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Coastal Habitat Mapping Using Remotely Piloted Aerial Systems (RPAS)

Mapping kelp, seagrass, and mussels with drones

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Summary

Remotely-Piloted Aerial Systems (RPAS) or drones are excellent tools for local-scale mapping of coastal habitats, including kelp forests, seagrass meadows, and rocky intertidal zones. While drone technology has become more accessible, there are many considerations beyond simply purchasing a device. The Hakai Institute has been using drones to map coastal habitats since 2014, and has an interest in sharing its expertise in this area.

This document provides guidance on how to:

- Setup a program for habitat mapping using drones.
- Plan and conduct flights for coastal habitat mapping.
- Create orthomosaics from drone imagery.
- Delineate habitat extents (kelp, eelgrass, mussels).

Resources

- Transport Canada - Drone Safety
- NRCan Site Selection Tool
- Nav Canada Flight Planning Drone App
- Kelp Mapping Guidebook

How to cite this document

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Drone mapping program considerations

To set up a habitat mapping program with drones, consider the following subjects.

- Equipment
  - Choosing a drone
  - Positioning (i.e. GPS, ground control)
- Training and staffing
- Permits and regulations

Suggested Equipment

- Transport Canada compliant drone with multiple batteries
- Controller with connected tablet or smartphone
- High-capacity, high-speed SD cards
- Ground control targets (for improved accuracy)
- RTK GPS for precise ground control point marking
- Ruggedized laptop for field use
- External hard drives for data backup
- SfM Software - e.g, Agisoft Metashape, Pix4D Mapper, Drone Deploy
- Mapping Software - e.g, QGIS, ArcGIS Pro

Drones

Several drone models are suitable for coastal habitat mapping. Some important factors to consider:

- Cost
- Durability
- Positioning - RTK GNSS
- Automated flight planning (or compatible with 3rd party apps)
- Sensor and shutter - global mechanical shutter is best
- Form factor - is it easy to launch and land from a boat or shore?

Some examples that work well:

- Autel EVO II Pro
- DJI Phantom 4 Pro - discontinued but reliable
- DJI Mavic 3 Enterprise / Multispectral
- Wingtra fixed wing
- Any Mini Drone Sub 250g, can fly in more locations legally

Positioning

It is important to consider the level of positional accuracy that is required. RTK drones, Ground Control Points, or some combination of these can be used.

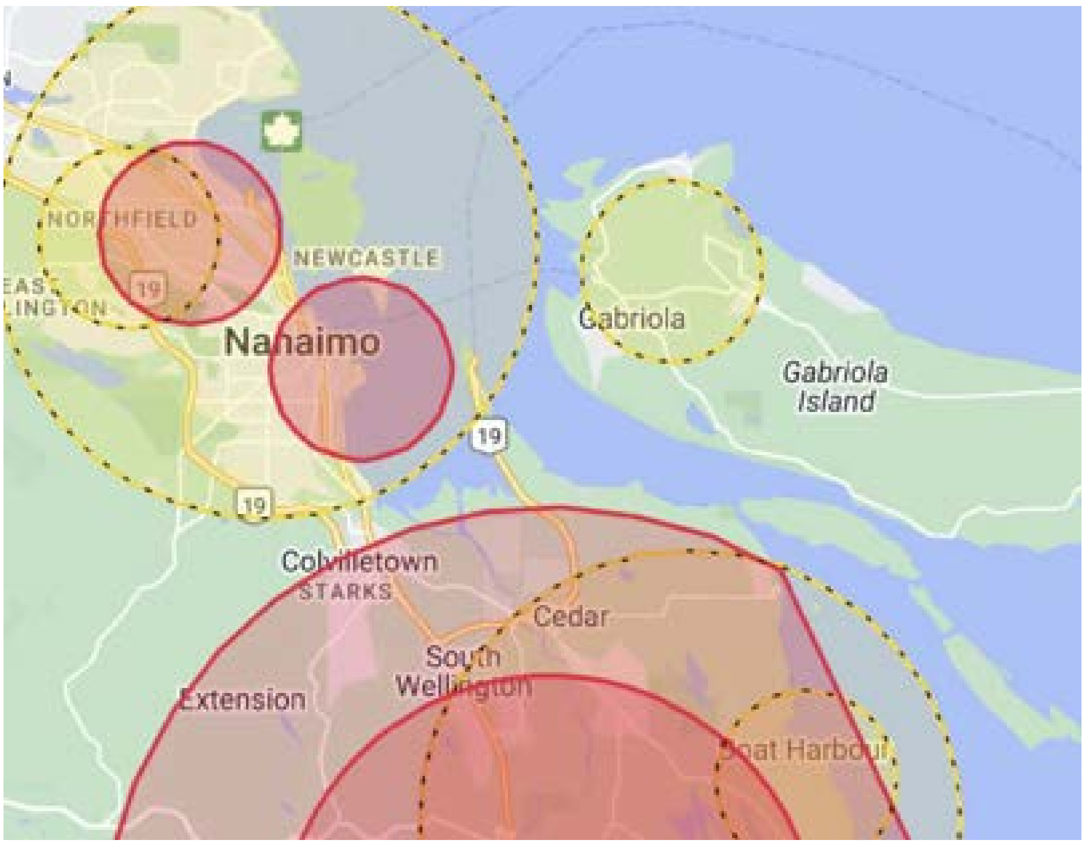
- The default of using the standard drone GPS for geotagging will give ~2m horizontal accuracy to an orthomosaic output. The vertical positioning will not be useful.
- Repeat surveying may only require an initial GNSS (Global Navigation Satellite System, e.g., GPS) survey. After that, repeat surveys can be georeferenced to the first survey.
- RTK Drones
  - Provide real-time, high-accuracy positioning during flight.
  - Reduce or eliminate the need for ground control points (GCPs)
  - Can achieve centimeter-level accuracy in ideal conditions.
  - May still require some GCPs for quality control and validation.
  - Higher initial cost compared to standard drones.
  - Must have a base GNSS station setup while conducting flight.
- Ground Control Points (GCPs) with RTK GNSS:
  - Traditional method offering high accuracy.
  - Requires more time in the field to set up and survey GCPs.
  - Ideal for projects requiring highest possible accuracy.
- For projects requiring precise and accurate vertical data, consider using both RTK drones and some GCPs for redundancy.
- Maintain detailed records of positioning methods and accuracies for each survey.
- Use consistent coordinate systems and datums across all temporal surveys.

Training/Staff

- Program management - permits, planning, oversight
- Pilot(s) that are licensed and understand how to fly drones for mapping, track flight hours and maintain up-to-date skills.
- Visual observer(s) - help the pilot maintain line-of-sight when flying the drone
- Drone management - keeping drones in good repair, licensed, and insured.
- Imagery processing - training in Metashape or Pix4D.
- GIS - mapping, geospatial analysis.
- Data management - storing imagery, outputs.

Permits and Regulations

- Register your drone with Transport Canada and label drone with registration number
- Track all of your drone flights in a Flight Log.
- Ensure required pilot certification (Basic or Advanced)
- Special Flight Operations Certificate (SFOC) for operations above 400’ or beyond visual line of sight
- Where necessarily, make sure you have liability insurance



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Best practices for planning and conducting drone flights for mapping coastal habitats

Guide to Drone Regulations and Practices

Canadian legal requirements for operating drones can be found on the Transport Canada Site.

This document will teach you how to map coastal habitats, but does not certify you to fly a drone legally. This section describes the steps to flying a drone legally in Canada.

1. Flying safely - checklist

- ❏ Learn the rules - take a ground school course online or in person.
- ❏ Get a pilot certificate - take the online test.
- ❏ Register your drone with Transport Canada.
- ❏ Consider getting liability insurance.
- ❏ Make sure you know your drone, and what to do in an emergency.
- ❏ Make a flight plan - know the airspace, hazards, and site information.

2. Flying drones for habitat mapping

Here are the basic field operation steps for drone mapping for coastal habitats. The main output from a drone flight is to collect overlapping photos that will go on to create a mosaic of the area flown.

1. Before going into the field

- **Research the study site.**
    a. Airspace - use NRCan Site Selection tool or NAV Canada App
    b. Are there airports, helipads, aerodromes nearby?
    c. What are potential hazards? e.g., Trees, roads, people, powerlines, buildings, airspace.
    d. If the flight is over private property make sure to have permission.
    e. What is the access to the site (boat, hike, car, etc)? How will you move gear and people safely?
- Make a drone flight **safety plan** and discuss it with everyone going into the field.
    a. Emergency procedures and protocols
    b. Communications, emergency and ATC phone numbers
    c. First aid, fire extinguisher, and other safety supplies
- **Test the drone** and tablet to ensure they are running properly.

a. Update any firmware if necessary.
b. Make sure you are able to work offline (test in airplane mode). In many cases you may not have cell or wifi available.

- Download all flight controller and mission planning applications that you will be using (such as DJI GO, DJI Flight, and Map Pilot).
- Bring storage - i.e. SD cards and spares, all formatted and ready for use.
- **Check batteries fully charged** for the drone, tablet, and controller.
- **Check the conditions** and tides to get the best time possible for image capture (enough light, low tide, calmer conditions, safe air traffic zone?).
- Have all necessary documents printed and available in the field including: site maps and mission plan, proof of insurance, necessary permits, drone operations manual, and all related training certificates.

Suggested acquisition guidelines for drone mapping different coastal habitats.

	Kelp	**Seagrass**	**Rocky Intertidal**
Target	Bull Kelp, Giant Kelp	Eelgrass (Zostera marina)	Mussels, surfgrass, fucus
Image Overlap	75%	75%	80%
Minimum resolution	10 cm	10 cm	3 cm
Drone Altitude	90-200 m	90-200 m	15-70 m
Speed	3-5 m/s	3-5 m/s	0.5-2 m/s
Tidal Range	Below 1.5 m	Below 0.5 m	Below 1 m
Required accuracy *For repeat monitoring, georeference to a basemap or previous survey*	2-5 m horizontal	0.5 m horizontal if aligning to *in situ* data.	0.05 m horizontal, 0.2 m vertical

- **Before going into the field, plan** a mission and save it in an application like **DJI Pilot or Map Pilot Pro**
    - Make sure the mission and basemap are saved for offline use, give it a meaningful file name.
    - In the settings, make sure that you have specified the model of your drone as this affects the mission planning settings
    - Adjust the flight path to cover the area being studied as efficiently and safely as possible. We suggest getting coverage greater than your area of interest to ensure good boundary mapping.

    - Include land and other features in your flight. Flights entirely over water will not create a proper orthomosaic. You may need to fly higher for an area with lots of open water to create an orthomosaic.
    - Flight altitude and image overlap will determine flight time.
        - Higher is faster, less resolution, less image storage, less blur
        - Lower is slower, higher resolution, more image storage, blur can be an issue (must fly slower).
        - Make sure that you have enough resolution for your species of interest (see Table above).
        - Fly similar elevations/resolution for long-term monitoring.
    - Each mission should get a unique identifier for tracking purposes. This will allow you to reference a given habitat dataset to a specific drone flight.
    - For most habitat-mapping purposes, a single grid flight pattern is acceptable.
        - For rocky intertidal habitats, a double grid flight pattern may be useful for capturing detailed terrain.
- Check the weather and NOTAMs (NAV Drone)

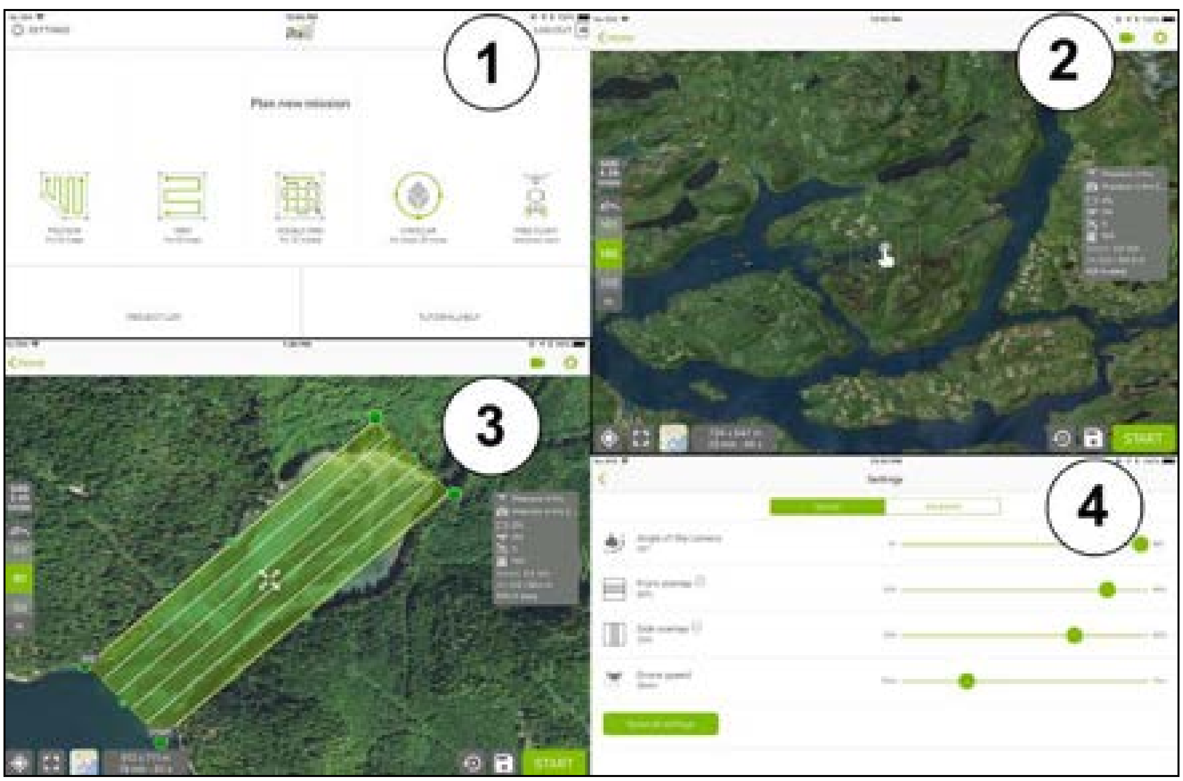


Figure 2. Example workflow using Pix4D Capture application (no longer supported application) and recommended settings which apply to any mapping application: 1) choose mission type - most commonly polygon, grid, or area, 2) choose mission location and extent, 3) choose flight altitude and adjust the extent of the area being covered, 4) in the settings tab choose camera angle of 90 degrees, overlap, drone speed.

In the field: drone setup and safety

- Take good notes and record all aspects of the mission. Location, time, tide, weather, pilot and spotter names, site map, and drone type. Transport Canada requires pilots to keep a log of all flights along with the above information.
- Inspect the drone to ensure it is in good working order.
- Check battery levels on all devices and ensure an adequate SD card is onboard.
- Check conditions (weather, tides, lighting, and safety).
- Ensure air space is clear and flight altitudes will be enough to clear trees.
- Collect JPEG images and test lighting levels and focus of the camera by taking test photos and viewing them through the flight planning application.
- In cold temperatures keep the drone batteries warm - cold batteries are less efficient and can take time to warm up before a flight can be completed.

Safe flying conditions

General weather advice

- Good visibility (maintain visual line of sight), high ceiling, low winds (<19 kn), low precipitation (nothing more than a light mist).
- Temperatures are above freezing (check for your specific drone).
- Watch for any storm activity or hazardous weather.
- Monitor the forecast for your area and weather stations.

Altitude and Distance

- Keep the drone below 400’ (120 m) unless you have permits to fly higher.
- Be aware that elevations are relative to your takeoff location.
- Keep the drone within your sight or in sight of a visual observer.
    - Generally this means the drone should be no more than 500 m away (horizontally).
    - See Appendix 1: for Visual Observer Training
- Keep constant watch for hazards like planes, birds, trees.
    - You must always give way to occupied aircraft.
    - Avoid wildlife interactions. While gulls and eagles are less likely to be bothered by a drone in flight, small birds of prey have been known to act more aggressively.

Flying the mission

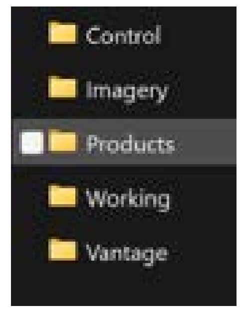
- Choose a stationary take off/landing site that is in an open area with good visibility of the entire mission area.
- Special considerations for for flying from boats:
  - Practice this skill, it's more dangerous than flying from land.
  - Be aware of the home point if the boat is moving.
  - Anchor the boat where possible.
  - Make sure all vessel occupants are aware what to do when landing and taking off.
  - Where gloves and safety glasses when taking off and landing (i.e. catching the drone).
  - Be aware of (consider turning off) obstacle avoidance if you need to catch the drone by hand.
- Check to ensure the airspace is clear and the takeoff area is safe.
- Using the mission planning application, activate the mission and maintain visual line of sight with the drone the entire mission.
- Be prepared to cancel the mission at any time.
  - In the case that you need to take over manual control of the drone, be aware of which way the drone is facing and what direction you would need to fly to bring the drone back to you. Do not just rely on the return-to-home function.
- Confirm that images are being taken. Check image capture throughout the flight as software glitches are common and can cause data to not be stored without the pilot noticing (e.g. watch SD card space).
- **Continually monitor battery level.**
- If you have time after the drone mapping mission, take scenic photos and photo spheres. These are invaluable for reporting on what the site environment looks like and for sharing.
- Once landed, preview the images and check for image blur (perhaps drone speed was too fast), focus (autofocus may not be set correctly), lighting (aperture and iso settings are not set properly), and all images where taken (SD card error).
- If unsure of quality, fly the mission again.
- Once the mission is complete preserve the SD card and take notes about the flight and any issues you may have had.

Data storage

- Backup the data in multiple locations as soon as possible after the mission.
  - Use multiple SD cards where possible, this reduces the chance of data loss.
  - We always use “working” and “archive” portable hard drives to backup our data while in the field.
- Use a flight log to track all of your drone missions. We use one similar to this, it also provides a unique ID for each mission. Example flight log sheet.

Organize your data carefully. At Hakai we use a structure of file storage that is the same for every mission:

- **Images**: contains the imagery that will be used to make the mosaic
- **Products**: Contains the final orthomosaic, as well as any other final products (e.g. DSM).
- **Vantage**: Contains images of the site that aren’t used to make the mosaics (i.e. site photos).
- **Working**: This is where “working” versions of orthomosaics, delineations, or other product files are stored.
- **Control:** Any files related to ground control GPS points or georeferencing.



We organize our missions by date and region. We also use a unique mission ID, location, and date in the folder and file names.
Examples:
Project naming structure: Region > Year > Site (YYYYMMDD_SiteName_MissionID)
    CentralCoast > 2018 > 20180512_Triqueteelgrass_U0062
Product naming structure (what goes in the Products folder):
YYYYMMDD_Region_SiteName_georef_MissionID.tif

Creating orthomosaics from drone images

We recommend Agisoft Metashape or Pix4D Mapper, or DroneDeploy for creating orthomosaics.

- Metashape seems to work better for water areas and can incorporate a glint masking workflow.
    - We find that it produces a better quality data product for mapping kelp forests compared to Pix4D.
- Pix4D Mapper has a better interface, but is less customizable.
- DroneDeploy is the most user friendly and is fully in the cloud.

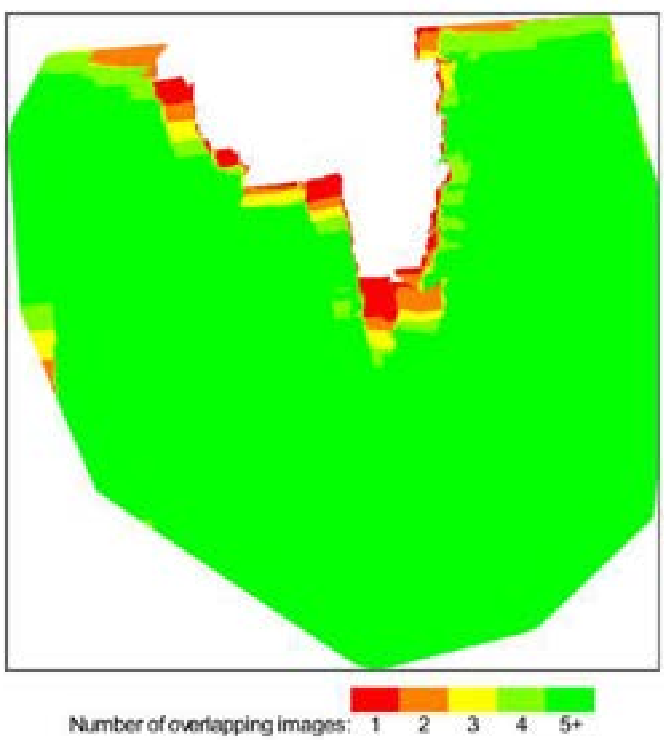
Once you have your images, input them into the structure from motion (SfM) software to create 3D models, digital surface models, and orthomosaics.

How SfM works:

1. The relative positions of the cameras are calculated based on these matched features.
2. A sparse 3D point cloud is created from the matched features.
3. This initial reconstruction is refined through bundle adjustment, optimizing camera positions and 3D point locations.
4. Dense matching algorithms then create a detailed 3D model of the scene.
5. A digital surface model (DSM) is generated from the dense point cloud.
6. Individual images are orthorectified using the DSM to remove perspective distortions.
7. The orthorectified images are then mosaicked together, blending overlapping areas.
8. Color balancing is applied to ensure consistency across the entire orthomosaic.
9. The final orthomosaic is georeferenced to align with real-world coordinates.

No matter which software you choose, there are some general factors to consider when running and assessing the outputs of the SfM process:

- Spatial Reference
  - What coordinate system are you using for your project (e.g., UTM, BC Albers)
  - Are you integrating with data from other sources?
- Image quality and overlap
  - This affects point density, ability to reconstruct complex features.
  - Are the images properly exposed and in focus, is there motion blur?
  - Check for images that are "uncalibrated", meaning they couldn't be tied to other images
- Ground control
  - Are you using ground control points?
  - Are you tying into other existing projects?
- Scene complexity
  - Areas with dense vegetation or steep terrain may be more difficult to reconstruct - increase the number of photos taken, increase overlap, and fly at higher altitudes.
- Lighting and shadows
  - Very bright or very dark areas may have difficulty with reconstruction



Delineating Habitat Extents

This section describes methods for delineating eelgrass, kelp, or mussel bed extent from a drone orthomosaic.

This can be a time-intensive process. We focus on achieving sufficient detail and resolution (both spatially and thematically) to produce a final product that will be useful to monitor changes in these habitats. The data generated will also serve as an independent validation for future remote sensing analyses. For kelp and mussels, Hakai provides an AI tool for automated classification of habitat extent in an orthomosaic (see section on Kelp-O-Matic below). For eelgrass we provide adapted methods (NOAA, 2001; Environment Canada, 2002) for delineating eelgrass extent, density and distribution.

Software and Data Requirements

1. Access to and basic working knowledge of a GIS software platform (e.g. ArcGIS,QGIS). Note: In this document we describe methods for ArcGIS but these methods are adaptable to other software platforms.
2. Orthomosaic (e.g. .tif drone image) of the habitat monitoring site.
3. A copy of "Habitat_delineation.gdb". (for eelgrass)
    a. This contains the template for eelgrass polygon feature classes and a sample drone image.
4. Any available field data and notes on species presence, density, etc.
    a. E.g. For eelgrass we often collected towed underwater video data to validate the subtidal edge of the eelgrass meadow.

Before you begin

Georeferencing

For time-series analysis, it's important that orthomosaics are aligned. New orthomosaics should be georeferenced to existing imagery for the area when such data exists. An existing survey with ground control points can be used as reference, or imagery can be aligned to a basemap or other source. Methods for how to do so in ArcGIS and QGIS can be found online.

Image quality

The quality of the orthomosaic will affect the confidence with which an individual is able to identify features within that image. Uncertainty should be documented in the confidence attribute and reviewed by a second analyst where possible. See section below on scoring confidence.

Multiple users/delineators

With each individual mapper there is the introduction of error as different people interpret and delineate images in different ways. Where possible, efforts should be made to have the same person delineate habitats to ensure consistency. In all cases the mapper should document their decisions. If possible, a secondary mapper can review and QA/QC the dataset.

Accuracy assessments

There is always some degree of error associated with maps, therefore it is important when and where possible, to try and quantify that error. Classification error occurs when a feature belonging to one category is assigned to another. Accuracy assessments are intent to place confidence limits on remote-sensing-derived information. Validation data, used to evaluate error, may come from various sources. For example, georeferenced towed underwater video data are used for validating remote sensing data products (e.g. Reshitnyk et al., 2014). You may also have other GIS data that were collected in the field (e.g. intertidal surveys, SCUBA surveys, etc).

Metadata

Metadata are data that describe and give information about other data. In the context of habitat mapping, metadata describe other attributes of the dataset that exist outside of an image such as what was the date and tide during which the imagery was collected, who did the delineation, what model of drone was used, etc.
Recording accurate metadata is crucial to allow an individual who may use those data in an analysis to fully understand all of the factors that are associated with the final delineated dataset generated from the methods described in this document.

Mapping kelp forests

This section describes how to map dominant canopy-forming kelp species giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*) distribution from RPAS imagery. What we map is the portion of each kelp that is present at the ocean's surface. At Hakai, we have been using drones to map kelp forests since 2015 and have developed specific expertise in mapping kelp forests in British Columbia.

The two kelp species differ in their phenology and morphology. Bull kelp is an annual (individuals typically grow and die within a year) while giant kelp is a perennial (individuals continue to grow for multiple years). Generally, bull kelp has a linear appearance due to the single large bulb (pneumatocyst) and trailing blades. Giant kelp tends to have a more feathery, blob-ish appearance and are typically larger than bull kelp.

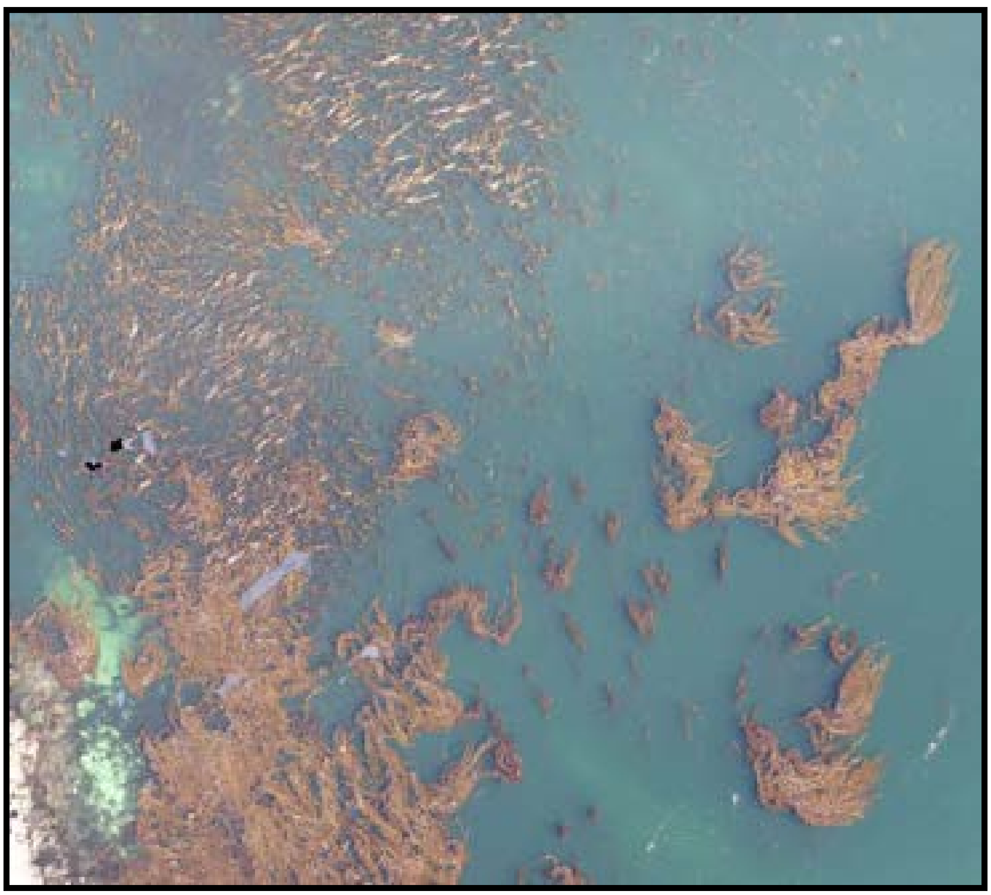
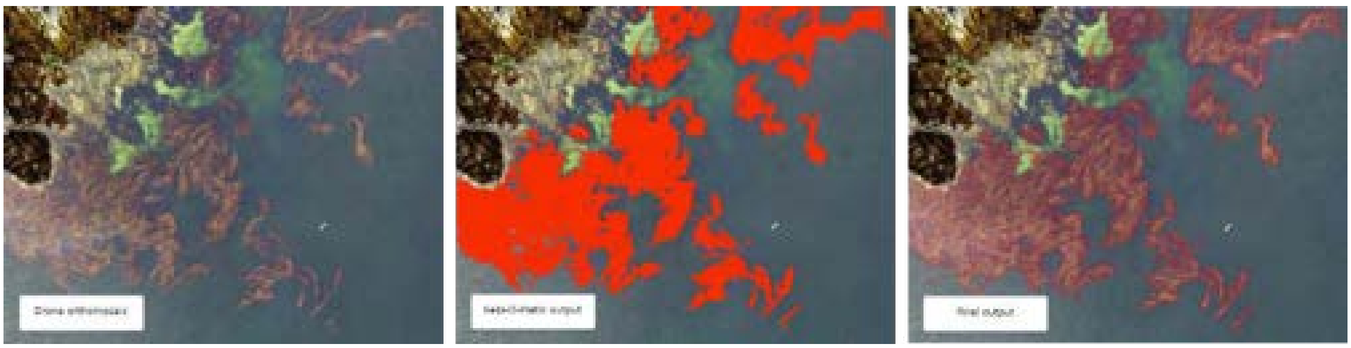


Image showing Nereocystis bed in the upper region transitioning to a Macrocystis bed in the lower region of the image.

Kelp-O-Matic for automated kelp mapping

The Kelp-O-Matic software can be used to automate the mapping of kelp or mussel pixels in RGB and multispectral (for kelp only) drone orthomosaics. It is open-source and free for anyone to use. We strongly recommend the use of this tool as it greatly reduces the time it takes to produce a dataset of kelp or mussel extent from your drone orthomosaic while maintaining accuracy (Reshitnyk et al., in review).

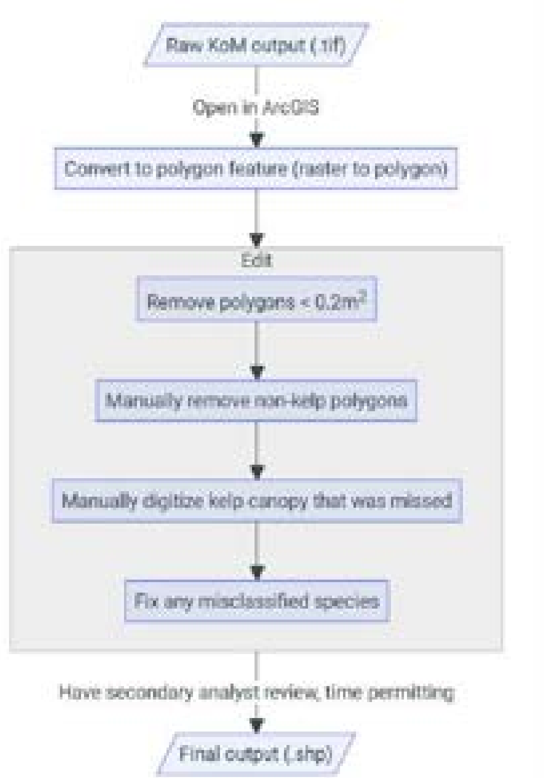
All of the documentation for how to use the kelp-o-matic software can be found on the website.



We provide a Beginner's Guide for how to install and run the tool as well as post-processing outputs in a GIS.

Kelp polygon workflow

The Kelp-o-matic (KoM) tool works well but is not perfect, so the output labels may require additional editing. Refer to the section on post-processing for detailed steps on editing and reviewing Kelp-O-Matic outputs prior to analysis. The workflow to the right shows how the label outputs of KoM are converted into final habitat polygons.



Data attributes and storage

It is important to include attributes for each kelp extent output that is generated so that valuable metadata is associated with that product. The table below provides a template for which attributes can be included for your dataset.

Mussel Mapping

Hakai has long been interested in monitoring the intertidal zone as it's a high biodiversity area. There are several important species that live in this ecological niche, with mussels being one the more important keystone species. Because of their importance, Hakai has been monitoring mussel beds on the central coast for nearly 10 years.

After creating the orthomosaics, we run the imagery through the following workflow:

1. Run the imagery through Kelp-o-Matic find-mussels to classify mussel pixels
2. Convert label output to polygon (polygon data or GDB feature class is fine)
3. Edit polygons to fix any errors from the ML model. Lasso tool works well.
4. Dissolve edits to remove any overlapping polygons
5. Have a second user QC the dataset
6. Add polygon attributes to describe the date, weather, or other metadata
7. Archive the polygon datasets at least annually

Limitations and things to watch out for

- Areas with steep terrain and high shadow are difficult to map
- Kelp-o-matic can't identify gooseneck barnacles, and may misclassify them
- Mussel areas should be calculated using surface area not 2D area

Eelgrass Mapping (*Zostera marina)*

Documenting changes in extent of eelgrass meadows is important for the conservation and monitoring of eelgrass ecosystems. In this document, methods are provided which describe the delineation of eelgrass, specifically eelgrass (*Zostera marina*). *Zostera japonica* is also present along the BC coast, however, it is not currently possible to differentiate between the two species based on RPAS surveys alone - field data are required to confirm the species. The steps and examples provided are for delineating eelgrass (*Zostera marina*) though we refer to eelgrass throughout the document.

Note: Existing methods for defining and delineating eelgrass habitat were developed by Environment Canada. While this document does borrow working definitions from the document, there are notable differences in how eelgrass density/percent cover is treated.

This section is broken into :

1. Definitions
2. Workflow overview
3. Before you start
4. Delineation methods
5. Tips and suggestions

Image of an eelgrass bed from a drone.

1. Definitions

The following definitions have been adapted from *Methods for Mapping and Monitoring Eelgrass Habitat in British Columbia* (Environment Canada, 2002) and *Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach* (NOAA, 2001).

1. **Eelgrass bed**
   - An area of eelgrass covering an area > 5 m^2
   - Generally, gaps greater than 3 m between plants separate eelgrass beds
   - A bed may be made up of multiple patches within 3 m of each other, where a patch of eelgrass is an area of eelgrass spanning > 1 m but less than 5 m in any direction

2. **Density**:
   - A categorical measure of the aerial coverage (% cover) of eelgrass within a given area (high, medium, low - see Table 1 pg. 16).

3. **Distribution**:
   - Continuous: Continuous is used to indicate that eelgrass is distributed evenly over most of the area within the bed (Figure 1). There may be some areas without eelgrass within the bed.

   - Patchy: Eelgrass is described as patchy when the bed or meadow is composed of many patches or islands of eelgrass, most of which are surrounded by areas without eelgrass. [...] The area between patches is usually either exposed substrate or macroalgae." (Environment Canada, 2002).

   - We refer readers to Appendix 6 of *Methods for Mapping and Monitoring Eelgrass Habitat in British Columbia* (Environment Canada, 2002) for other visual examples of patchy versus continuous eelgrass distribution.

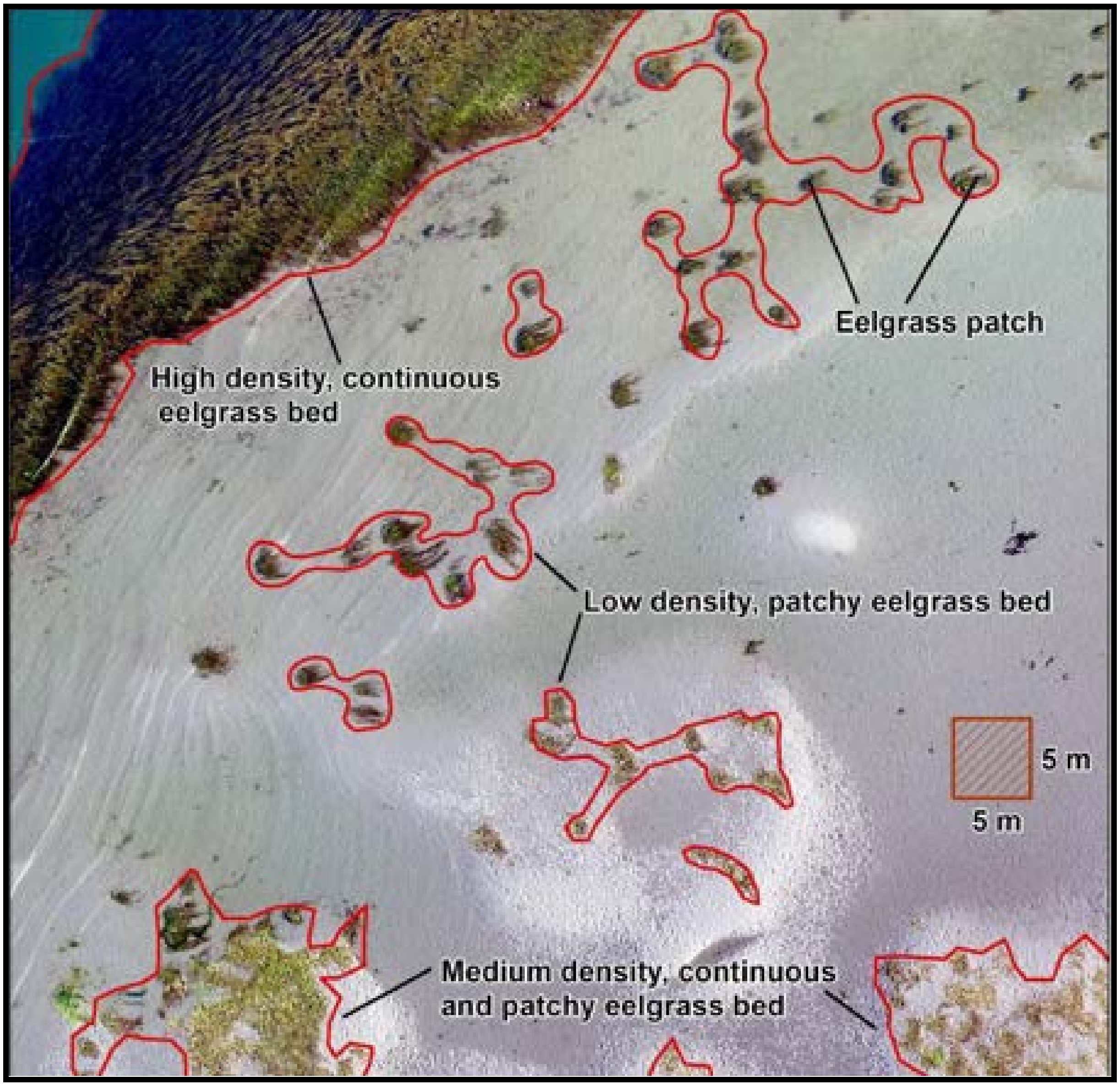


Figure 1. Image showing delineated regions of eelgrass (red polygons) of different distributions and densities

2. Workflow steps for delineating eelgrass

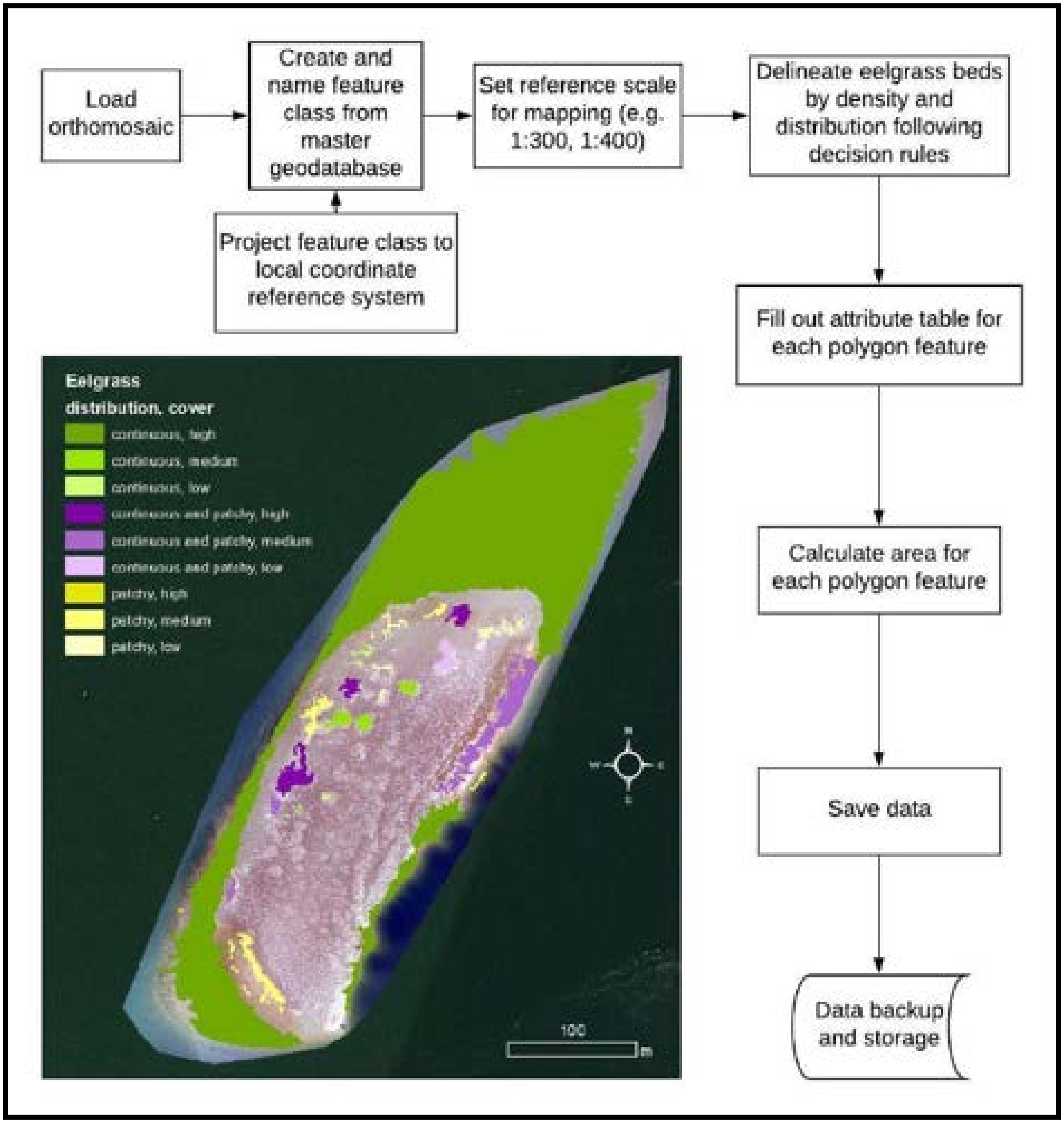


Figure 2. Workflow of eelgrass delineation methods. In this workflow feature class refers to a collection of polygons which have a common set of attribute columns.

3. Before you start

- The confidence for mapping a given scene will be influenced by many factors (quality of the imagery, conditions on the day of the survey, complexity of the site). Do your best, be consistent, document uncertainty (see A note about scoring confidence section below).

- Using a consistent reference scale is helpful. 1:300 is recommended for this work.

- Look over and browse the entire image area before you start your delineation. It's good to get an overall impression of how eelgrass is distributed across the site.

Below are recommended interpretation decision rules adapted from *NOAA Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach*. When in doubt, referring to these recommendations will help decision making during delineation.

1. The outer boundaries of beds are more important than internal structure (patchiness, shapes or sand patches within) of beds.
2. The outer boundaries of beds are more important than density categorizations within beds (see Figure 1).
3. One of the most difficult decisions to make is whether areas with patches of eelgrass are one polygon of patchy eelgrass or individual eelgrass polygons. In this case, the minimum mapping unit of 5 m^2 should be used to make the determination (See Figure 1).
4. Erring on the side of lumping is preferred except in areas where small patches are the only vegetation. In deciding whether to exclude or include an area with only a few patches (> 1 m^2), include the polygon of patchy eelgrass if the area is greater than 25 m^2. Err on the side of including these areas rather than excluding them.
5. A cutoff should be approximately 10 percent eelgrass cover. Areas with less than 10 percent cover are unlikely to be reliably delineated.

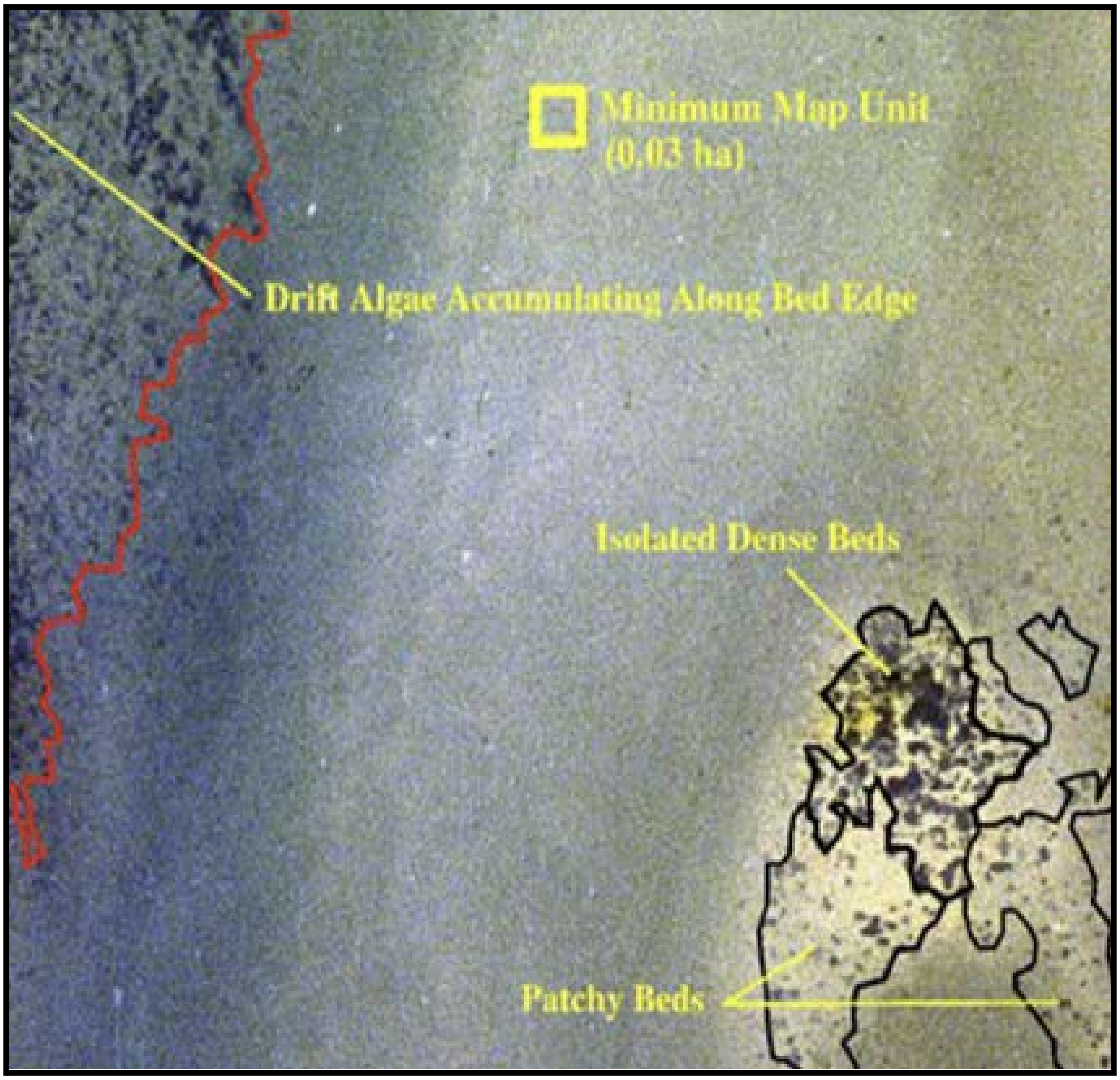


Figure 3. Example from *[NOAA Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach](#)*.

4. Rules for eelgrass delineation

NOTE: We provide Habitat_delineation.gdb with an example dataset with a raster and classified eelgrass delineation to refer to.

1. For continuous beds (evenly distributed eelgrass), draw a polygon by following the outer boundary of the eelgrass bed.
    a. Patches within ~ 1 m of the boundary should be included if the patch is at least 1 m^2).
2. For patchy beds, the following delineation decisions should be followed:
    a. **Do not** delineate a patch which is < 1m^2 and **not** within 3 m of another patch.
    b. Any patch > 3 m or larger (in any direction) should be delineated.
    c. Patches within 3 m of each other should be considered as part of the same bed. If a patch is < 1m^2 and within 3 m of another patch, these should be grouped together in the same polygon.
    d. If in doubt, err on the site of lumping patches together into a single bed than drawing multiple smaller beds.
3. Avoid including bare areas within a polygon (more detail for bed delineation is better).
4. Follow the contours of the bed and be consistent with the level of detail (polygon point density). Include a point every 1 - 2 m Stay within 0.5 m of the edge of the eelgrass bed. The eelgrass should be entirely contained within a polygon.
5. Fill in the attribute table with appropriate data. Consistency in labeling is vital.
6. If you have any issues or confusion of species make a mark in the comments tab of the attributes table to ensure it is looked at more closely.

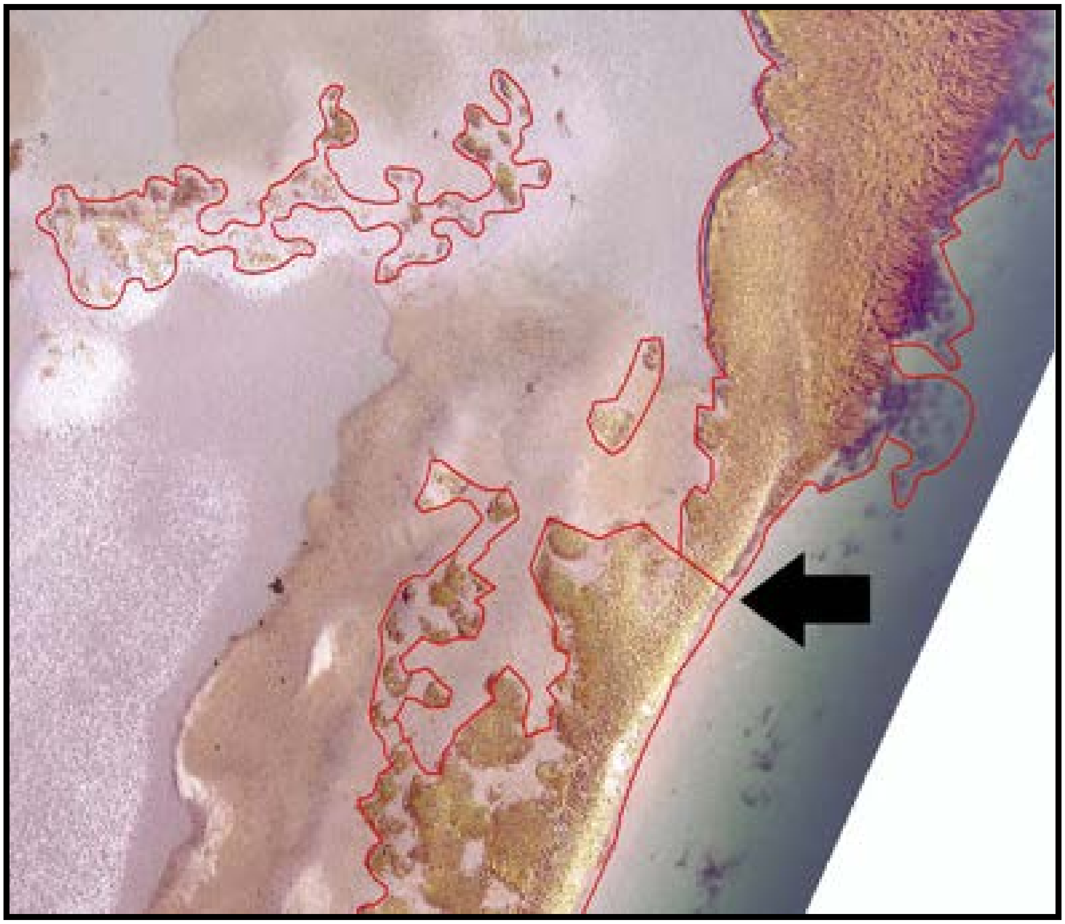


Figure 4. In this example the bed changes from continuous to a mix of continuous/patchy, therefore the decision was made to separate the beds even though there is a continuous boundary.

7. You may choose to create or split a bed where you see a change in the bed distribution and/or density even though the boundary is shared. See the example below.
8. When in doubt, refer to the “Before you start” section for recommended interpretation decision rules.
9. **<u>Save your work regularly.</u>**

5. Tips and Suggestions

1. Quality of delineations will decline with fatigue. Take time between periods of delineation to help maintain consistent effort.
2. While this document tries to provide rules and guidance on delineation, interpretation is also required. There will be times when a rule provided does not fit a step listed here. In these cases, be consistent and document choices in the notes of the attribute table.
3. When entering a polygon use the handy “length” indicator, which should show you the length of each segment in metres.. This can be handy for determining if neighbouring eelgrass beds should be all connected as one or separate. Alternatively, you may set up a grid or graticule to help visualize distance.
4. Hold down the “c” button on your keyboard to pan around while you are editing your eelgrass bed. This can be helpful for delineating large area.
5. Create keyboard shortcuts for tools that are used often to help save time.

ArcGIS has an online Introduction to the Editing tutorial which is a very helpful reference.

6. What does eelgrass look like in an image?

There are many factors that affect what eelgrass looks like in an aerial image. When it comes to eelgrass delineation it is up to the analyst to use image interpretation techniques based on colour, tone and texture to differentiate between eelgrass and non-eelgrass regions. Confidence comes from practise and knowledge of the site. When available, use ground truthing photos and field notes can be very helpful in image interpretation.

General tips and observations

1. Generally, shallow/exposed eelgrass is a deep forest/emerald green shade. Brighter/neon green is typically green algae (e.g. Ulva sp.).
    a. This colour may change based on epiphytic load (ie. other algae growing on the eelgrass). Eelgrass with other algae growing on it is common in areas with higher human populations. In these cases eelgrass may look more brown or red.

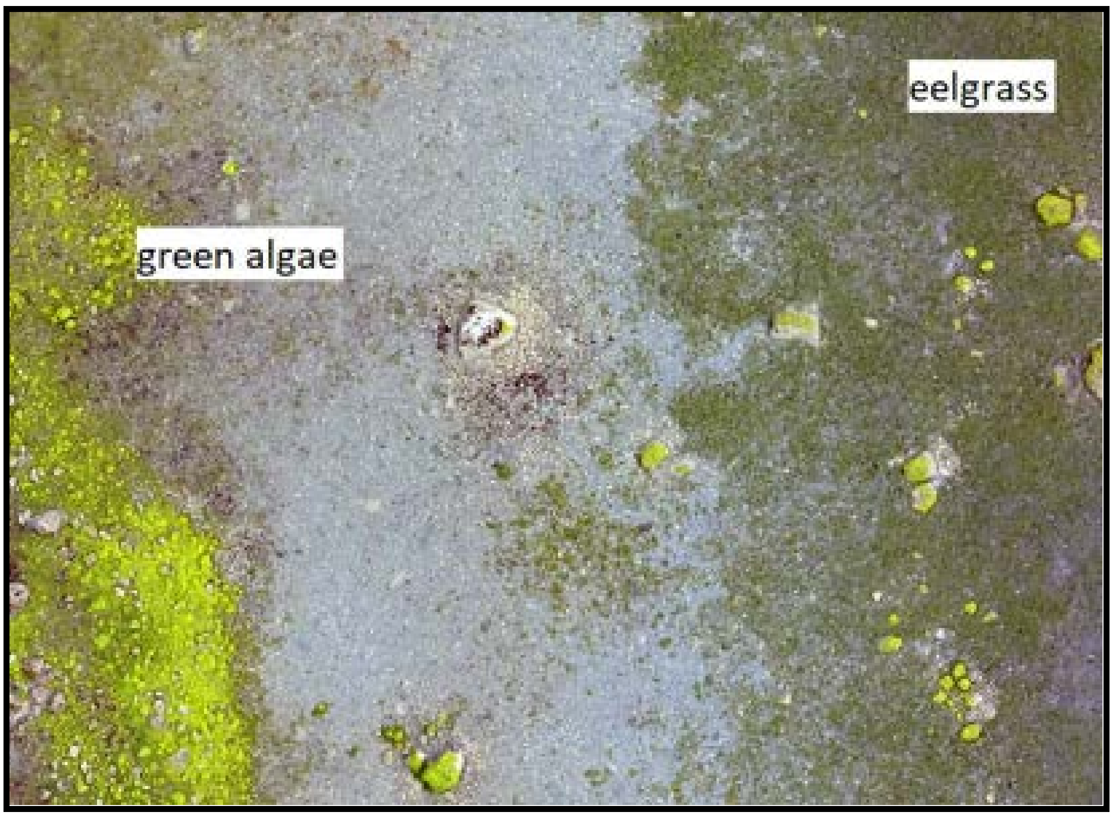


Figure 5. Image showing green algae and eelgrass (Z. marina).

2. The deeper the eelgrass is underwater, the darker and less defined it looks. It becomes increasingly difficult to differentiate between other types of submerged vegetation as depth increases. For mapping, the assumption is made that a bed extends into the subtidal and is therefore a continuous extent.

Figure 6. Image example of shallow and deep eelgrass (Z. marina) distribution.

3. Dense eelgrass is easier to identify than sparse eelgrass. Where there is more eelgrass, it is easier to identify in an image. Sparse eelgrass beds (more common in upper intertidal regions and during early summer) may be difficult to identify as the blade length is typically shorter and plants are further apart.

    a. Below is an example of the same area in spring and late summer showing the same region with different eelgrass density.

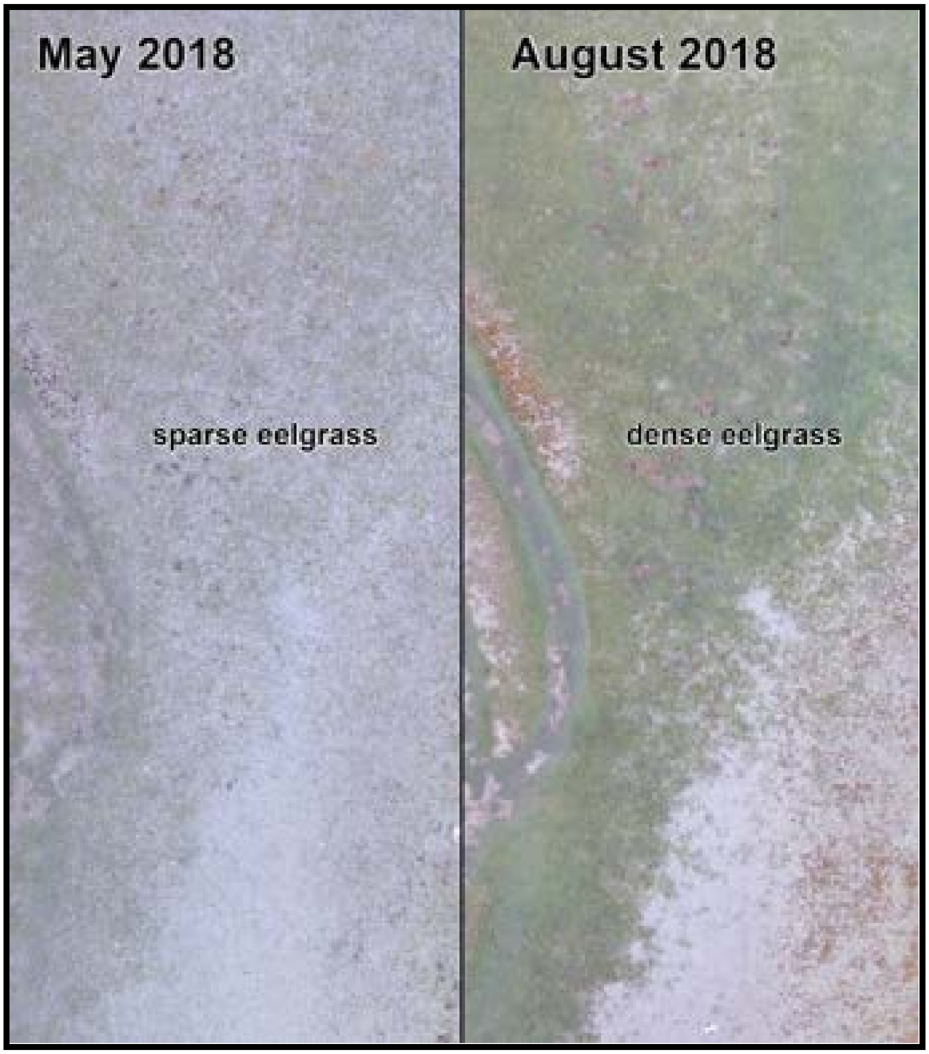


Figure 7. Orthomosaics of eelgrass bed taken in early summer and late summer showing differences in eelgrass density.

7. Delineation methods for eelgrass

1. Open ArcGIS
    a. Load the orthomosaic
    b. Navigate to the *Habitat_Delineation.gdb* in ArcCatalog
        i. Make a copy of *Eelgrass_MASTER* polygon feature. This polygon has been populated with all of the relevant attributes and drop down menu options
            1. Rename the copied version to reflect the site.E.g. Eelgrass_Region_Site_YYYYMMDD
        ii. Load this polygon data into ArcMap

Table 1. Attributes and description for eelgrass polygons

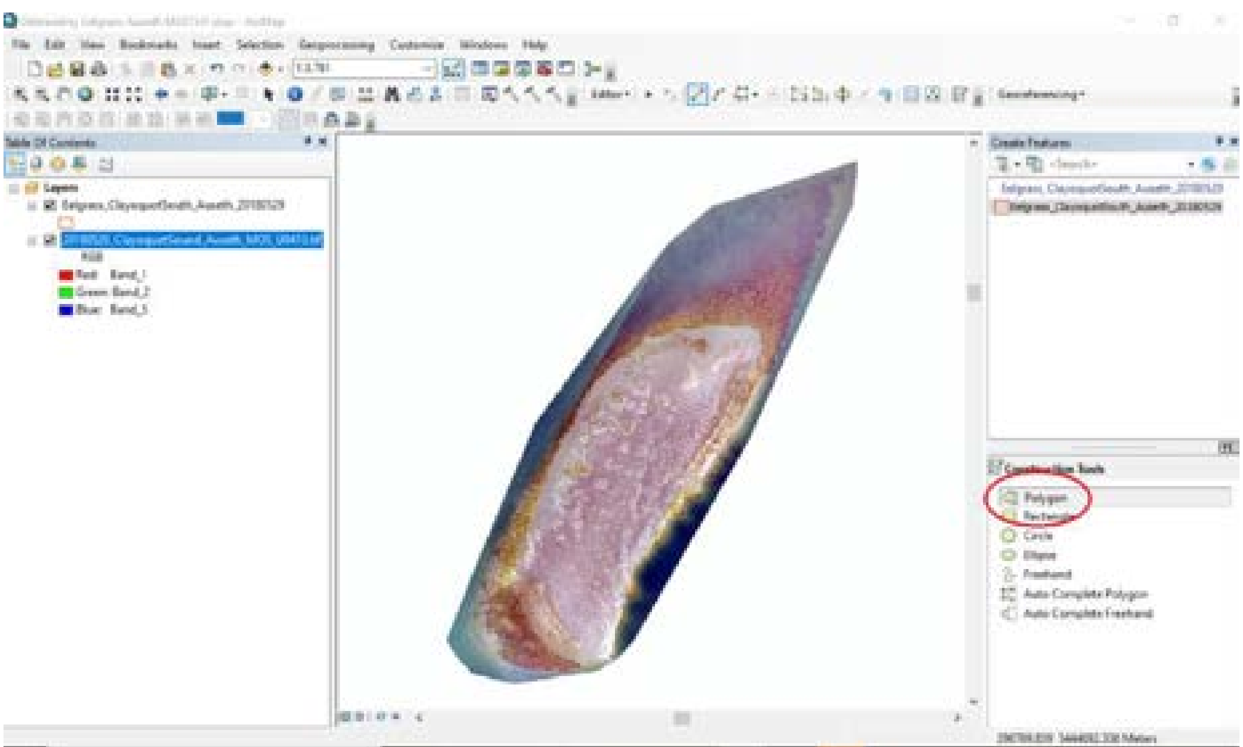
Attribute name	**Type**	**Attribute options**	**Attribute description**
species	Text	Zostera marina Zostera japonica mixed	The species of eelgrass that is being mapped.
distribution	Text	P - patchy	Patchy - bed contains isolated patches of eelgrass. Distance between patches is at least 1 m. Bare patches more than 50% of area.
		C - continuous	Bed mostly vegetated, may have some bare patches.
		CP - continuous and patchy	Bed is continuous with significant bare patches. Bare patches are more than 25% of the bed area.
density	Text	High	> 60% vegetated cover, delineated area has more eelgrass than bare cover
		Medium	40 - 60% vegetated cover, delineated area has approximately 50/50 eelgrass and bare cover
		Low	<40% vegetated cover, delineated area has more bare cover than eelgrass
Area	Float	Numeric	Area (m^2) of eelgrass bed
Confidence	Text	High, Medium, Low	How confident is the mapper about the above category assignments?

notes		text	Option to describe issues with delineating eelgrass, how much effort, how confident is the mapper in their final delineation.

2. Set view scale between 1:300. This will keep the “zoom” in level consistent during delineation.

3. Right click eelgrass layer > Edit Feature > Start Editing
   a. Editor toolbar will show up in the top frame

   b. Click Create Features  button. Create Feature panel will appear
   c. Click on your polygon name, options for Construction Tools will appear at bottom of pane
      i. Select “Polygon”
      ii. You are ready to start drawing polygons.



d. Remember to save your work regularly by going to Editor > Save Edits

e. When you are done drawing, fill out the attribute table for each delineated eelgrass polygon using Table 1 (you must still be in editor mode).

f. To populate the area attribute, in the attribute table, right Click Area column in the attribute table > Calculate geometry
   i. Property = Area
   ii. Units = m^2
   iii. Click OK

10. When delineations complete
    a. Editor > Save edits
    b. Editor > Stop editing

Habitat polygon data attributes

Once you have a final habitat polygon dataset that has been reviewed and finalized, we recommend including attributes to each polygon data. The table below documenting attributes to your dataset ensures proper data attribution and metadata.

Table - Data dictionary for spatial extent of habitat extent derived from RPAS surveys. Bold names are strongly recommended attributes.

Descriptive name	**Variable name**	**Variable description**	**Units or variable categories**
File Name	filename	Name of the polygon data. Naming convention is YYYYMMDD_Region_ Site_kelp.shp	text
Site name	name	Name of the survey site.	text
Date of image acquisition	img_date	Date that image was acquired.	YYYY-MM-DD
Repeat	repeat	Frequency of site analysis.	Text. E.g. repeat, unique, longterm.
Region	region	Larger geographic region where kelp was mapped.	Text. E.g. Calvert, Central Coast.
Dataset Provider	data_prov	Name of institute providing data.	Text. E.g. Hakai Institute.
Original image spatial resolution (m)	img_res	Spatial resolution/cell size of the orthomosaic from which kelp canopy was digitized.	Numerical. Meters.
Sensor name	sensor	Specific sensor or sensor type that was used for image collection.	E.g. DJI Phantom 4 Pro
Dataset identification	data_ID	Name of source image, or other ID that can be used to identify the dataset that the delineation was based on.	na
Tide Height (m)	tide_m	The tide height chart datum) during image acquisition.	Meters (MLLW)
Description	descrip	A description of what the polygon dataset represents. Indicate as specifically as possible the name, model and source of the imagery. Indicate if more than one source of imagery was used, if data were collected on multiple days, etc.	text

Habitat Type	habtype	Habitat type delineated - seagrass or kelp.	E.g. kelp
Sharing	sharing	Description of data sharing requirements. Public means it will be shown on the map. Not to be shared on a web map means exactly that. All of the datasets will require a request to be shared.	text
Citation	cite	List of authors, organizations for the citation of the data.	text
Contact	contact	Who to contact for data sharing.	text
Dataset DOI	DOI	DOI if the dataset has one.	text
Location	file_loc	Where the data (polygon data) are stored internally at Hakai Institute.	text
Links	links	Link to metadata record or readme.	text
Species	species	Name of species being delineated.	text
Area	area_m	Areal extent of polygon.	meters squared
Perimeter	perim_m	Perimeter length of the polygon feature.	meters
Delineation_method	delin_meth	Method used to delineate the polygons.	Text. E.g. Manual, pixel classification (aka image indice), pixel classification and manual
Confidence	conf	Confidence of the analyst about classification of the polygon.	Text. High, medium, low
Analyst	analyst	Initials of the analyst who did the delineation.	E.g. LYR - Luba Yvanka Reshitnyk
Notes	Notes	Additional comments from the analyst.	text

A note about the "confidence" attribute score:

There are many factors that may influence the confidence that an analyst has in the classified output from an RPAS survey. There may be site factors (e.g. site complexity, mixed species present) and/or environmental factors (e.g. variable lighting, turbidity, wave action) which reduce the accurate delineation of habitat extent. Assessing confidence levels in habitat mapping allows us to determine if observed changes over time are genuine or potentially uncertain.. You may choose to combine confidence intervals (e.g. medium-high) and describe parts of the imagery which have less confident outputs (e.g. perhaps inshore areas are confidently mapped and offshore areas are less confident due to high wave action).

Below we provide a general rubric of how to score confidence:

- High confidence:
  - image quality: calm sea state, consistent light (full sun is best but fully overcast can also be good), low (if any) blur
  - Site characteristics: only single species present, clear water conditions (important for seagrass mapping), habitat is continuous and dense
- Low confidence:
  - Image quality: variable or very low lighting, high wave and wind
  - Site characteristics: many species present (lots of mixing), turbid water conditions, habitat is sparse

For seagrass mapping, we refer readers to Nahirnick et al. 2019 - Mapping with confidence; delineating seagrass habitats using Unoccupied Aerial Systems (UAS) - for additional details on understanding the impacts of site and environmental conditions for seagrass mapping.

Low light conditions may make delineation decision making more difficult. This image shows *Nereocystis* along the shoreline and *Macrocystis* further offshore. (1:400)

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