed classified in orange for the same area (right)

To summarise: > import orthomosaics > project in ITM > co-register > clip to equal area > remove land > classify > convert to seaweed polygon > extract area value.

4.3 Survey Results

The average seaweed coverage for each tidal height for the three main survey sites can be seen in Figure 20. Each bar shows the average seaweed coverage for each tide height in m^2, with the standard deviation (SD) shown in red. The seaweed coverage generated at low tide surveys are greater than those at high tide. Conversely, maps at higher tides produce slightly more variation, as measured by the SD. This means that low tide surveys allow more seaweed to be measured and more consistently than other tide levels.

Figure 21 shows much the same as Figure 20, only with average seaweed for each flight height rather than tidal height. There is a slight trend towards an increase in the amount of seaweed visible with flight height, but overall the difference has much less impact than tidal height, and the SD deviation is much larger.

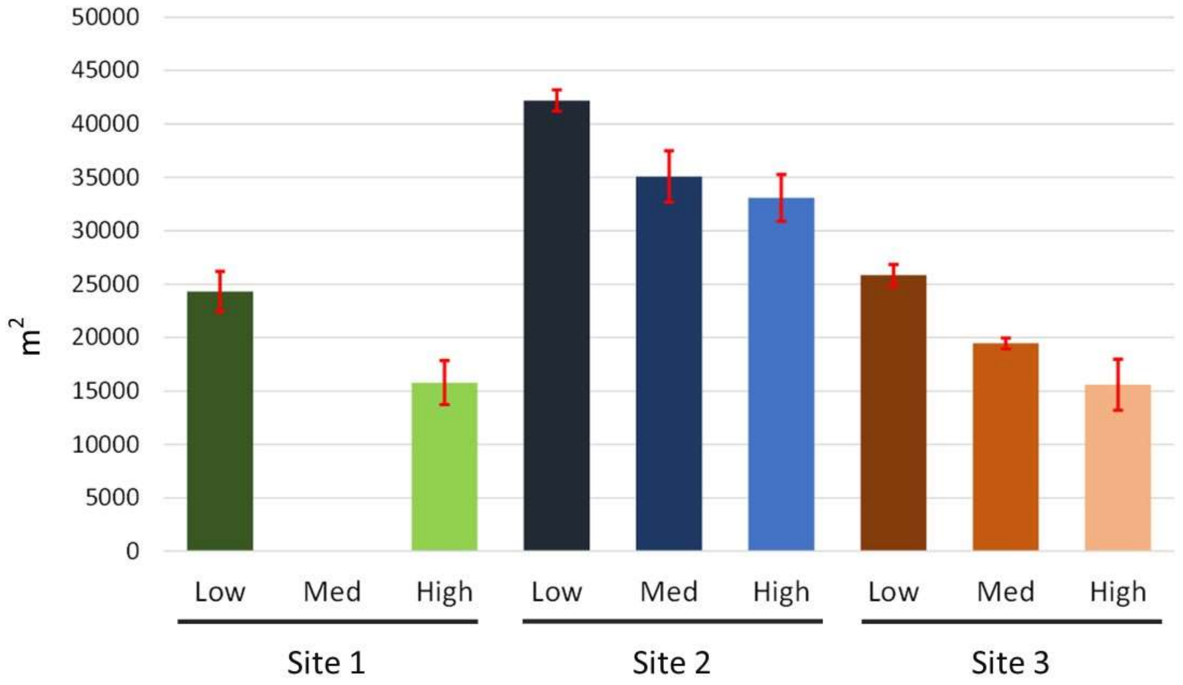


Figure 20: Seaweed coverage (bars) and standard deviation (red) from the three main survey sites at low, medium and high tide

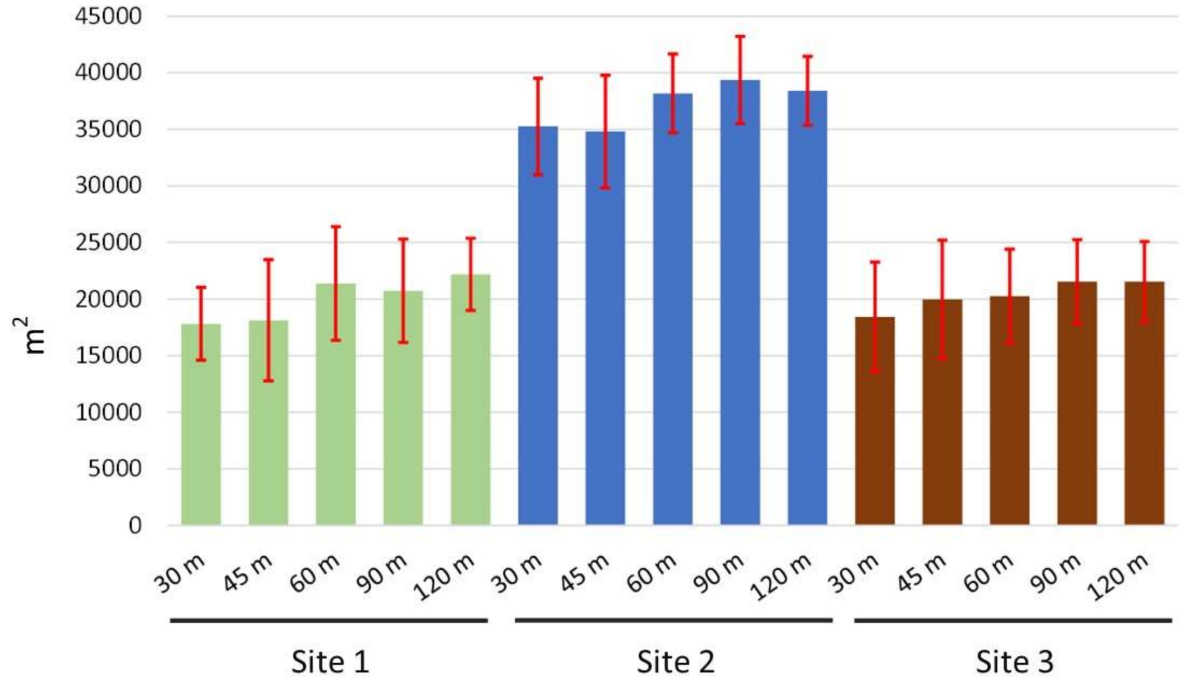


Figure 21: Seaweed coverage (bars) and standard deviation (red) from the three main survey sites at each of the five drone survey heights

4.3.1 Survey Details

The seaweed cover for all 41 surveys can be found in Table 2. Across the three main test sites seaweed coverage ranged from a low of 12,315 m^2 at the 30 m high tide survey in site 3, to a high of 43,230 m^2 at the 90 m low tide survey of site 2. The average seaweed cover across each site was 20,047 m^2 for site 1, 37,052 m^2 for site 2, 20,350 m^2 for site 3 and 79,096 m^2 for site 4, with the average proportion covered by seaweed being 26%, 50%, 48% and 21%, respectively.

Table 2: Table displaying the seaweed coverage (m^2) at each test site, for every tide level and flight height

		30 m	45 m	60 m	90 m	120 m	Average
Site 1	Low	21021	23488	26390	25305	25364	*24314*
	High	14591	12782	16367	16171	18987	*15780*
Site 2	Low	40467	41791	42828	43230	42660	*42195*
	Mid	35292	30514	37222	35515	36882	*35085*
	High	30009	32138	34483		35704	*33083*
Site 3	Low	24122	26724	25290	26554	26567	*25851*
	Mid	18879	19256	20363	20363	19181	*19609*
	High	12315	13949	15137	17688	18856	*15589*
Site 4	Low	N/A	N/A	N/A	N/A	115303	*115303*
	High	N/A	N/A	N/A	N/A	42889	*42889*

On average, the drop in coverage from low tide to high tide was 35%, 22% and 40% for sites 1, 2 and 3, respectively. This means that for every 1 m rise in tide, seaweed coverage was reduced by an average of 18.7% (Figure 22).

As mentioned in section 2.2, site 4 was chosen to emphasis the effect of tidal height on seaweed coverage across a large area. Here, the drop from low tide to high tide was 63%, meaning a 27.3% reduction in seaweed coverage for every 1 m increase in tide. This further highlights the strong influence that tidal height has on seaweed visibility, even in relatively shallow and clear water.

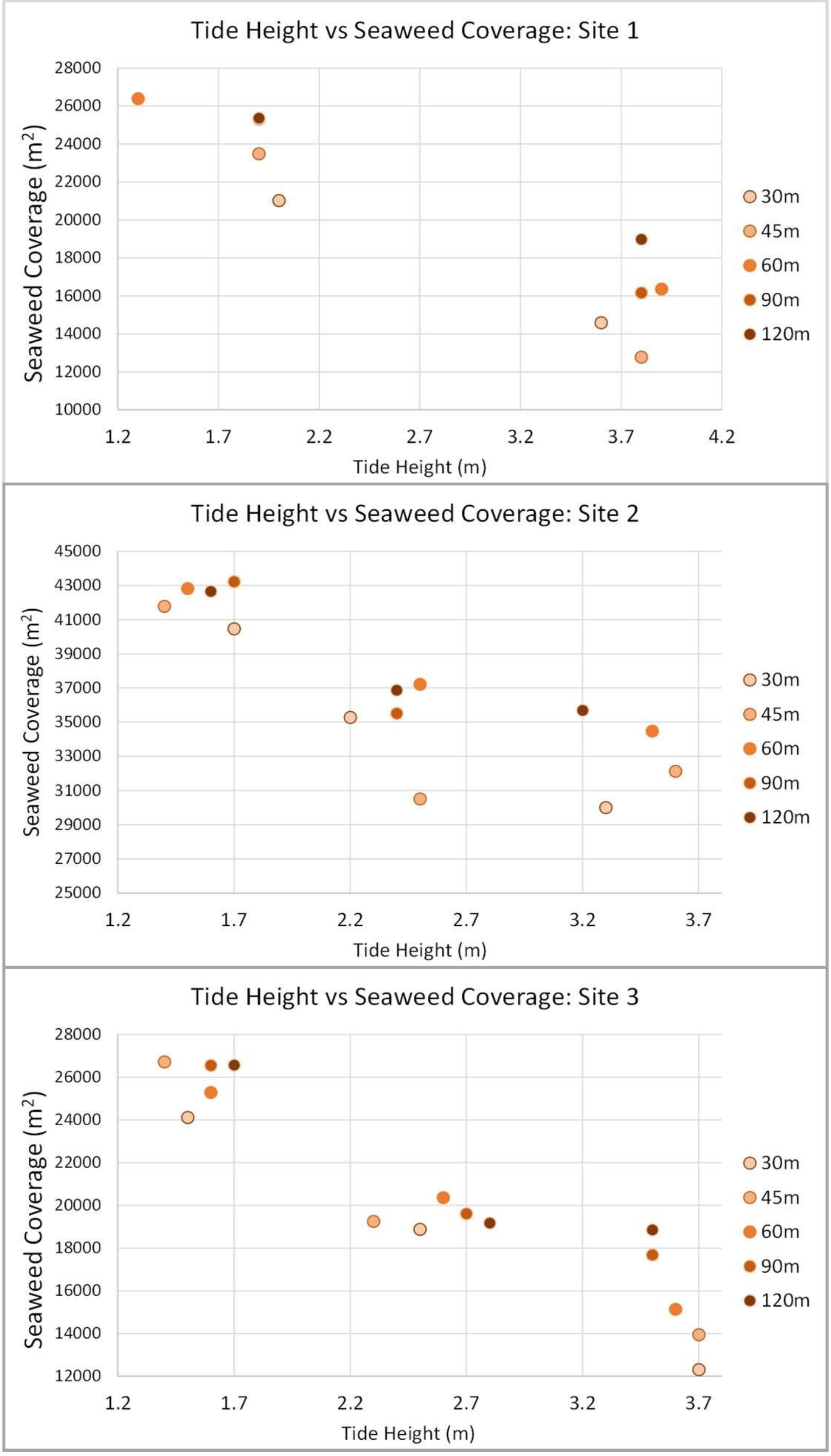


Figure 22: The relationship between tide height and seaweed coverage across all three primary survey sites

5 Recommendations

Two main recommendations can be drawn from the presented case study:

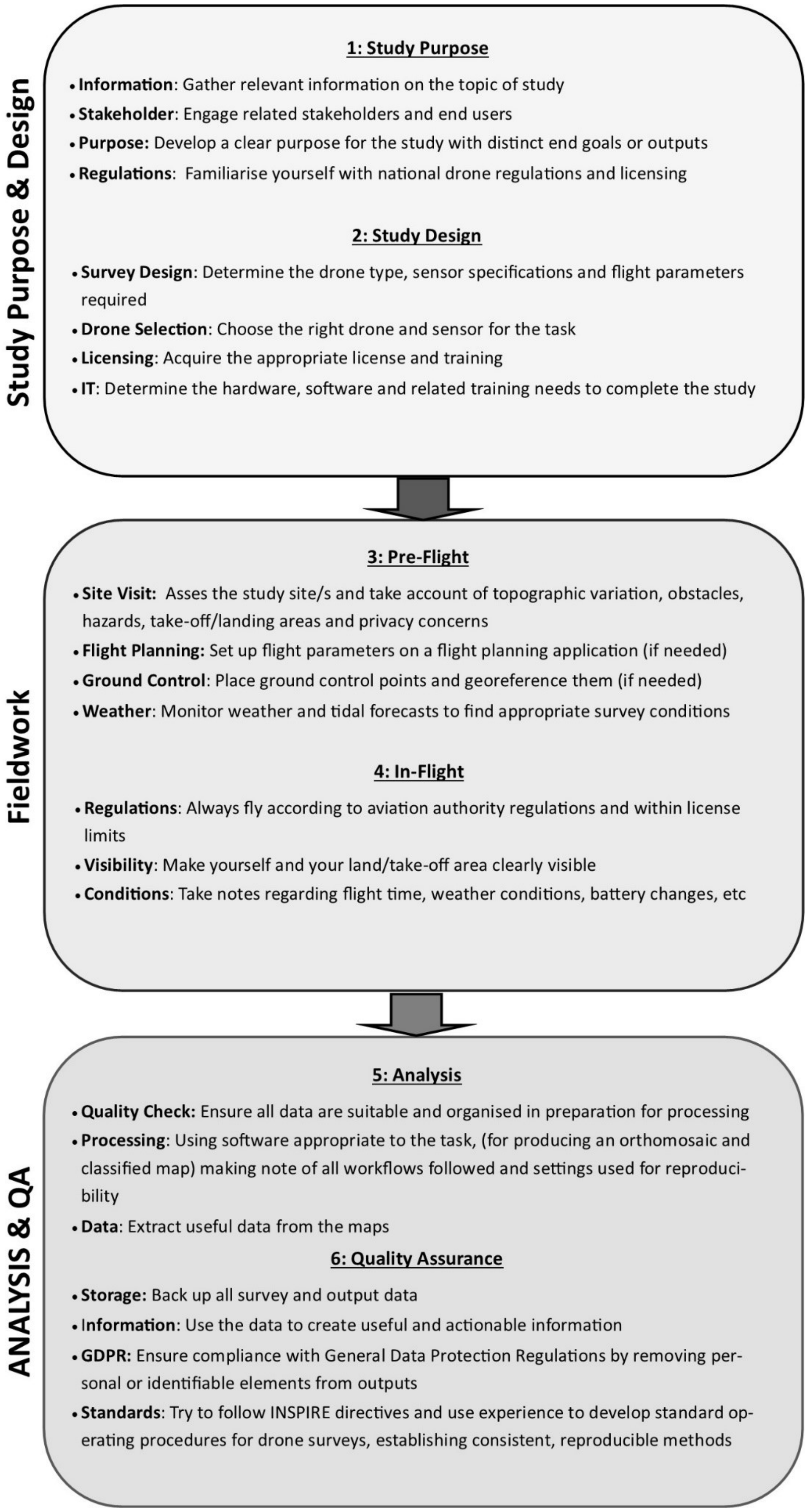
1. Conduct surveys during the lowest tidal levels where possible
2. Fly the drones at a high elevation (~120 m)

The survey results made clear that even small increases in the tidal height can have important ramifications for the amount of seaweed capable of being surveyed. The seaweed coverage capable of being mapped via drone decreases by an average 18.7% for each meter the tide rises, with a maximum of 27.3% per meter at site 4. This highlights the need that, with a standard drone camera that captures RGB images, surveys should be conducted at the lowest tide levels possible. There may be a way to compensate for increases in tide height if one already knows how tidal height effects visible seaweed coverage, but this is likely to vary from one site to the next.

The results also show that flight height exerts a small influence on the classification and extraction of seaweed coverage values, with coverage increasing very slightly with survey height. While this difference is small and variable, flying at an elevation of close to 120 m (the maximum allowed with standard drone licenses) allows the survey to be completed quickly, reducing the average flight time by 73% compared to the 30 m elevation flights. This helps to minimise tidal variation during the survey and reduces the likelihood of interruptions due to changing weather conditions.

6 Conclusion

Through rigorous study design, careful survey methods and insightful analysis (Figure 23), drone surveying can be an effective and efficient way to map seaweed coverage, even down to millimetre resolution. This can be achieved using off-the-shelf drones, basic licensing, standard software and established processing approaches. From the case studies presented here, flying at a high elevation during low tide will provide the best opportunity to map the most seaweed cover. Drone technology has the potential to become a useful and accessible tool for coastal managers, enriching local knowledge of seaweed resources and enhancing their sustainable management.



Study Purpose & Design

1: Study Purpose

- **Information**: Gather relevant information on the topic of study
- **Stakeholder**: Engage related stakeholders and end users
- **Purpose:** Develop a clear purpose for the study with distinct end goals or outputs
- **Regulations**: Familiarise yourself with national drone regulations and licensing

2: Study Design

- **Survey Design**: Determine the drone type, sensor specifications and flight parameters required
- **Drone Selection**: Choose the right drone and sensor for the task
- **Licensing**: Acquire the appropriate license and training
- **IT**: Determine the hardware, software and related training needs to complete the study

Fieldwork

3: Pre-Flight

- **Site Visit:** Asses the study site/s and take account of topographic variation, obstacles, hazards, take-off/landing areas and privacy concerns
- **Flight Planning:** Set up flight parameters on a flight planning application (if needed)
- **Ground Control**: Place ground control points and georeference them (if needed)
- **Weather**: Monitor weather and tidal forecasts to find appropriate survey conditions

4: In-Flight

- **Regulations**: Always fly according to aviation authority regulations and within license limits
- **Visibility**: Make yourself and your land/take-off area clearly visible
- **Conditions**: Take notes regarding flight time, weather conditions, battery changes, etc

ANALYSIS & QA

5: Analysis

- **Quality Check:** Ensure all data are suitable and organised in preparation for processing
- **Processing**: Using software appropriate to the task, (for producing an orthomosaic and classified map) making note of all workflows followed and settings used for reproducibility
- **Data**: Extract useful data from the maps

6: Quality Assurance

- **Storage:** Back up all survey and output data
- **Information**: Use the data to create useful and actionable information
- **GDPR:** Ensure compliance with General Data Protection Regulations by removing personal or identifiable elements from outputs
- **Standards**: Try to follow INSPIRE directives and use experience to develop standard operating procedures for drone surveys, establishing consistent, reproducible methods

Figure 23: Summary of the basic steps required in carrying out a drone-based seaweed survey

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