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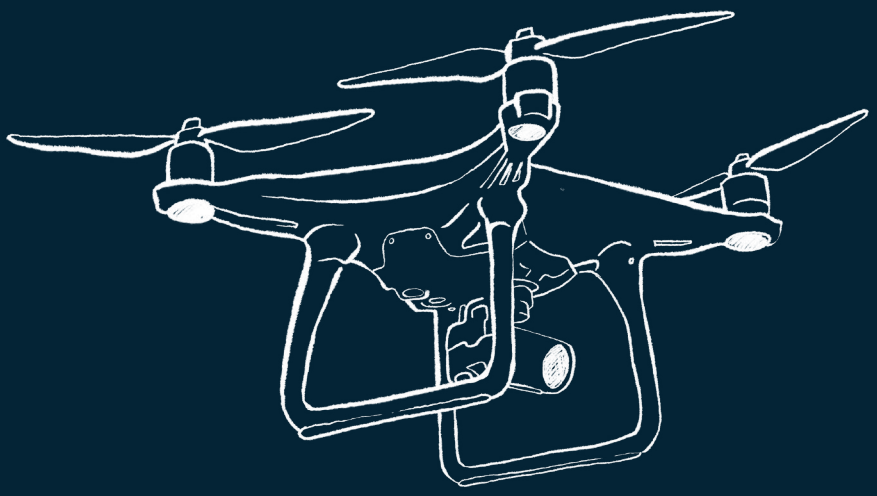

MONITORING PLASTIC POLLUTION ON BEACHES WITH DRONES

A FIELD GUIDE

CONTENTS

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INTRODUCTION

This handbook is designed to guide scientists and the public on the best way to survey beaches for plastic pollution. While significant progress has been made to enable drone technologies to combat plastic waste, much of this information remains inaccessible - locked behind paywalls, commercial applications or in highly technical documents. Here, we aim to enable anyone with a drone to contribute, by providing resources for planning and conducting flights, selecting the right gear, processing data and getting results that can be shared with the wider community.

We provide methods for both standard consumer-grade cameras (RGB) found on hobbyists drones, and more advanced thermal (TIR) and near infrared (NIR) cameras. In both cases, there are approaches that can enhance the utility of your data, benefiting not only yourself, but also local government, community initiatives and scientists.

This handbook is by no means the last-word in the topic. We encourage feedback that can make this resource as useful as possible, for as many people as possible. If you have suggestions, local information or wish to help translate it into another language, please get in touch!

PRE-FLIGHT PLANNING

Before surveying beach plastic pollution, the most important thing for success is to make a plan to ensure safe data collection.

☐ **Ensure you have landowner permission for where you plan to fly your drone.**

This can be hard to find in some locations. Have a look online, or check beach car park signs. The local government environment or water quality team will often be able to point you in the right direction if it is not immediately obvious.

☐ **Ensure you have the necessary accreditation.**

For example, in the UK under the Civil Aviation Authority (CAA) you need a flyer ID for every individual flying the drone and an operator ID to indicate who is responsible for managing a drone or model aircraft. The EU has very similar rules, as does New Zealand. In Australia, you require a RePL (Remote Pilots Licence) to conduct non-recreational activities with drones.

☐ **Ensure your proposed flight plan is out of airspace restrictions.**

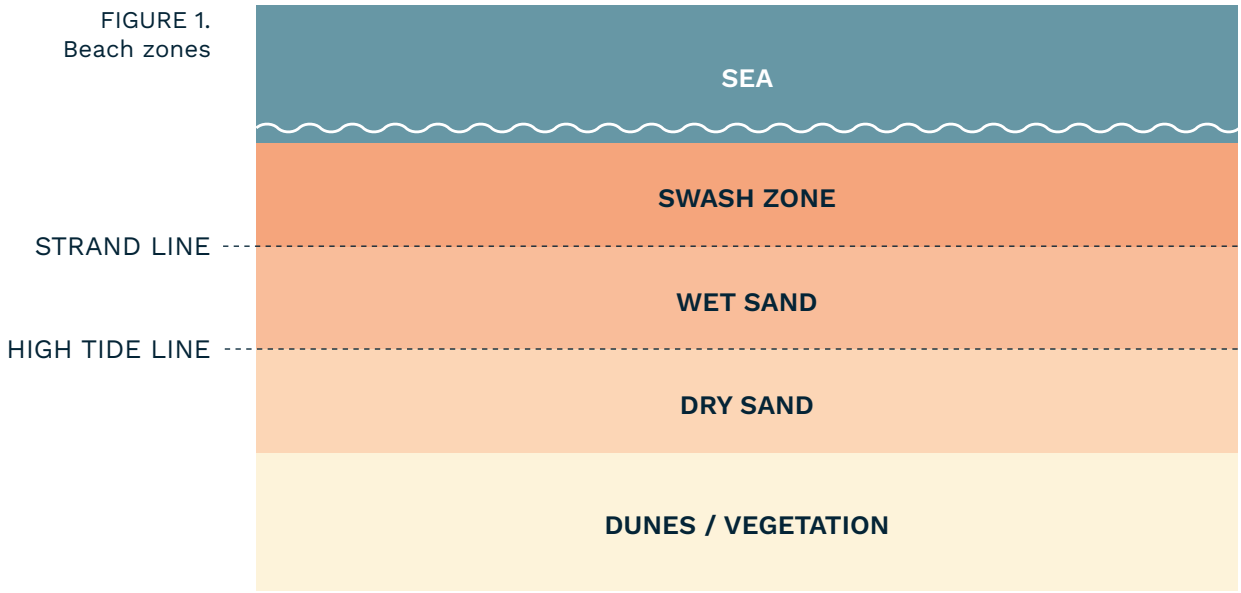
Check for ground hazards. For example, check for sites of special scientific interest, ports, bathing areas and power lines. These restrictions may mean that some beaches cannot be surveyed by drone.

☐ **Check the tide times and heights.**

Tide times and heights affect which elements of the beach you are able to survey. Access to the high tide line, the strand line, the swash zone or the dunes behind all vary throughout the day (see Figure 1).

Beach accessibility may also vary throughout the month due to different high tide times and heights. You should be aware of the high tide mark on the day you plan to survey, and plan accordingly if there is a risk your access path will be submerged.

FIGURE 1.
Beach zones



KIT LIST

General

- [ ] **Drone(s)**

  The ideal platform is a drone that mounts both a RGB-NIR (Red, Green and Blue and Near Infared) and a TIR (Thermal Infared) camera. However, such a drone would be both expensive and relatively rare at time of writing.

  Most people have access to equipment that only mounts a RGB camera. This is still useful! However, the data analysis processing is harder, and is limited to the size of plastic it can detect. A drone with a RGB-NIR camera can do more, and can be used to detect smaller plastic against more complex backgrounds than a simple RGB camera.

- [ ] **Multiple batteries**

  Particularly on a windy day, a full beach survey will easily consume several hours of battery.

- [ ] **Memory cards**

  Use a fast card with at least 60GB of storage is recommended in order to collect data without worrying about running out of space during a survey.

- [ ] **Ground Control Point (GCP) boards or targets**

  These are 30-50 cm flat objects that you can place on the ground to provide points of reference during your survey. Choose a GCP that will contrast with the sediments of the beach you are surveying. If working on beaches with lighter coloured sediments, choose a dark coloured GCP. You can make GCP boards cheaply by spraying an old chopping board black, and then taping a cross shape with white tape on it. Ultimately you want regular, high contrast, objects that are easily carried and placed into your survey area.

- [ ] **Backpack**

  Ensure you have a means of carrying a heavy drone easily. Carrying 10+ kg cases by hand over soft sand and dunes by hand is difficult and can be made easier with a backpack.

- [ ] **Control plastic**

  Control plastics are useful in a drone survey to enable accurate calibration of sensors and cameras, validating the detection algorithms by providing known reference points. This enhances the reliability and consistency of data collection and analysis, allowing for effective benchmarking and quality control across different environmental conditions.

  Make sure you're familiar with the properties of your control plastic (such as size, shape, colour, polymer, etc.) It is useful to bring a variety of types, sizes and colours to test detection limits. Ensure they are large enough to be easily seen and found again once you are done.

  Keep photos and a record of the plastic items. If it is possible to keep the items, they may be useful for further laboratory work to support analysis.

- [ ] **Handheld GPS device**

  Bring a handheld GPS device to record the locations of your GCP boards and control plastic. There are apps to do this on a smartphone, e.g. MyGPSCo-ordinates or CoverDrone FlySafe.

- [ ] **Sand pegs or tent pegs**

  These can help secure items such as the landing pad for your drone. Beaches are often windy, so having a way to secure lighter items can save you trips down the beach when something gets blown away.

- [ ] **Surveying tape**

  This can also be a useful addition to your kit if you are working over a large area to mark pegs and objects you need to relocate later. Sun glare and a large flat surface can make it difficult to spot low lying objects.

  It is also handy for marking out the edges of your survey area, if you are working on a beach with members of the public present. Most jurisdictions require you to immediately cease flight activities when someone gets too close to an active flight. Marking out the activity area helps the public know where flying is going to happen, and also makes it easier for you to see if someone has entered an area that requires you to land.

- [ ] **Dry bags or ziploc bags**

  Bring these to keep equipment, hard drives, samples, etc. safe from moisture.

- [ ] **Field diary**

  This will be used to log your location, weather conditions and observations etc.

Personal safety

- [ ] **High-viz clothing**

  This can help the public identify that you are conducting a survey, which reduces the chance of having a member of the public walk into your flight zone and needing to ground your drone.

- [ ] **Suitable clothes for the weather**

  Fieldwork often requires long hours outdoors, so wearing the right clothing is essential. Opt for lightweight, breathable fabrics that offer sun protection. Long-sleeved shirts and trousers can help protect your skin from the sun and insect bites. A wide-brimmed hat and UV-protective sunglasses are also recommended. Sturdy, comfortable footwear is crucial for walking on uneven terrain, and layers are ideal for adapting to changing weather conditions. Be prepared for changing weather by bringing a waterproof jacket and trousers to protect against rain, and a windproof layer for blustery conditions. Ensure your clothing is durable enough for tough environments and flexible enough to adapt to rain, wind, and sun.

- [ ] **Sun protection**

  Be mindful of prolonged sun exposure, as you could be in the sun for hours at a time. Ensure you are well-prepared by staying hydrated with water and electrolytes, and applying suncream regularly.

Kit for thermal surveys

- [ ] **Thermocouples and logger**

  This is the means by which you can measure the ‘true’ contact temperature of the sand or substrate on which the plastic is resting.

- [ ] **A pocket weather station (e.g. Kestrel)**

  When working with thermal data, having a very localised measure of wind speed and air temperature is very useful.

- [ ] **GCP boards modified for thermal imagery**

  This is best achieved by taping a pattern (e.g. a cross with varying numbers of lines) onto a standard GCP board using aluminium tape. The aluminium tape reflects all thermal radiation and therefore is highly distinctive. It also gives you means by which you can estimate the downwelling / reflected radiation in the scene, if the tape is applied smoothly.

Data analysis

- [ ] **Memory card readers and adapters for all kit used**

  Note differences in Mac / PC setup.

- [ ] **Hard drives (at least 1 TB)**

  Ensure you have at least two for data backup, stored separately during the survey campaign, travel and afterwards.

  Remember that Mac / PC have different drivers and that plugging a Mac formatted drive in a PC can cause data corruption issues. While they are more expensive, solid state drives with rubber casing are a good option for field work.

- [ ] **Logger control software**

  What you need will be dependent on your kit, e.g. HoboWare.

- [ ] **Image processing software**

  This is needed to field check results and validate your approach, e.g. pix4D mapper, DJI Terra.

  It is generally recommended to avoid the DJI or drone-specific software as it tends to be too limited for scientific purposes and if doing anything with thermal. However, it is good for generating ‘quick looks’ to sanity check your work if that is all you have available.

  An open source option for processing drone imagery is Open Drone Map (ODM). There is a paid version (around $50) that has a nice UI and is plug and play, a web version (webODM), or if you are savvy with computers and comfortable using programming tools, there is a free option. ODM can also be deployed in a cloud environment if more GPU/RAM are needed for processing large datasets.

  Custom code/software can also be used to extract radiometric values if required. See data analysis section for more..

SURVEY FLIGHT DESIGN

General concepts

Sensors should be calibrated by measuring their performance in a controlled setting prior to use in the field. This can be hard for the public to achieve, but is still possible using a simple photo reference card to test a standard RGB camera, or a black bucket of water with a thermometer in it to test a thermal camera.

- You are looking for absolute error compared to a standard, i.e. the known properties of the photocard or the temperature that the thermometer in the water is reading.
- You also want to check for relative error across the field of view (e.g. vignetting: when a camera produces an image that is darker around the edges, which can often occur in thermal cameras).
- While citizen scientists may not then use these results directly, if you pass your calibration data onto a scientist or an agency, they can use it to process the data more accurately and to a good standard.
- If your calibration attempts show a consistent error, make sure you record this, as you can use your calibration to correct the data later. However, if the error is random and hard to figure out you may need to reconsider the drone you are using, as it will be hard to get good data from your surveys.

Create a standard survey flight path, considering the required overlap of photos based on sensor and homogeneity of the target surfaces.

- There are pros and cons of bigger vs smaller areas. This decision depends on your overall research goals and certainty of ability to detect your target plastic in the given environment. If you're unsure of this, start with a small area and using control plastic, before moving to larger areas.
- Flight speed should also be considered. While faster flying means you can cover more area, it's important to minimise any blurring or distortion from flying too fast (and vibration of the drone) given the small size of the objects we're interested in.

When surveying the foreshore, make sure your sample transect covers from the swash-zone through to the dunes (see Figure 2), to make sure you sample the whole beach, but also to help automated geolocation and mosaicking of the images, overcoming some of the issues with capturing only homogenous sand or seaweed scenes.

If you are doing sample transects of a beach, rather than the whole beach, you need to do a minimum of three transects. This is to ensure your sampling regime is less likely to be subject to random bias or error.

Decide on your target area size per transect. This will be a function of both the maximum battery life of your drone, the weather and the relative homogeneity of the beach (i.e. if the beach is all the same, then you can sample a smaller area and remain representative of it).

We suggest a drone flight height of 10 metres as a baseline if you are surveying for micro to meso plastics. If your focus is on macro plastics then 20-30 metres is suitable.

Plastic is typically in the strand line, but also commonly observed caught in vegetation at the top of the beach slope. This is another reason why you should make sure your transect covers as much of the shore-to-sea as possible.

Flight path

It is imperative that the images overlap, so that there are no data gaps.

- Thermal needs at least 80-90% overlap.
- RGB/RGB-NIR needs at least 50-70% overlap.

Different sensors within the same payload have different fields of view, so image overlap needs to account for this. Make your choice based on the smallest field of view of all the cameras on your drone, or select the sensor most important to your work to negate this.

The flight plan can be created in flight planning software before a survey. However, moving between beaches or dealing with a very dynamic tidal zone, a lack of cell phone coverage and a rapidly changing environment when on the beach may preclude the use of pre-drawn flight plans.

- This can be mitigated by pre-downloading the map and satellite imagery of the beaches.
- However, it is recommended that you are comfortable with flying a manual survey pattern in addition to being familiar with how to create a software defined plan in the field, if that option is available in your equipment.

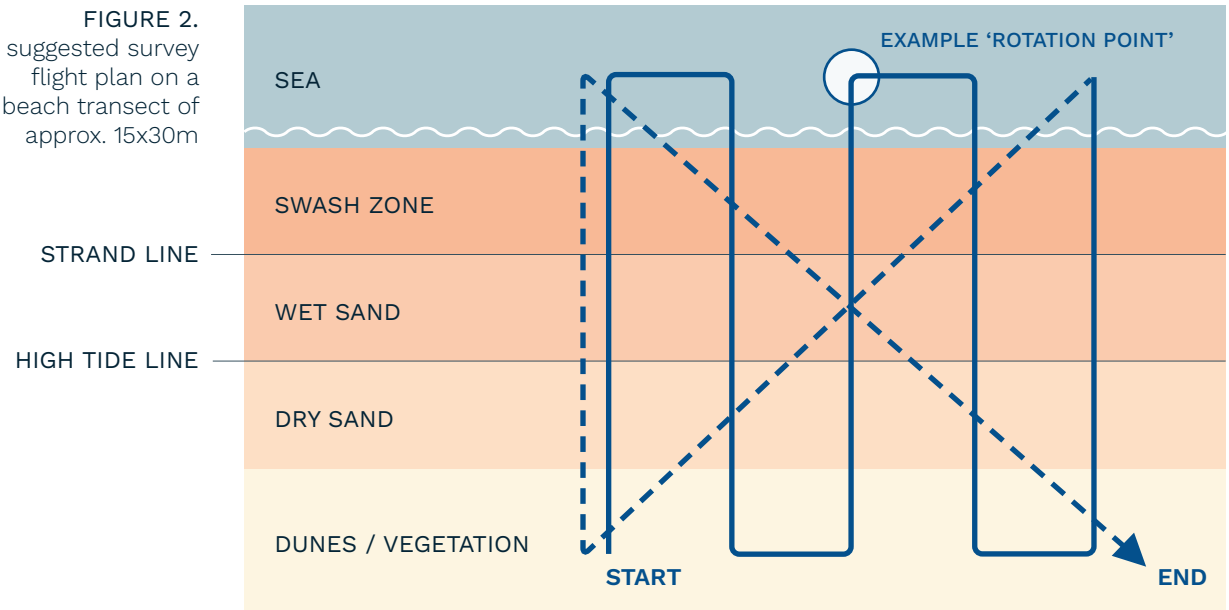
At each 'rotation point' of the drone, capture additional images with each rotation of the drone, in order to generate further imagery that has a different observation angle to that generated along the perpendicular survey lines.

- Angular observation effects can become important when analysing scenes with complex surfaces, such as stony beaches.

At the end of a survey, we recommended carrying out two crossing transects to capture images of a different orientation throughout the whole scene (see dashed lines in Figure 2).

- This provides more images and data over the most important area of the sampling region, at a different orientation to the standard survey lines.
- Carrying out these crossing paths can also help generate data that is then used to account for intra-survey variability of temperature or illumination changes between the perpendicular survey lines.

FIGURE 2.
A suggested survey flight plan on a beach transect of approx. 15x30m



In-flight safety

Take off from a clean, stable location, ideally either on top of a hard case or a matt that you have placed down.

Landing on top of a case is difficult, particularly in high wind, so a matt is the preferred solution. This is particularly important for drones that have belly sensors and not particularly high legs, as you risk scratching the lens of the belly senors when landing on coarse sand or stones.

A team of three is recommended, with one pilot and two safety observers. The safety observer's job is to watch the drone as the pilot focuses on the survey, scan the nearby airspace for incoming disruptions like birds or other aircraft, and to manage members of the public if they pass by or attempt to pass through a survey site.

Post-flight routine

- **Brush sand off drones**, especially access ports, sensors, gimbals and moving joints. A make-up brush works well!
- **If equipment becomes wet, make sure to dry it thoroughly** and check for salt residue, which should be removed with a cloth slightly dampened with fresh water.
- **Immediately charge batteries and controllers** using appropriate converters.
- **Extract data to the hard-drives**, labelling your data folders in a logical and consistent way.
- **Fill in the daily field-diary,** noting:
    - Location
    - Weather conditions
    - Any anomalous events or disturbances to the data collection
    - Plastic observed by the team
    - GPS locations of the GCPs
    - Information which may be useful in explaining plastic/litter abundance
- Don't forget to pack up all your gear and control plastic.

Things to remember

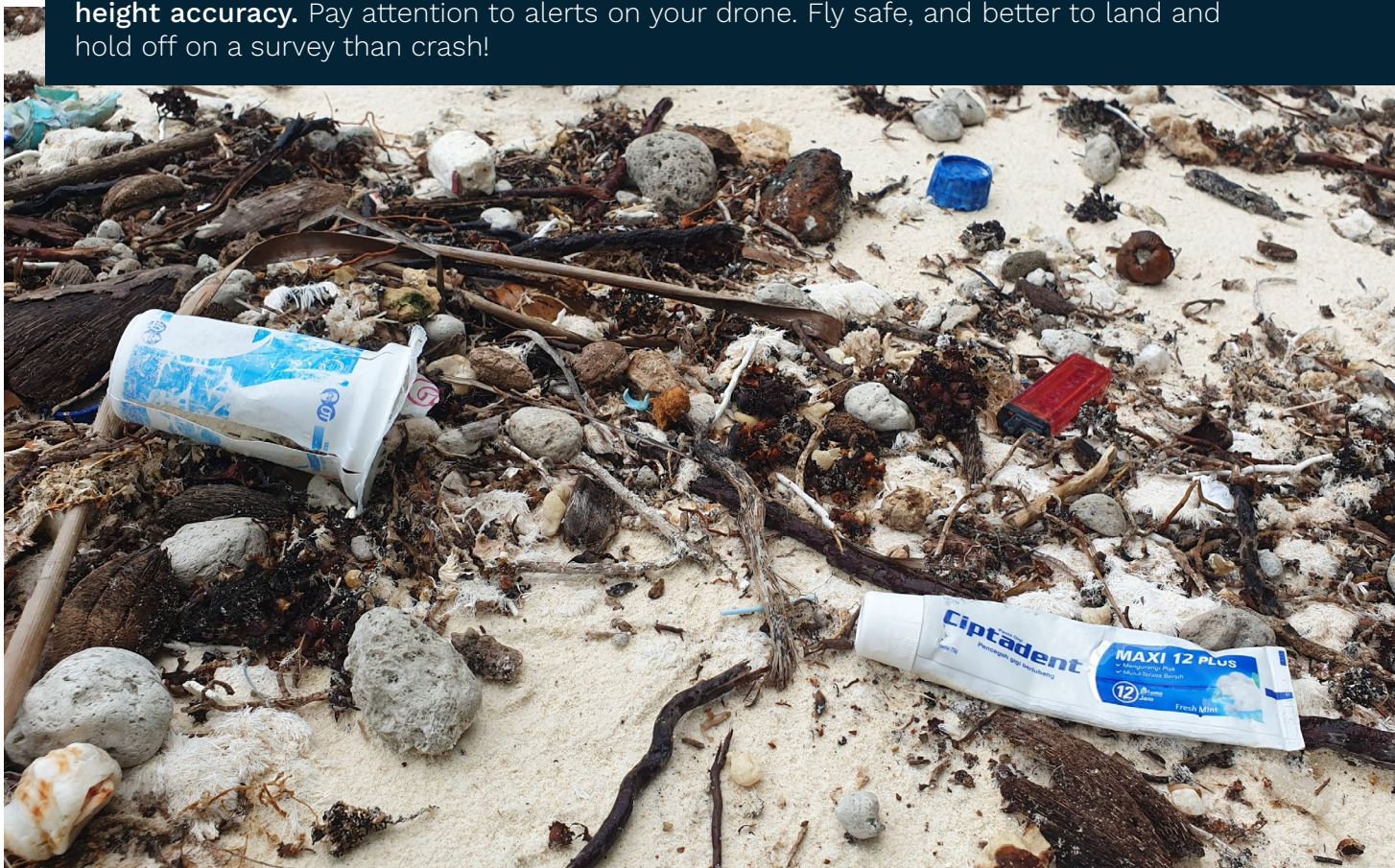
If the target area is overly homogeneous, even with GCP boards, it will not be able to be analysed and automatically stitched together by the software packages typically used to do so.

- Essentially, if you sample a flat beach that is all the same sand, even if it has seaweed on it, and does not capture the swash zone or the dunes/vegetation, you are likely to run into problems.
- Sand pegs and survey tape can be useful here, as they can be used to provide visual markers when stitching imagery together. If you use this method though, it is important you remember to exclude the survey tape from any plastic counting done later on from the processed imagery.

Drones measure height relative to take off point, not absolute height. Height is also often measured primarily with a barometer on the drone, so high winds and/or changes in weather systems will affect your vertical accuracy.

Familiarise yourself with, and remember, the constraints of each location. Take into account both local and national regulations, e.g. the Civil Aviation Authority.

High wind speeds can cause all sorts of issues with drone flying in addition to height accuracy. Pay attention to alerts on your drone. Fly safe, and better to land and hold off on a survey than crash!



DATA ANALYSIS

After completing your drone survey, the next important step is to process the data you collected so that it can be effectively used by yourself and others. Luckily, there are several software options available to cater to different budgets and preferences. The list below is not exhaustive, but includes some currently popular choices.

- **Pix4D:** This commercial software is widely used and offers advanced capabilities for processing drone data.
- **GeoNadir:** Also a commercial option, offering similar features to Pix4D.
- **Open Drone Map (ODM):**
  - ODM is open source and offers both paid and free options, allowing users to select the most suitable package for their needs. The standalone installer, available for a one-time fee, provides a comprehensive set of tools for processing drone imagery. It includes features such as orthophoto generation, point cloud creation, and 3D reconstruction.
  - WebODM is a browser-based solution that can be a good option for processing large datasets using cloud computing resources.
  - If you are comfortable with Docker, you can set up a self-hosted version of ODM on your local machine. Detailed instructions for downloading and installing the software with Docker are available on ODM's Github page (link **here**).
- **Segment Anything Model (SAM):** This is a model that is finding increasing use in combination with drone image data. If you are interested in using your data with SAM to pick out plastics from your survey, you can find open source packages on Github (**here** and **here**).

It's important to note that the mentioned software options are not officially endorsed by the authors. It's advisable to conduct thorough research and consider other available software options before making a decision.

MAKING USE OF YOUR DATA: COMMUNITY AND OPEN SCIENCE PROJECTS

There are several community-led and open science projects that can make use of data collected on beached plastics from drones, or may be able to use other ancillary data you have collected during your survey. These projects aim to address the issue of plastic pollution and contribute to a better understanding of its impact on the environment.

Tangaroa Blue | https://tangaroablue.org/

Tangaroa Blue maintain a database of plastic debris on Australian beaches. They provide data collection sheets to help guide participants on the type of information to collect on plastic items. If you want to contribute to the Tangaroa database, the methodology can be found here, and a downloadable datasheet here.

TACO | https://paperswithcode.com/dataset/taco

TACO is an expanding dataset of images that showcase waste found in natural environments. The dataset includes pictures of litter taken in various settings such as forests, roads, and beaches. While not specifically targeted at drone images, it is a growing database that can be used for training models to detect plastic debris.

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