National Environmental Science Program

# 11. Benthic Observation Survey System (BOSS) to survey marine benthic habitats

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## Introduction

Marine benthic images are commonly used to quantify habitat composition, ground-truth remote data and predict the extent of habitat types (Pelletier et al., 2020). Such imagery is now widely used to calibrate spatial analyses such as distribution models and change-over-time mapping (Mastrantonis et al. 2024). Benthic images captured by platforms such as divers, drop cameras, towed-video, Remotely Operated Video (ROV), and Autonomous Underwater Video (AUV) are generally acquired from downward-facing cameras, with a field of view that is relatively constrained (~70$^o$ x ~40$^o$) and covers a small area per sample unit (~ 1 m$^2$, Bennett et al., 2016; Sheehan et al., 2016). Horizontal-facing images, using the same field of view, have a larger area (~25 m$^2$) and are useful in a variety of situations and ecosystems (Bennett et al., 2016). Downward-facing images generally provide higher taxonomic resolution for sessile assemblages and sub-canopy species than horizontal-facing images, and improved estimates of mobile invertebrate numbers (Perkins et al., 2020). However, the larger area per sample unit of horizontal-facing images better aligns with resolutions of remote sensing products such as bathymetric lidar (~25 m$^2$) and optical remote sensing platforms (~100 m$^2$). Obtaining ground truthing data at a commensurate scale to remotely sensed products is an important consideration when modelling extent or community composition (Mastrantonis et al. 2024). Horizontal-facing imagery is also more effective for monitoring the cover of erect habitats including canopy algae and corals (Bennett et al., 2016; Vergés et al., 2016), particularly if stereo images are captured allowing the dimensions of biota to be measured (Langlois et al., 2021). Stereo images further allow the sample unit to be standardised across varying visibility (Broad et al. 2023; McLean et al. 2016). The structural dimensions (i.e. height) of benthic biota can be an indicator of anthropogenic and environmental impacts, with imagery from Baited Remote Underwater stereo-Video (stereo-BRUV) surveys being successfully used to measure the recovery of soft-coral height after the cessation of trawling across an area of continental shelf (Langlois et al., 2021), and the impacts of marine heat waves on macroalgal canopy height (Vergés et al., 2016).

Spatially-balanced survey designs can increase sampling efficiency by evenly spreading samples in space and across the range of covariates of interest (e.g., depth and relief) (Robertson et al., 2013). Typical platforms for collecting benthic images (i.e. divers, towed-video, ROV, and AUV) have logistical constraints that result in them generally being deployed along transects, or in discrete patches or mosaics (Sheehan et al., 2016). By contrast, drop cameras provide point-samples, providing a more spatially independent method of gathering benthic data (Robertson et al., 2013). Where rapid repeated deployments are possible, drop cameras are suited to ground-truthing relatively large spatial areas (Pelletier et al., 2020) and sites requiring validation can be chosen based on covariates of interest (Mastrantonis et al. in review). Transect-based sampling can also be used in a spatially balanced manner, but care must be taken to account for spatial dependence within transects and clusters of transects (Foster et al., 2020). Regardless, transect-based and locally-dense sampling can introduce clusters of samples within similar environmental settings, or spatial bias, that can weaken subsequent statistical analyses (Robertson et al., 2013). While drop cameras have clear logistical and efficiency advantages for sampling larger areas, due mainly to the brevity of their deployments and relative ease of obtaining independent observation units, deeper water environments (>200 m) increase time for deployment and create logistical challenges. Below these depths, multi-platform swarms, either of AUVs and ROVs conducting transects, are likely to be more cost-effective (Liu et al., 2023).

We have developed a remote wide-field drop camera system, called the Benthic Observation Survey System (BOSS), with a combined field of view of approximately 270˚ (Figs 1-2), amenable to stereo- or mono-camera configurations (Fig. 3). The design originated from an integrated fibre-optic camera system developed by Rick Starr at Moss Landing Laboratories for sampling demersal fish assemblages, that developed from rotating stereo-video landers (Starr et al., 2016, Matthews et al. 2024). The system was adapted to be able to be rapidly deployed and retrieved from a variety of vessels into water depths of 2 to 200 m and is self-righting on the seabed (Figs 1-3), with a single deployment in 30 m of water taking just 8 minutes with a 5-minute bottom time. This tool is suited to the collection of widespread georeferenced point samples, enabling the cost-effective sampling of broad areas using spatially-balanced sampling designs, to produce benthic habitat coverage predictions (Fig. 1) or inform other environmental assessments (i.e. benthic biota dimensions). We demonstrate this method through a project led by Traditional Owners of the south-west of Australia to characterise the habitats associated with ancient submerged coastline features across the continental shelf, to inform further detailed analysis (Langlois et al. ). We provide a standard operating protocol (SOP) for the BOSS with information on system design, field operation, image annotation, data validation, and examples of a workflow to generate a habitat map product (Fig. 1). We highlight the benefits of using multiple horizontal fields of view to characterise benthic habitat heterogeneity but also suggest that future studies should investigate the potential of collecting demersal fish assemblage information comparable to Starr et al. (2016).

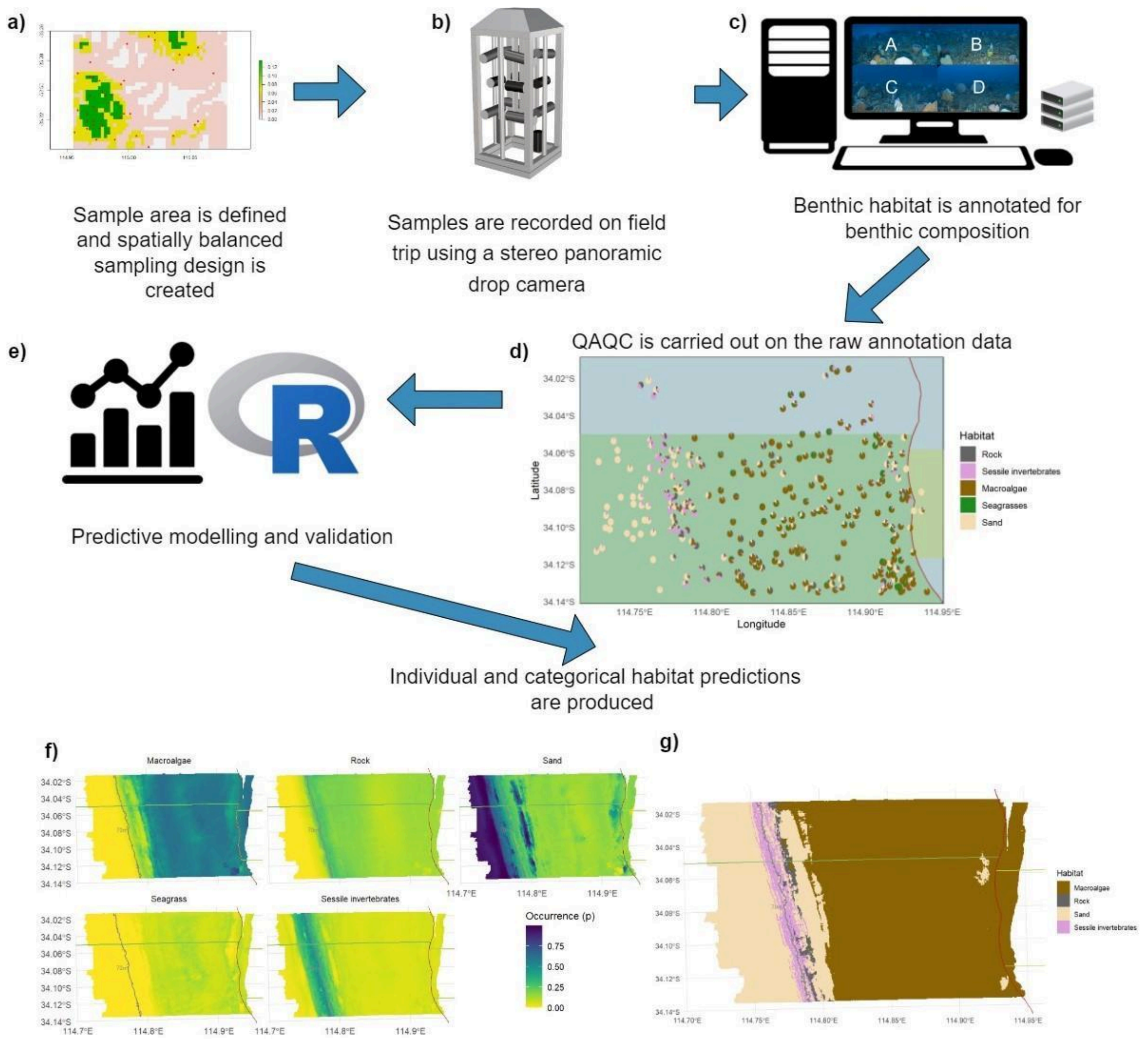


**Figure 1**: BOSS workflow for benthic composition ground truthing and production of predictive spatial models. a) Spatially balanced design with inclusion probability, b) drop camera, c) imagery annotation, d) quality control, e) predictive modelling and validation to produce f) probabilities of occurrence for individual habitat classes and g) categorical habitat predictions.

## Design and Methods

### SOP development

The development of the SOP followed the approach described in Przeslawski et al. (2023). Briefly, experts and users in marine imagery and habitat classification were invited to join a working group and contribute to the content of the SOP. The SOP will be maintained as part of a broader suite of sampling methods used for marine monitoring established by the Australian Government's National Environmental Science Program (marine-sampling-field-manual.github.io).

## System design

The BOSS has two variants: a stereo system (Fig. 2) and a lighter-weight mono system (Fig. 3). Both consist of a sturdy aluminium frame to secure and protect the camera equipment, a flotation compartment at the top and a bolt-on base weight. The buoyancy and weighting counteract to create a self-righting action, with flotation provided by compression-resistant syntactic foam or subsurface floats. The weighting and compression-resistant buoyancy means that no adjustments are necessary to work, up to the limits of the camera housings and buoyancy (i.e. 1,000 m). When weights are removed, either system can be safely carried by two people (i.e. <35 kg). In the stereo version, eight horizontally-facing cameras are secured to brackets aligned in four stereo pairs at 90-degree intervals (Fig. 2c), and an optional downward-facing camera can be mounted within the buoyancy compartment to collect more traditional imagery (Fig. 4a). Brackets are provided for four lights. In the stereo version, camera brackets are secured to a common central column (Fig. 2a and 4a) and removed from the outer frame to reduce the risk of any physical impacts on the outer frame compromising the stereo calibration. By using small-form action cameras with external battery packs and large capacity memory cards, it is possible to film continuously for 12 hours and not require the camera housings to be opened until the end of the day, thus reducing risks to equipment, calibration stability, and substantially increasing efficiency in the field. Further information on cameras and photogrammetry are provided in the Camera and photogrammetry section below. In the stereo system, each pair of cameras is separated by 500 mm, with the top camera in each pair angled 8 degrees downward and the bottom camera horizontal (Fig. 1) to provide adequate separations and overlap of imagery (Langlois et al. 2020).

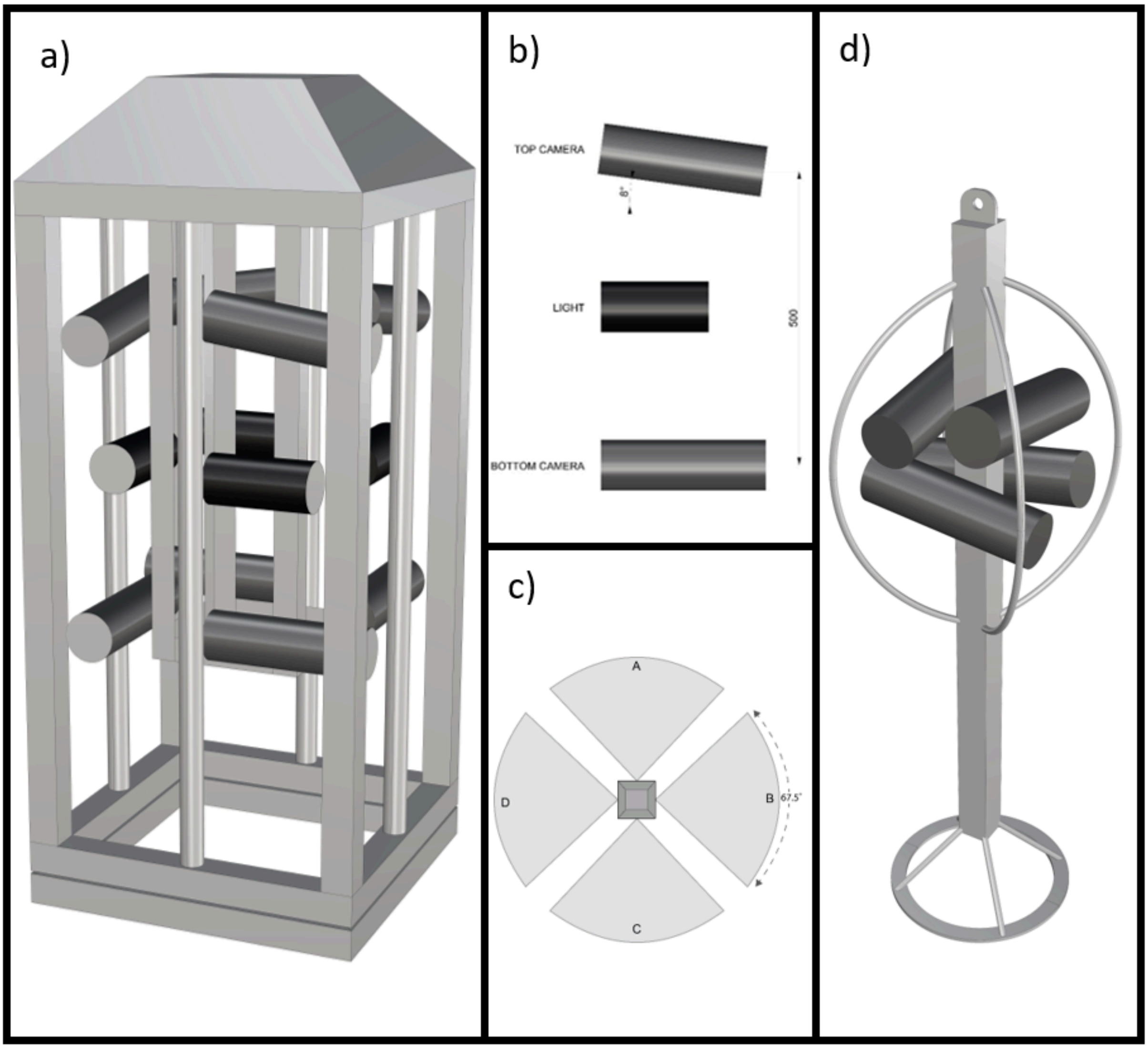


**Figure 2**. BOSS design. a) stereo configuration with camera pairs mounted on internal base bar cassette, showing camera housings (grey) and lights (black), b) specifications of the stereo camera separation and angle of convergence, c) overhead field of view showing the wide 270o field of view, and d) lighter weight mono configuration.

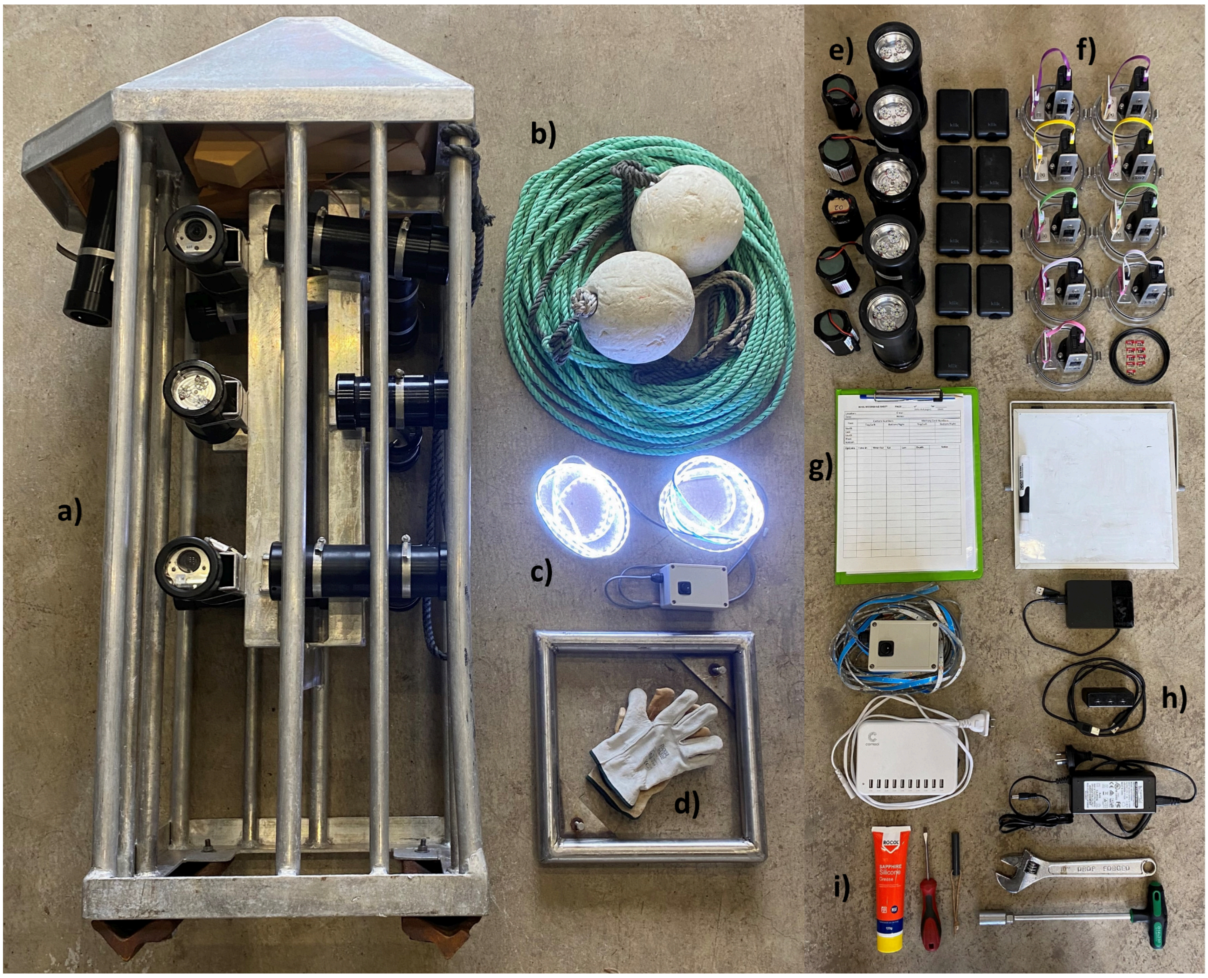


**Figure 3.** BOSS equipment required for deployment. a) Stereo camera frame with an additional downward facing camera mounted in buoyancy compartment, b) rope and floats, c) synchronisation diodes, d) detachable ballast and gloves, e) lights and batteries, f) cameras, battery packs, SD cards and spare O-rings, g) field metadata sheet, whiteboard and marker, h) charging equipment and downloading footage, and i) tools including silicone grease.

### *Camera and photogrammetry*

Camera specifications can influence the accuracy of taxonomic identification, and stereo-measurements require careful adherence to camera alignment and calibration protocols. In our system, we record video with Sony FDR-X3000 cameras filming at 1920 x 1080 pixels, a frame rate of 60 frames per second and using the 'medium' field of view setting (~67.5˚). We recommend the use of cameras with a minimum resolution of 1920 × 1080 pixels (Langlois et al. 2020; Harvey et al. 2010) and a minimum capture rate of 30 frames per second, with all settings standardised across cameras. Higher camera resolution will generally improve taxonomic identification, but all systems should be thoroughly tested before deployment for overheating issues or write speed limitations at higher-quality settings.

To maintain stereo-calibrations, cameras must have video stabilisation disabled, and a fixed focal length can allow measurements both close to and far from the camera when correctly calibrated

(Boutros, Shortis, and Harvey 2015; Shortis, Harvey, and Abdo 2009). Field of view settings should be chosen to limit distortion in the image rather than maximise the field of view. White lights (550 - 560 nm) are recommended for low-light conditions (Birt et al. 2019). We recommend seeking manufacture and calibration advice for the frame from recognised providers, to ensure that the tight tolerances for effective stereo-vision are met. Each housing and camera set should be uniquely identified to ensure that individual cameras are used only in the housing they are calibrated in. Any changes to camera positions (e.g. if a camera is dismounted during battery replacement) will disrupt the calibration, increasing error in length measurements.

Video cameras can skip or lose frames, disrupting synchronisation among cameras and requiring the use of manual reference points such as a clapper board shown at the start of each take. The wide-field stereo-video drop camera system is designed to record many successive deployments but requires manual synchronisation at regular intervals. We use a flexible strip of waterproof LED lights to generate a simultaneous flash at all nine cameras. The chosen camera model should be tested to determine how often resynchronisation needs to occur to maintain accurate stereo measurements.

## Sampling design

Using sampling strategies appropriate for the study objectives will allow valid inferences, interpretations, and generalisation of resulting data (Robertson et al., 2013). For surveys of habitat composition to ground-truth remote sensed data or existing spatial predictive models, we recommend spatially balanced a priori stratification of survey locations as per Balanced Acceptance Sampling (BAS) or Generalised Randomised Tessellation Structures (GRTS) (Robertson et al., 2013). BAS and GRTS approaches can be implemented using R packages 'MBHdesign' (Foster et al., 2020) or 'spsurvey' respectively (Kincaid et al., 2007). Resampling and spatial coverage can be minimised by separating individual samples in space. Minimum separation distance is dependent on the spatial heterogeneity in the acquired data and should be tested during statistical analysis with spatial variograms, and any significant autocorrelation taken into account (Robertson et al., 2013).

## Field logistics

We recommend the drop camera be deployed for a standard duration, with trials indicating five minutes bottom time allows any sediment suspended during the landing to settle, resulting in clear footage of the habitat. Shorter deployments may be sufficient for areas with limited sediment, and the ideal deployment length should be determined based on study objectives. Local fishing vessels fitted with trap retrieval equipment such as a swinging davit arm or a 'pot-tipper' and winch are ideal for deploying and retrieving both the stereo and mono-video systems, especially in deeper waters (Fig. 3). These vessels are usually suited to the local sea conditions, and the involvement of experienced commercial skippers may provide valuable logistical and local knowledge. Due to the weight of the stereo-system with weights attached (~50 kg), we strongly encourage the engagement of commercial fishers and deckhands who are experienced at deploying weighted traps and their expertise will be beneficial and likely result in better Occupational Health and Safety outcomes. A field deployment checklist is provided in Tables 1-5.

**Figure 4**. Lighter weight mono-configuration wide-field drop camera system being deployed by hand (left) and stereo-configuration wide-field drop camera system deployed from a commercial fishing vessel fitted with a 'pot tipper' (right).

### *Field Deployment Checklist*

We provide here a series of checklists that ensure that all data is collected consistently in the field.

### *Pre-field work*

**Table 1.** Pre-fieldwork checklist.

| Step | Action |
|---|---|
| 1 | Check equipment as shown in Fig. 3. |
| 2 | Conduct 3D calibration of stereo-camera pairs following (Boutros, Shortis, and Harvey 2015). We recommend an enclosed pool environment with good visibility. This must be repeated at the end of the field campaign, or if any camera or housing positions have changed. |

| | |
|---|---|
| 3 | Ensure sampling design can be imported to the research vessel navigation system or bring a standalone navigation and depth sounding system for the skipper. |
| 4 | Ensure sufficient data storage capacity for downloading all video imagery collected, and for back-up copies. |
| 5 | Ensure sufficient spares for the wide-field drop camera and check the condition of o-rings (Fig. 3). |
| 6 | Create a camera metadata sheet or preferably use a capture device (e.g. FieldMaps for ArcGIS, tablet computer with GIS) to record the sample and memory card unique identifier (Table 6). Prepare a field metadata sheet to record unique sample identifiers, time, GPS coordinates and other necessary metadata entries (Table 7). |

### *Pre-deployment*

**Table 2.** Pre-deployment checklist.

| Step | Action |
|---|---|
| 1 | Set up the wide-field stereo-video drop camera frame, including ropes and floats (if necessary). |
| 2 | Check all camera batteries are charged and memory cards are formatted. |
| 3 | Check the light batteries and synchronising device battery. |
| 4 | Discuss deployment, retrieval procedures and safety with the skipper and crew. |

### *Deployment*

**Table 3.** Deployment checklist.

| Step | Action |
|---|---|
| 1 | Turn on all cameras and synchronise together. Turn on all battery packs and check that cameras are charging (if applicable). |
| 2 | Check camera settings are consistent. |
| 3 | Film the metadata sheet with the information of each camera to attribute this to the recorded video footage. |

| | |
|---|---|
| 4 | Check the camera housings are dry and clean before aligning and inserting cameras. Check o-rings are not pinched or dirty. |
| 5 | Turn on all exterior lights. |
| 6 | Once on site, and at the command of the master of the vessel, experienced personnel or deck hands should physically deploy the drop camera and ropes clear of the vessel. At this point a GPS mark should be recorded. |
| 7 | The vessel should remain directly on the site whilst deploying the drop camera. During the settlement time on the seabed, contact between the vessel and camera system can be maintained with the drop camera via the ropes, however no tension should be held on the ropes to ensure that the drop camera is not moved from the sampling location. Alternatively, the rope with floats attached can be dropped and retrieved once the sample time has elapsed. |
| 8 | Ensure all field metadata has been collected (see Metadata collection). |

### *Retrieval*

**Table 4.** Retrieval checklist.

| Step | Action |
|---|---|
| 1 | Once the deployment time is complete, the vessel should remain directly on top of the sampling location while the drop camera is retrieved. |
| 2 | Once the drop camera has been retrieved, it should remain on the deck or securely fastened to the pot tipper or davit arm as the vessel transits to the next sampling location. The upcoming unique sample code should be shown to all cameras. Frequent checking and resynchronisation of cameras should occur to ensure that all cameras are recording, lights are turned on and any issues with loss of stereo calibration due to dropped frames are accounted for. If any cameras stop recording during the recording period, then all cameras should be restarted to maintain synchronicity. |

### *End of day checks*

**Table 5.** End of day checklist.

| Step | Action |
|---|---|
| 1 | Once the drop camera is on the deck at the end of the day's sampling, dry the housings and remove cameras, battery packs and memory cards. |

2 Review, download and backup all footage at the end of each day, using clear naming conventions for filenames and folder structure (Fig.5).

3 Ensure all metadata is backed up and set all equipment to charge for the next day's sampling.

## Metadata collection

Metadata should be collected to ensure that imagery can be georeferenced and needs to be maintained throughout the planning, fieldwork, imagery download, and annotation phases to ensure data quality. Examples of metadata requirements are provided below.

We provide templates for metadata (Tables 6-8) and file organisation (Fig. 5) here.

**Table 6.** Example of a completed camera metadata.

| Date | Face | Top camera | Top SD card | Bottom camera | Bottom SD card |
|---|---|---|---|---|---|
| 20220408 | A | 1101 | 200 | 1102 | 201 |
| 20220408 | B | 1103 | 202 | 1104 | 203 |
| 20220408 | C | 1105 | 204 | 1106 | 205 |
| 20220408 | D | 1107 | 206 | 1108 | 207 |
| 20220408 | Downwards | 1109 | 208 | *NA* | |

**Table 7.** Example of a completed field metadata sheet.

| Sample | Date | Time | Longitude (dd) | Latitude (dd) | Depth (m) | Notes |
|---|---|---|---|---|---|---|
| MEG001 | 20220408 | 10:01 | 113.15 | -34.05 | 24.1 | |
| MEG002 | 20220408 | 10:05 | 113.16 | -34.06 | 24.7 | |
| MEG003 | 20220408 | 10:08 | 113.17 | -34.07 | 24.3 | Checked all cameras |
| MEG004 | 20220408 | 10:12 | 113.18 | -34.08 | 22.8 | |
| MEG005 | 20220408 | 10:16 | 113.19 | -34.09 | 21.9 | |

**Table 8.** Example of completed annotation metadata columns, to join to field metadata.

| Status | Annotation.date.completed | Observer | Video.notes |
|---|---|---|---|
| Fished | 20220408 | Tim | |
| Fished | 20220408 | Tim | check octocoral |
| No-take | 20220408 | Tim | |
| No-take | 20220408 | Tim | |

| | | |
|---|---|---|
| No-take | 20220408 | Tim |

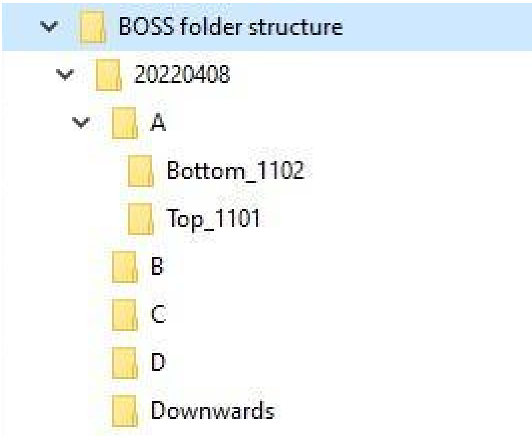


**Figure 5.** Folder structure for downloaded footage. Footage is stored in a parent folder indicating the date the footage was recorded on, with separate folders for each of the eight stereo cameras and the downwards camera.

## Image synchronisation, compositing and stereo calibration

To ensure that the imagery from each camera can be effectively composited to be viewed simultaneously, both the lightweight mono-video and the larger stereo-video drop camera systems require synchronisation. In particular, for stereo-video imagery, we recommend a minimum of four intermittent synchronisations should be done throughout the day. We propose the use of a flexible strip of waterproof LED lights, for synchronisation, to generate a simultaneous flash in the fields of view of all eight or four horizontally facing cameras (Fig. 2c). We provide wiring diagrams for this synchronisation hardware in the Synchronisation diode section. Video from each set of four horizontally facing cameras must be synchronised and composited into a single video stream (Fig. 6). We recommend using VidComp software which is freely available from seagis.com.au. For the stereo-video version of this platform, the use of a video composite is formed from standard fields of view, to minimise barrel distortion, rather than the typical 360o image which is formed using 'fish-eye' or 'omnidirectional' lenses. Standard lenses result in a less distorted image that is more suitable for stereo-calibration. For the stereo-video calibration procedures, we recommend the widely used and supported SeaGIS CAL (seagis.com.au/bundle.html) software and recommend calibrating cameras frequently, before and after each field campaign (e.g every two weeks or 300 deployments). Frequent calibration will ensure against loss of stereo capability which could come from camera misalignment or swapping of cameras (i.e. optical properties vary within camera models).


**Figure 6**. Synchronised and composited imagery from four horizontal cameras.

### *Synchronisation diode*

We recommend that video rather than still imagery is collected and by using action cameras with external battery packs and large capacity memory cards, it is possible to record video for the whole day of field work and not require the camera housings to be opened until the end of the day.
However, to ensure that the imagery from each camera can be synchronised, both the lightweight mono-video and the larger stereo-video wide-field drop camera systems will require intermittent synchronisation with diodes, out of the water, throughout field deployment to enable imagery to be composited (see below for Image compositing).

For stereo-video imagery, we recommend intermittent with a minimum of four synchronisations should be done throughout the day. We propose the use of a flexible strip of waterproof LED lights, as synchronisation diodes, to generate a simultaneous flash in all eight or four horizontally facing cameras (Fig. 7) and provide wiring diagrams for this synchronisation diode (Fig. 8).

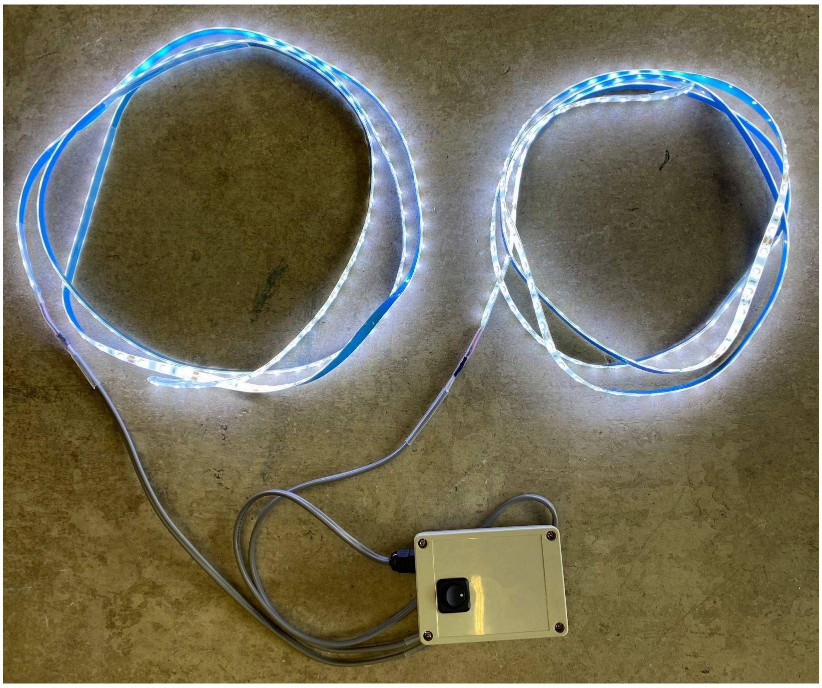

**Figure 7.** Synchronisation diode.

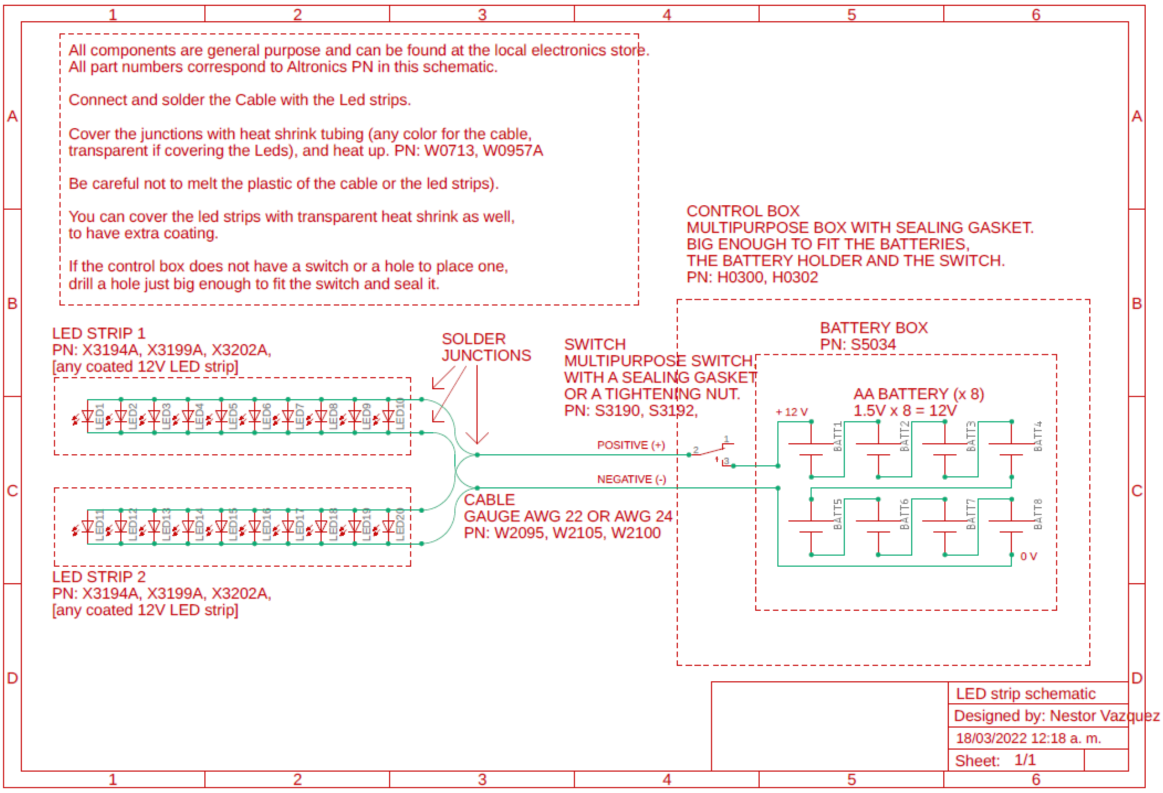


**Figure 8.** Schematic diagram of synchronisation diode wiring.

## Image annotation

*Annotation software*

There is a range of readily available image annotation software and platforms available such as TransectMeasure (www.seagis.com.au/transect.html), Squidle+ (squidle.org), CoralNet (coralnet.ucsd.edu), BenthoBox (benthobox.com), and ReefCloud (reefcloud.ai), all of which are suitable for mono video annotation. For stereo-video annotation, we have used SeaGIS EventMeasure (seagis.com.au/event.html) and recommend this as a widely used and well-supported software workflow for stereo-annotation and measurement.

*Image annotation*

For horizontally facing wide-field imagery, we recommend annotating 20 random points assigned to the lower 50% of each image. We provide example annotation and quality control workflows (globalarchivemanual.github.io/CheckEM/). A simulation study of point annotation of downward-facing imagery found that 20 points would provide an adequate estimate of variance in benthic assemblage composition whereas 80 points would provide a highly consistent estimate (Dumas et al. 2009). Similarly, for the horizontal-facing images collected by the BOSS, we explored the implication of annotating one field of view, using 20 points, to up to four fields of view, a total of 80 points, across multiple independent tropical, subtropical, and temperate locations (Effect of increasing number of fields of view on habitat observations and cost of data collection, code publicly available at github.com/UWA-Marine-Ecology-Group-projects/paper-boss-habitat/). We found generally more precise estimates of habitat composition using 40 to 80 points, annotating two to four fields of view, justifying our recommendation to annotate the combined field of view (~270º) of the four cameras, to characterise benthic composition (Supporting Information 5).

For annotation of benthic composition, we recommend the CATAMI classification schema (Althaus et al., 2015), which classifies habitats into morphological groups. This schema is also recommended for similar marine sampling protocols for towed video, ROVs, AUVs (Przeslawski et al., 2023) and benthic composition from BRUV (Langlois et al., 2020). We provide a controlled repository of CATAMI formatted for use in TransectMeasure available at github.com/GlobalArchiveManual/annotation-schema, which also includes species-specific annotation for certain common and easily identifiable taxa from the CAAB classification schema relevant to Australia (Rees et al., 1999). Also included is an annotation schema for visual estimates of structural complexity or relief (see Langlois et al., 2020).

### *Effect of increasing number of fields of view on habitat observations and cost of data collection*

The benefits of using wide-field or 360-degree cameras has been demonstrated when quantifying fish assemblages (Whitmarsh, Huveneers, and Fairweather 2018; Pelletier et al. 2021), but is also beneficial when characterising benthic habitats (Mallet et al. 2021; Pelletier et al. 2020). A wide-field of view, made up of multiple composited views, reduces issues with observation direction in single view systems, where at habitat edges or in high-relief environments where the dominant seascape feature may be missed (Mallet et al. 2021). We further demonstrate the value of additional fields of view (Fig. 9), by showing that habitat heterogeneity per sample increases as the number of fields of view increases, each of approximately 70o wide, across seven locations from the subtropical Abrolhos Marine Park (Western Australia) to the temperate Franklin Marine Park (Tasmania). The code and data are publicly available at github.com/UWA-Marine-Ecology-Group-projects/paper-boss-habitat/. The increase in effort to annotate this additional imagery is minor (1-2 minutes) and the field time required to deploy a single view versus multiple view system is the same. The relative increase in habitat classes varied across marine parks surveyed from a limited increase (e.g. Eastern Recherche Marine Park) to a two-fold increase in the number of habitats identified (South-west Corner Marine Park, Fig. 9). At least two fields of view provide a consistent benefit to sampling habitat heterogeneity, and up to four fields of view can be beneficial at some locations, with minimum increases in annotation costs. Having more information on habitat heterogeneity better informs any habitat distribution modelling and mapping, thereby justifying the use of additional fields of view.

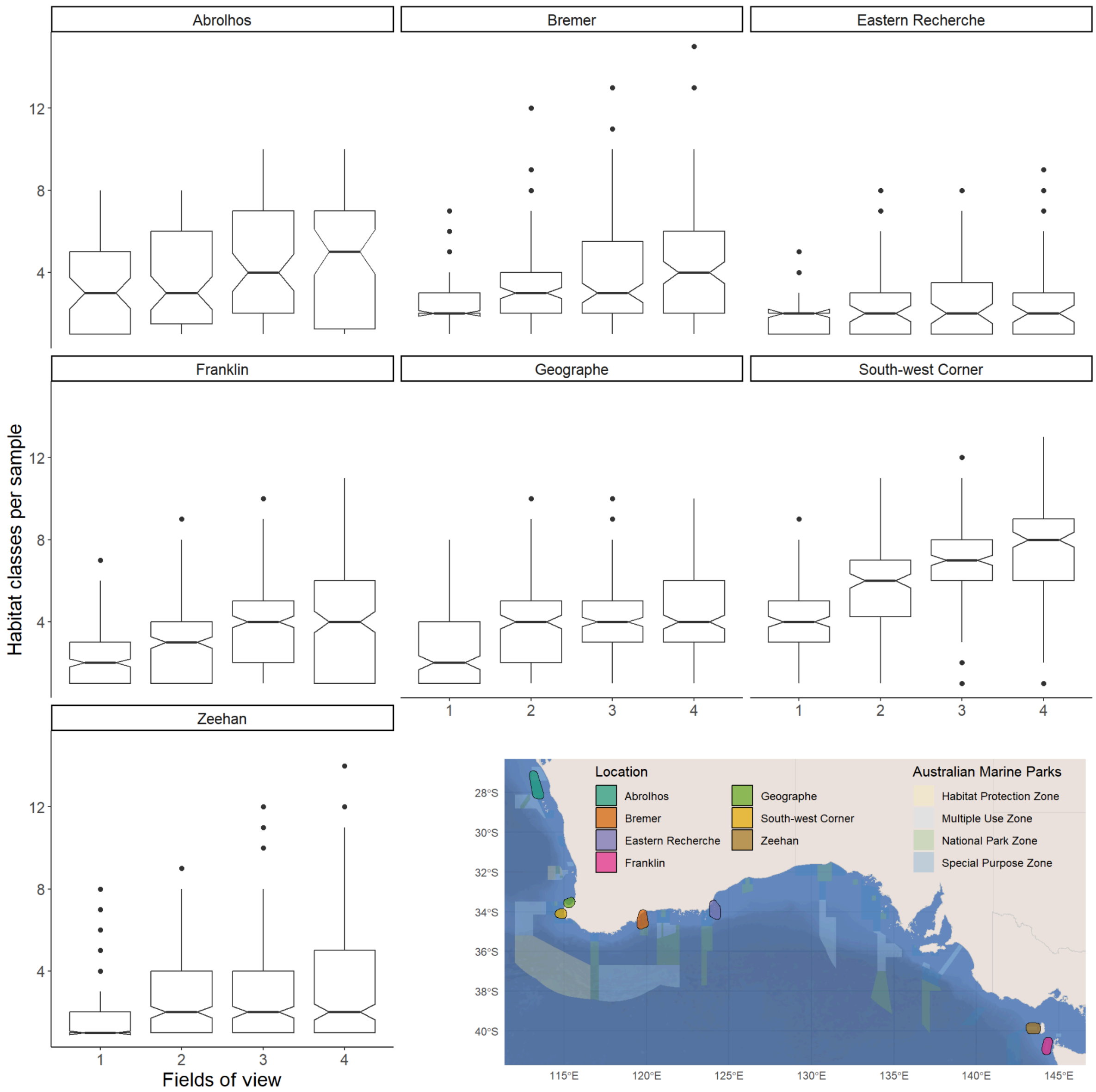


**Figure 9.** Relationship between number of fields of view and number of habitat classes detected across seven continental shelf locations within the Australian Marine Parks..

## Quality control and data curation

Quality control and data curation workflows are vital to ensure data is findable, accessible, interoperable and reusable (FAIR, Wilkinson et al., 2016). All corrections should be made within the original annotation files to ensure data consistency over time. We recommend the following approaches to ensure quality control:

- Annotators should complete small identical 'training' image sets where habitat classes are known, to assess competency and benchmark accuracy.

- Quality assurance should be carried out by a senior analyst and involves a randomised review of 10% of annotated images and data within a project. If accuracy is below 95% for all identifications, imagery should be re-annotated.
- All annotators should meet periodically as a group to discuss image classification to ensure that consistency is maintained throughout the project.

We propose a series of simple visual quality control plots to identify outliers and provide examples of these in the annotation guide (globalarchivemanual.github.io/CheckEM/, Fig. 1).

## Conclusion

The need for marine spatial planning and concerns about the environmental impacts of anthropogenic activities (including climate change, pollution and offshore industries) has led to a growing requirement for large-scale habitat characterisation to inform management, through mapping or environmental assessments. The drop camera system described here is robust, wide-field, and horizontal-facing, in either the stereo or mono-video variations. It is specifically designed for rapidly collecting benthic habitat composition and has been demonstrated to improve habitat quantification across a range of depths from 2 - 220 m. The system is ideal for collecting spatially balanced point samples over large areas, which can be logistically restrictive for other survey platforms, either due to their long deployment times (e.g. stereo-BRUVs), limit on number of ascents (e.g. scuba) or need to be tethered or supported along transects with a finite time underwater (e.g. ROV, AUV), which typically lead to nested or spatially constrained sampling (Monk et al., 2018; Shortis et al., 2008). The optional use of stereo-cameras enables the usable area of the image and range of observation to be quantified and included as an offset in analysis (e.g. when turbidity varies among sites, Broad et al., 2023). Photogrammetry of stereo images also enables the measurement of additional metrics such as algal canopy height or the dimension of benthic biota (Langlois et al., 2021; Vergés et al., 2016). These data are highly amenable for medium to large-scale habitat mapping of marine parks (Leleu et al., 2012), detection of recovery in benthic biota after trawling (Langlois et al., 2021), and environmental impact assessments of emerging industries such as offshore renewables (LaFrance et al., 2014).

## Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was created in 2023 as part of Version 2.1.

The version control for Chapter 11 (field manual for drop cam) is below:

| Version Number | Description | Date |
|---|---|---|
| 1 | There was no drop camera manual included in Version 1 of the field manual package | 28 Feb 2018 |
| 2 | There was no drop camera manual included in Version 2 of the field manual package | July 2020 |

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|---|---|---|
| 3 | Publicly released as Chapter 11 through online portal | March 2024 |


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## References


Althaus, F., Hill, N., Ferrari, R., Edwards, L., Przeslawski, R., Schönberg, C. H. L., Stuart-Smith, R., Barrett, N., Edgar, G., Colquhoun, J., Tran, M., Jordan, A., Rees, T., & Gowlett-Holmes, K. (2015). A Standardised Vocabulary for Identifying Benthic Biota and Substrata from Underwater Imagery: The CATAMI Classification Scheme. *PloS One*, *10*(10), e0141039.

Bennett, K., Wilson, S. K., Shedrawi, G., McLean, D. L., & Langlois, T. J. (2016). Can diver operated stereo-video surveys for fish be used to collect meaningful data on benthic coral reef communities? In *Limnology and Oceanography: Methods* (Vol. 14, Issue 12, pp. 874–885). https://doi.org/10.1002/lom3.10141

Boutros, N., Shortis, M. R., & Harvey, E. S. (2015). A comparison of calibration methods and system configurations of underwater stereo-video systems for applications in marine ecology. In *Limnology and Oceanography: Methods* (Vol. 13, Issue 5, pp. 224–236). https://doi.org/10.1002/lom3.10020

Broad, A., Rees, M., Knott, N., Swadling, D., Hammond, M., Ingleton, T., Morris, B., & Davis, A. R. (2023). Anchor scour from shipping and the defaunation of rocky reefs: A quantitative assessment. *The Science of the Total Environment*, *863*, 160717.

Foster, S. D., Hosack, G. R., Monk, J., Lawrence, E., Barrett, N. S., Williams, A., & Przeslawski, R. (2020). Spatially balanced designs for transect-based surveys. *Methods in Ecology and Evolution / British Ecological Society*, *11*(1), 95–105.

Kincaid, T., Olsen, T., Kincaid, M. T., & Imports, M. (2007). *The spsurvey Package*. http://ftp.uni-bayreuth.de/math/statlib/R/CRAN/doc/packages/spsurvey.pdf

LaFrance, M., King, J. W., Oakley, B. A., & Pratt, S. (2014). A comparison of top-down and bottom-up approaches to benthic habitat mapping to inform offshore wind energy development. *Continental Shelf Research*, *83*, 24–44.

Langlois, T. J., Goetze, J., Bond, T., Monk, J., Abesamis, R. A., Asher, J., Barrett, N., Bernard, A. T. F., Bouchet, P. J., Birt, M. J., Cappo, M., Currey-Randall, L. M., Driessen, D., Fairclough, D. V., Fullwood, L. A. F., Gibbons, B. A., Harasti, D., Heupel, M. R., Hicks, J., … Harvey, E. S. (2020). A field and video annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. *Methods in Ecology and Evolution / British Ecological Society*, *11*(11), 1401–1409.

Langlois, T. J., Wakefield, C. B., Harvey, E. S., Boddington, D. K., & Newman, S. J. (2021). Does the benthic biota or fish assemblage within a large targeted fisheries closure differ to surrounding areas after 12 years of protection in tropical northwestern Australia? *Marine Environmental Research*, *170*, 105403.

Leleu, K., Remy-Zephir, B., Grace, R., & Costello, M. J. (2012). Mapping habitats in a marine reserve showed how a 30-year trophic cascade altered ecosystem structure. *Biological Conservation*, *155*, 193–201.

Liu, G., Chen, L., Liu, K., & Luo, Y. (2023). A swarm of unmanned vehicles in the shallow ocean: A survey. *Neurocomputing*, *531*, 74–86.

Monk, J., Barrett, N. S., Peel, D., Lawrence, E., Hill, N. A., Lucieer, V., & Hayes, K. R. (2018). An evaluation of the error and uncertainty in epibenthos cover estimates from AUV images collected with an efficient, spatially-balanced design. *PloS One*, *13*(9), e0203827.

Pelletier, D., Selmaoui-Folcher, N., Bockel, T., & Schohn, T. (2020). A regionally scalable habitat typology for assessing benthic habitats and fish communities: Application to New Caledonia reefs and lagoons. *Ecology and Evolution*, *10*(14), 7021–7049.

Perkins, N. R., Hosack, G. R., Foster, S. D., Monk, J., & Barrett, N. S. (2020). Monitoring the resilience of a no-take marine reserve to a range extending species using benthic imagery. *PloS One*, *15*(8), e0237257.

Przeslawski, R., Barrett, N., Carroll, A., Foster, S., Gibbons, B., Jordan, A., Monk, J., Langlois, T., Lara-Lopez, A., Pearlman, J., Picard, K., Pini-Fitzsimmons, J., van Ruth, P., & Williams, J. (2023). Developing an ocean best practice: A case study of marine sampling practices from Australia. *Frontiers in Marine Science*, *10*. https://doi.org/10.3389/fmars.2023.1173075

Rees, A. J. J., Yearsley, G. K., Gowlett-Holmes, K., & Pogonoski, J. (1999). *CSIRO National Collections and Marine Infrstructure (formerly CSIRO Marine and Atmospheric Research)*. CAAB - Codes for Australian Aquatic Biota. https://www.marine.csiro.au/data/caab/

Robertson, B. L., Brown, J. A., McDonald, T., & Jaksons, P. (2013). BAS: Balanced Acceptance Sampling of Natural Resources. In *Biometrics* (Vol. 69, Issue 3, pp. 776–784). https://doi.org/10.1111/biom.12059

Sheehan, E. V., Vaz, S., Pettifer, E., Foster, N. L., Nancollas, S. J., Cousens, S., Holmes, L., Facq, J.-V., Germain, G., & Attrill, M. J. (2016). An experimental comparison of three towed underwater video systems using species metrics, benthic impact and performance. *Methods in Ecology and Evolution / British Ecological Society*, *7*(7), 843–852.

Shortis, Seager, & Williams. (2008). Using stereo-video for deep water benthic habitat surveys. *Marine Technology*. https://www.researchgate.net/profile/Mark-Shortis/publication/233526348_Using_Stereo-Video_for_Deep_Water_Benthic_Habitat_Surveys/links/0deec52b3521743ce4000000/Using-Stereo-Video-for-Deep-Water-Benthic-Habitat-Surveys.pdf

Starr, R. M., Gleason, M. G., Marks, C. I., Kline, D., Rienecke, S., Denney, C., Tagini, A., & Field, J. C. (2016). Targeting Abundant Fish Stocks while Avoiding Overfished Species: Video and Fishing Surveys to Inform Management after Long-Term Fishery Closures. *PloS One*, *11*(12), e0168645.

Vergés, A., Doropoulos, C., Malcolm, H. A., Skye, M., Garcia-Pizá, M., Marzinelli, E. M., Campbell, A. H., Ballesteros, E., Hoey, A. S., Vila-Concejo, A., Bozec, Y.-M., & Steinberg, P. D. (2016).

Long-term empirical evidence of ocean warming leading to tropicalization of fish communities, increased herbivory, and loss of kelp. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(48), 13791–13796.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., … Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, *3*, 160018.