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10. Field Manual for Imagery Based Surveys using Remotely Operated Vehicles (ROVs)

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Platform Description

Remotely Operated Vehicles (ROVs) are piloted, tethered unmanned submersibles typically controlled from a vessel (sometimes from other fixed structures such as oil and gas platform jackets) via a reinforced umbilical cable as the main tethering device. The tether historically provided electrical power and also allowed the real-time transfer of data between the vessel and ROV to be transmitted. With advancements in battery technology, smaller ROVs can now be powered by onboard battery systems, which reduces the diameter of the tether, decreasing drag and improving ROV maneuverability. The motion of ROVs are controlled by multiple thrusters that allow movement and manipulation in all directions and speeds up to 3 knots. Onboard cameras and sensors provide data and visual information that is relayed back to the surface personnel to observe the seabed or other structures and control the ROV. Onboard sensors typically provide feedback on water depth, temperature, currents, orientation and location of the ROV. The attachment of manipulator arms can also allow for specimens and samples to be collected (including in the water column).

ROVs were originally designed in the mid-1980s to complement manned scientific submersibles. With the increase in technology since, ROVs have gained acceptance because of their distinct advantages over manned submersibles in many areas, notably reduced risk to pilots and researchers. For instance, they can remain on the seafloor for extended periods efficiently performing large surveys, running extended time series observations, and conducting multidisciplinary operations (Shepherd 2001, Macreadie et al. 2018, Sward et al. 2019). A large volume of data is transmitted to the surface, via multiple channels including real time video, sonar, CTD (conductivity–temperature–depth) data, real time location and other information.

ROVs are available in a range of sizes and configurations from smaller observation-class vehicles (~3-20 kg for mini and ~30-120 kg for regular-sized models) to larger work-class systems (100-1,500 kg for light- and up to 5,000 kg for heavy-duty models), which vary in power, depth rating, accessibility, and additional payload capabilities (Baker et al. 2012, Capocci et al. 2017, Huvenne et al. 2018). As a result of the versatility, ROVs are increasingly being used for deep-water surveys, with published examples of using ROVs for physical sampling via manipulator and grabber arms, scanning sonars and high-definition cameras to provide researchers with still or video images of the physical environment (Shepherd 2001, Leckie et al. 2015, Robert et al. 2017, Macreadie et al. 2018) and associated sessile mega-benthic taxa (Salvati et al. 2010; Thresher et al. 2014; Lacharité et al. 2015; Cánovas-Molina et al. 2016; Price et al. 2019; López-Garrido et al. 2020) as well as mobile organisms (such as fish; Karpov et al. 2006, Pradella et al. 2014, McLean et al. 2017, Thomson et al. 2018). ROVs may be better at collecting individual organisms than other commonly used sampling platforms, with intact sponges in excellent condition collected by an ROV and damaged or fragmented sponges collected from sleds and trawls (Tabachnick et al. 2019). With advances in technology, a wider range of ROV models are becoming available, including many low-cost systems, resulting in a greater uptake by researchers.

For further information on the advantages and disadvantages of ROVs compared to other benthic imagery and sampling platforms, refer to *Comparative assessment of seafloor sampling platforms* Przeslawski et al. 2018 and review by Sward et al. 2019).

Scope

The primary aim of this field manual is to establish a consistent sampling protocol for marine benthic assemblages using ROVs and to facilitate statistically sound research to allow comparisons between studies. This manual will focus on the use of ROVs for the collection of still and video imagery of fish and associated seabed habitats but consider researchers may use them for other purposes as detailed in Table 10.1. We also consider all ROV classes here and provide some guidance around the limitations associated with each class. The document leverages the expertise of the working group focusing on still and video imagery (Chapters 4 and 7 for example, but see Table 10.1 for a brief summary of additional uses for ROVs). The scope of the manual covers equipment, pre-survey preparation, field procedures, and post-survey procedure for using ROVs to photographically and videographically survey seabed assemblages (including fishes) found within Australia's vast marine estate.

Table 10.1: Additional uses of ROVs in monitoring the marine environment that are not covered in this manual (modified from McLean et al. 2020).

Payload	Description
CTD	Seawater temperature and salinity depth profiles
Bio-optical sensors	Fluorescence and backscatter (turbidity) sensor
Light meter	Upwelling and downwelling light, photosynthetically active radiation (PAR)
Dissolved oxygen sensor	Dissolved oxygen concentrations
pH sensor	Water column pH
Water sampler	Water column samples for microbes, nutrients, pollutants, chlorophyll using bottle samplers
Acoustic telemetry, Hydrophones/passive acoustics	Detection of tagged and untagged animals, migration patterns, connectivity
Scanning/Imaging sonar	Bathymetry, structural complexity
Sediment Corers/grabs	Sedimentology or biogeochemistry e.g. particle size, sediment chemistry
Faunal traps	Deployment and retrieval of baited traps for sampling of mobile fauna, including fish and invertebrates
Faunal sampling	*In situ* sampling of sessile and mobile fauna, including pelagic and demersal fish and benthic invertebrates

ROVs in Marine Monitoring

Using ROVs to visually monitor marine ecosystems has experienced a rapid increase over the past two decades as a result of cheaper, smaller ROVs becoming available as well as improved access to oil and gas sector ROVs (e.g. through the SERPENT initiative; Macreadie et al. 2018) and philanthropic ROVs (e.g. Schmidt Ocean Institute). Researchers have used ROVs in monitoring the impacts of invasive species (Whitfield et al. 2007), assessing marine protected areas (Dauble 2006, Torriente et al. 2019) assessing population trends in demersal fishes (reviewed in Sward et al. 2019), mapping of benthic habitats (García-Alegre et al. 2014, Torriente et al. 2019), examining diversity in reef communities (including on vertical walls; (Robert et al. 2017, Price et al. 2019), detecting marine litter (GESAMP 2019), and assessing spatial and temporal changes in fish and sessile benthos associated with artificial structures (such as oil and gas infrastructure; McLean et al. 2017, Bond et al. 2018).

While ROVs can be used for deploying a variety of sensors, as well as taking samples of substrata and organisms (Table 10.1) they are also used to generate spatially accurate photomosaics and finescale digital elevation models. Multibeam data which is often available with accurate georeferencing can provide important information regarding habitat types and structural complexity but is often limited to cell resolutions of 50 cm to 5 m. Finescale digital elevation models from ROV photomosaics can be done at 1-10 cm cell resolution, and on vertical structures (something AUVs currently struggle to achieve), thus enabling extremely detailed structural information to be extracted (Robert et al. 2017). Additionally, and perhaps more importantly, the benefits of using ROV to provide digital elevation models is that they also provide colour information (via the photomosaics), which is crucial for identification of species and evaluation of condition (e.g. live vs. dead coral).

ROVs are not without their limitations when visually monitoring organisms. Different classes of ROVs are better suited to certain situations and components of a species assemblage (Table 10.2). There is generally a trade-off with high-quality macro-imagery and ROV functionality associated with high costs and technical requirements (Figure 10.1). When using ROVs for visually monitoring marine organisms, researchers should consider the potential effects of differing light intensity and wavelength, impacts of sound intensity and frequencies (for example, large hydraulic ROVs are noisy), and consequences of vehicle speed, size, altitude on survey bias particularly on mobile organisms. Research suggests that a combination of these factors can have substantial effects on the data collected (Stoner et al. 2008, Ryer et al. 2009, Rountree & Juanes 2010). While all sampling platforms have associated biases, the limited access to work-class ROVs and a steady uptake of cheaper smaller vehicles may make ROVs particularly prone to this bias. This is particularly important if different vehicles are used between regions (e.g. inside vs outside no-take reserves) or across time series sampling.

A key advantage that ROVs have in a monitoring context is their ability to be dynamically controlled in 'real time' across a range of depths and habitats. This is because data are streamed real time which means that the vehicle can survey vast areas with constant supervision and can be easily focused on areas of interest. ROVs are the only marine imagery systems available in Australia that are able to readily collect quality imagery from highly rugose environments, including vertical rock walls, steep slopes, and overhangs. These environments are prevalent in many marine parks, along the continental slope and offshore reefs. Similar to AUVs, when equipped with acoustic positioning (e.g., ultra-short baseline, USBL), ROVs can be piloted along precisely defined transects, at a constant altitude, with the geolocation of individual still images along this path as well as forward facing stereo-video (along with other sensors if required/fitted). The geolocation of imagery and flight paths allows relatively precise repeat transects to be conducted for monitoring purposes, and also for the imagery to be used to ground-truth multibeam sonar (Ierodiaconou et al. 2011), assessing the effectiveness of marine protected areas (Torriente et al. 2019), as well as for modelling the environmental factors driving species' distributions (Salvati et al. 2010, García-Alegre et al. 2014, Lastras et al. 2016). Although ROVs have been shown to collect comparable reef fish assemblage data as diver-operated video and slow towed video (Shchramm et al 2019), they are uniquely suited to collect data in environments that are otherwise challenging to other sampling platforms.

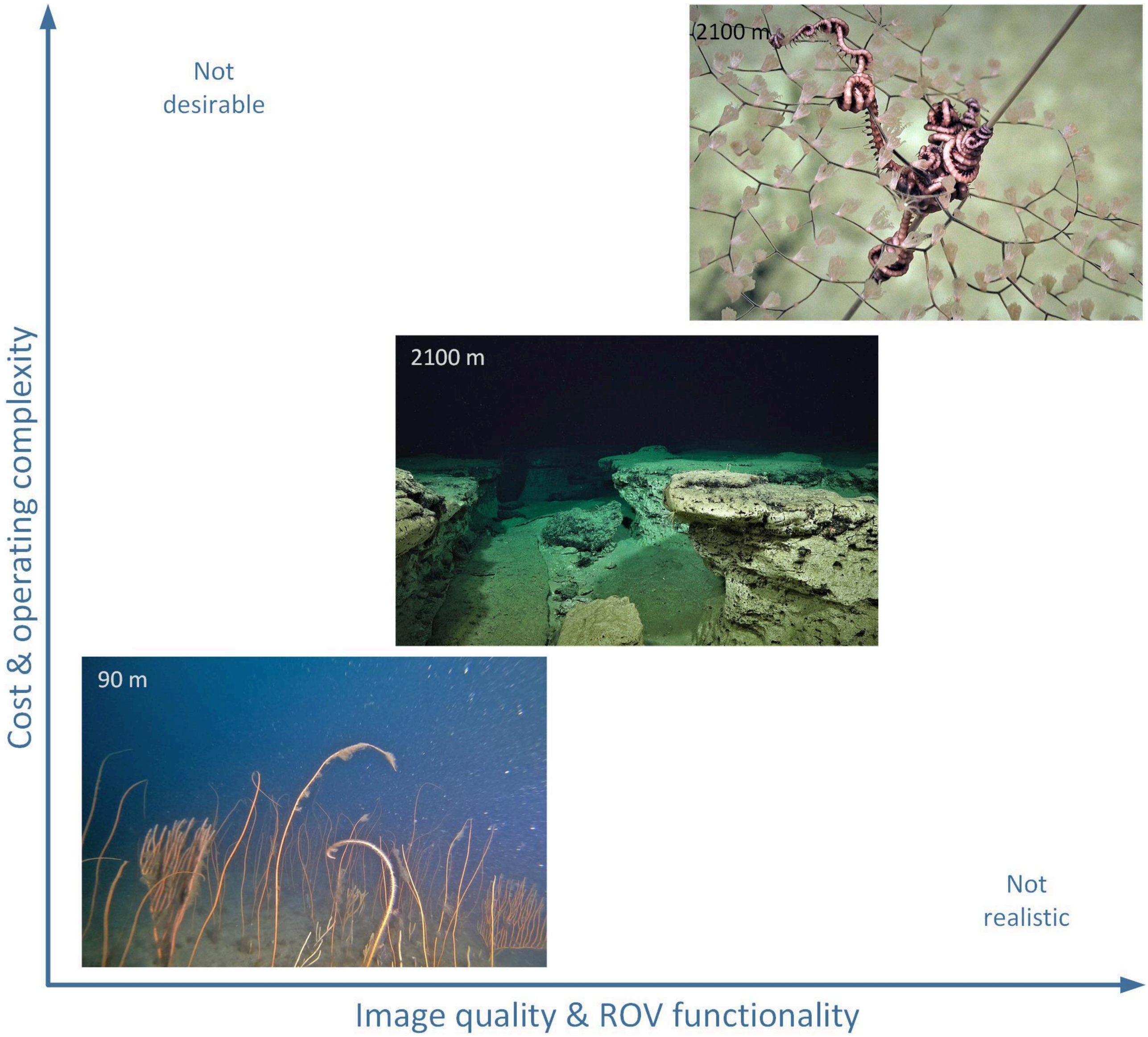
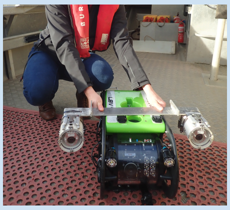
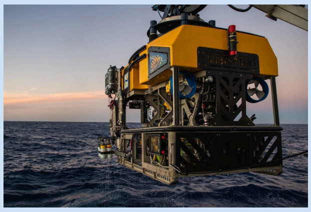


Figure 10.1: Sample images showing the tradeoffs for different ROVs: [left]: sessile invertebrates from Hunter Marine Park from a BlueRobotics BlueROV (with a heavy kit upgrade) fitted with stereo GoPro HERO7 Black cameras, [middle] limestone outcrops along a canyon slope in the Gascoyne Marine Park from the ROV SuBastien's situational camera, and [right] brittlestars entwined around a black coral from the ROV SuBastien's 4K camera.

Table 10.2: Summary of ROV classes and considerations associated with each when used for monitoring Australia's marine estate (table modified from JNCC, 2018).

ROV class	**Class I:** **Observation**	**Class II:** **Observation (with payload option)**	**Class III:** **Work**
			
Definition and capability	Typically < 40kg in weight these vehicles are primarily intended for observation only. Fitted with inbuilt camera and lights, may be able to handle one additional sensor (such as USBL), simple grabber claws, as well as an additional stereo-video camera.	Larger vehicles than Class I, weighing ~100-150kg, are capable of basic physical sampling and observations. Capable of carrying multiple cameras and sensors as well as simple gabber claws.	Weighing <~5000kg, these vehicles have a broad carrying capability and operational conditions (e.g. depth and currents). Usually used in deeper waters (i.e. off continental shelf) these are the most complex and versatile of ROVs used. They are often used in the Oil and Gas sector.
Examples	BlueROV, Boxfish, DeepTrekker, Fusion, Ocean Modules V4 S300, OpenROV, Seabotix LBV300, Trident, VideoRay Pro4	Ocean Modules V8 M500, Pollox, Phantom, Saab Seaeye Falcon (DR)/Cougar XT	Argus Mariner XL/Worker, Hercules; Holland, Isis; Jason 2; Kiel6000; Ocean Modules V8 L3000, SuBastian
Scale of operation^	Fine (<20m) - Meso (200m - 1km)	Meso - Macro (>1km)	Meso - Macro
Max. operational conditions	Depth: <100m Sea state: <2m Current: <1.5kt	Depth: 0 - 300m[#], Sea state: <3m Current: <3kt	Depth: >300m, Sea state: <4m Current: <4kt
Deployment type	Manual	Manual (<300m depth) or vessel A Frame/crane and winch or Launch And Recovery System (LARS) package.	LARS package or vessel A-frame/crane (for shallow deployment). A moonpool is a further option.
Tether management	Free swimming - tether connected to ROV. Clump weight recommended in deep/high current deployments.	Single body on main umbilical (live boating) or Tether Management System (TMS).	Single body on main umbilical (live boating) or TMS.

Approx. survey cost per day*	AUD 2,000 - 10,000	AUD 5,000 - 40,000	AUD 50,000 - 120,000
Approx. purchase cost^^	AUD 10,000-250,000	AUD 200,000-1,000,000	AUD 1,000,000-6,000,000+
Vessel requirements	Fixed platform (jetty/pontoon/oil/gas platform), small vessel (<10m) (with or without power supply) or other small vessel.	Shallow draught vessels suitable for inshore waters (10-30m), for extended offshore surveys larger (~>30m) vessels will be used.	Large vessel (~>50m) with Dynamic Positioning (DP), deck capacity for container storage and LARS.

^ Ability to navigate across distance

Deep Rated vehicles are available for >300m but have limited mobility at these depths.

* Planning and field work only. Purchase of ROV, consumables, processing of samples and reporting are not included.

^^ Estimates include basic positioning systems (such as USBL), grabber/manipulator and depth rated stereo cameras. Based on quotes from the companies as well as catalogue entries.

Pre-Survey Preparations

Ensure all permits, safety plans and approvals have been obtained. Any research undertaken within Australian Marine Parks (AMPs) requires a research permit issued from Parks Australia. Refer to AusSeabed's permit guide for further useful information: www.ausseabed.gov.au/resources/permit. The observation of animals should be undertaken in an ethical manner and in many cases, surveys may require approval from an Animal Ethics Committee.

Define the aim of the project. This is a mandatory step in any marine monitoring project, but with their multiple capabilities (imagery, sampling, sensors), projects using ROVs may be particularly vulnerable to competing research interests or distractions during a dive. A clearly defined aim or hypothesis ensures the ROV pilot stays on task and is not distracted.This may be done in conjunction with local communities including Traditional Owners. See Indigenous Leadership and Collaboration in Chapter 1 for further details.

Confirm sampling design is statistically sound with adequate spatial coverage and replication, and addresses the aim or hypothesis. This is generally achieved through the use of an explicit randomization procedure to ensure that a sufficient number of independent replicates are obtained (Foster et al. 2017, 2019, Smith et al. 2017). See Chapter 2 for further details on sampling design.

Select appropriate transect design for ROV deployment (Foster et al. 2019). The decision to which transect design is most appropriate is driven by the question being addressed, the applied capabilities of the ROV (i.e. sampling may be applied concurrently with image acquisition), the environment, available time and logistics of ROV deployment and retrieval (e.g. size of system). For example, tether and vessel drag within environments exposed to strong currents makes piloting an ROV along a predetermined transect difficult if not impossible. In such situations ROVs (particularly small ROVs) may not be the best system for temporal monitoring purposes because of the challenges with maintaining physical position to enable sufficient overlap between repeat surveys (i.e., within 20 m) (e.g. Przeslawski et al. 2012 in northern Australia). In addition, some consideration must be given to the unique capability of ROVs to traverse steep slopes, including vertical deployments, when undertaking quantitative image transects of a set distance. For these situations, calculated distance cannot be 'as the crow flies' and will rely on high-resolution bathymetry as well as continuous monitoring by the ROV crew during deployment to determine actual distance traversed.

For marine monitoring of demersal fishes on the continental shelf a transect of ~150-200 m is sufficient. Monk et al. (Unpublished) contrasted three transect lengths (50, 100, 150 m) finding that at least 150 m was a generally sufficient design for monitoring purposes of demersal fish diversity (< 200 m). For surveys aiming to collect imagery of the epibenthos, or in deeper environments, then longer transects are possibly required to gather sufficient imagery to characterise the focal regions.

For surveys that include fauna of mixed mobility, for example fish and invertebrates, a dual transect approach may be suitable. The transect area can first be surveyed rapidly to ensure individuals of highly mobile taxa are included, and then again at a slower speed to ensure observation of smaller and more cryptic species.

For survey of fauna associated with topographical features, for example seamounts, vertical reef structures or oil and gas facilities, transects conducted in an arc around the feature may be more suitable than linear transects. The ROV can be thrusted laterally, allowing cameras to be consistently oriented toward the feature throughout the transect.

<u>Stereo-cameras specifications and calibration (must be pre- and post-calibrated)</u> in shallow water using the techniques similar to those outlined in Boutros et al. (2015). We recommend cameras with full, high-definition resolution of at least 1920 x 1080 pixels and a capture rate of at least 30 frames per second. Higher camera resolution will improve identification of fish, and the pixel selection required for measurement, but some models of action cameras can overheat at high resolution. Higher frame rates reduce blur on fast-moving species. To maintain stereo-calibrations, cameras must have video stabilisation disabled, and a fixed focal length can facilitate measurements both close to and far from the camera systems when correctly calibrated (Boutros et al. 2015). The field of view should be standardised and chosen to limit distortion in the image (e.g. no more than a medium angle, ~95° H-FOV). When sampling demersal fish assemblages at typical maximum range (6 m) from the cameras, Boutros et al. (2015) suggested a separation < 500 mm will result in a decrease in the accuracy of measurements. Cameras are fixed to a rigid base bar to preserve the stereo-calibration required to calculate accurate length and range measurements (Boutros et al. 2015). As outlined in Chapter 5 for stereo-BRUVs, SeaGIS software and 3D calibration hardware is recommended for calibration of stereo video imagery. For doward-facing stereo still imagery, then a similar approach documented in Chapter 4 for AUVs, can be taken, using a base separation of at least 300 mm at 500mm altitude (noting higher altitudes will require larger base separations) is important to obtain well-lit and calibrated images (Boutros et al. 2015).

<u>Decide on appropriate navigational systems (e.g. USBL) and required spatial precision of imagery</u>. In many cases a USBL should be used for both navigation and georeferencing imagery. However, other methods can be employed such as doppler velocity logging or simple timed directional transects for navigation and calibrated stereo imagery or stereo lasers for image scaling. For many ROV studies the choice of navigational and georeferencing of imagery is often limited to what is fitted to the unit available. However, appropriate effort must be given to this during the survey planning phase as it may limit the questions sought to be answered by the imagery. For example,

spatial precision is very important for fine scale analysis whereas navigational accuracy is important for temporal replication. Some alternative navigational methods, simple timed directional transects are sometimes used if a USBL is not used, are not well suited to temporal replication as the exact spatial location of the track cannot be determined. This results in resultant data needing to be pooled to transect level. This reduces a key advantage of ROVs that individual observations can be co-location with finescale covariates (such as from multibeam sonar). This makes data collected in this fashion more akin to stereo BRUVs or underwater visual census which essentially aggregate individuals to a sample. We suggest that both accuracy and spatial precision need to be addressed for distance and swept area determination.

Ensure appropriate software is installed on onboard laptops (e.g. ROV navigation software platform, GIS, etc), and potential users are familiar with it so that the ROV can be tracked and its mission success monitored while underway. It is worth setting all equipment up in the laboratory or at dock to ensure everything is operational and no software updates are required.

Ensure a trained technical team. For the work-class ROVs, a professional technical and piloting team with training specific to the designated ROV will be required. For the smaller ROVs, training on piloting and technical issues is still highly recommended during the pre-survey planning stage.

Field Procedures

Many of the steps in this section are designed for smaller class ROVs and are to be managed by researchers or general marine technicians. Work-class ROVs will have their own deployment protocols based on the technical capabilities and logistic requirements for the particular ROV and associated professional team, and these may supersede the specific steps below.

Onboard sample acquisition

Complete an on-site briefing.
Prior to deployment, a deployment briefing should always be completed to ensure the operation can be completed safely. Always take a precautionary approach to risks associated with vehicle deployment. See Chapter 1 for further information about risk assessments.

Set up and test the ROV system.
Allow sufficient time during survey mobilisation to undertake system checks, calibrations and testing of equipment and account for unforeseen problems; in most cases it will be possible to complete all system setup and tests within half a day. The conduct of pre-start checks should be noted in the trip log and any test failures specifically recorded for later-reference. Detailed settings for each component should be made using relevant operations manuals (e.g. USBL operations manual etc.).

Acoustic tracking setup

- Set position of GPS receiver. *Differential GPS is mandatory for repeat site monitoring.*
- Measure offsets of USBL transceiver head to GPS receiver and put offsets into navigation systems.
- Deploy USBL transceiver (e.g. pole or vessel mounted).

- USBL calibration dockside is a good idea as well to verify that range and bearing (and depth if estimated by USBL) are within expected tolerances. Understanding the selection and recording of filtering/smoothing settings of the USBL system should also be noted.

On-deck tests should include, but not limited to, the following checks:

- on-board data storage
- on-board power (if fitted)
- cameras
- tether management system (including assessing for nicks in tether)
- strobe lighting
- thrusters (assessing for fouling and operation)
- Manipulator arm(s) and sample container(s) (if fitted)
- all blanking plugs are installed
- crane and associated shackles are working order
- check all seals/o-rings and blanking plugs are good working order
- check all surface communications

Wet testing should include checks of the following:

- Thrusters (including all directions)
- USBL and internal navigation (e.g. compass and avoidance sonar)
- cameras and strobes
- avoidance/scanning sonar (if fitted)
- through-water communications

Conduct ROV transects

Pre-deployment

- Transects should only be undertaken in areas where the substratum is known, preferably in the form of multibeam mapping, so as to avoid entrapment and potential loss of ROV. Do not deploy blind, as this increases the risk of equipment loss and damage, as well as unnecessary impact on potentially vulnerable ecosystems.
- Once final transect locations have been determined, provide the locations of the transects (usually in ESRI shapefile format or start and end waypoints) and associated multibeam maps (in geotif format) to the ROV crew responsible for piloting missions. Cross-check the

uploaded transect corresponds to the correct area on the geotif (i.e. ensure the geographic coordinates are defined for all spatial data).

- Discuss the desired target location and the feasibility of deploying at that location. Main items to take into account are:
  - Terrain. To minimise the risk of a deployment in highly rugose seafloor (e.g. walls) it is recommended that transects should be conducted up or along walls. Also consider the water visibility. If there are any large ridges, boulders, drop-offs, etc. along the proposed transect with minimal forward vision (< 10 m) there may not be a large margin for avoidance.
  - Currents/weather/sea state. During the transect, the USBL display will show the boat and ROV position, allowing the skipper and ROV pilot to discuss tracks and adjust speed if required. This can limit the manoeuvrability of the ship and depending on the direction of the prevailing wind and sea, is not always possible on a particular heading. As the sea-state and swell can affect the ships manoeuvrability when travelling at low speeds it is essential to regularly check the weather forecast to ensure the sea state is acceptable and the platform can be safely deployed and retrieved.
  - Depth. Be aware of the depth limitations of the ROV and the length of the tether.
  - Entanglement procedure. Discuss potential entanglement procedure (detailed below) making sure each person is familiar with their role.
- Prepare for ROV launch and recovery on deck and ensure only essential personnel participate in its preparation and deployment.
- Place USBL transceiver in water and ensure functionality.
- Ensure tether is connected, turn on ROV and run all surface checks of the ROV as per manufacturer's requirements.
- Check camera settings (if external cameras are being used).
- Check data sheet is ready (note site, camera numbers and memory card numbers).
- Turn external cameras on, check there is battery and storage space available.
- Insert cameras into housings, check that the housing is dry and that there is no sand, hair or other objects obstructing the o-rings, and ensure there is a good seal and the o-ring is not pinched.
- Film data sheet or clapper board so that the site/location is identifiable at the beginning of the video (only needed if cameras are external to ROV).
- Film diode, or use clapper board, or alternative device to synchronise video footage.
- Correctly insert the deployment release pin (if using).

ROV deployment

1. Vessel master must ensure the vessel is positioned at the start of the transect location.
2. Following the signal to deploy from the vessel Master, use the crane and/or A-Frame to lift and guide the ROV from the deck into the water. Or, if using a small observation class ROV signal to the deckhand to gently place the ROV in the water ensuring the thrusters are disabled or unarmed.
3. Minimise the time taken from when the ROV is out of reach, to when it is lowered in the water, so as to reduce potential swing and impact against the vessel. As soon as the ROV enters the water, pilot it below or away from the vessel to avoid drifting into or over the ROV.
4. Using appropriate software (see Pre-Survey Preparations), rapidly pilot the ROV to the seabed and at the start of transect location to avoid drifting off the starting point.
5. Confirm imagery and positional data are being recorded where possible (e.g. recording indicators, hard drive operating).

ROV maneuvering

1. At the start of the transect flash lights or something similar should be used to indicate the start of the transect. This is important to be able to sync footage with a USBL track (if used) when the cameras are not integrated into the ROV.
2. The ROV should be positioned so that it is on course for the transect trajectory before the transect start-point, so that movements are stable when it reaches the start of the transect. Once the ROV is following the planned transect track the pilot can switch to 'auto-heading' to hold course (if available).
3. The flight elevation of the ROV should be set (either manually or automatically) and maintained at ~ 1 m from the seafloor to facilitate a consistent field of view (i.e. ~5 m width transect for mobile organisms with this width being measurable if calibrated stereo cameras are fitted). Try to maintain a constant forward momentum of ~ 0.5-1 ms^{-1} (1-2 kt). Avoid stopping or chasing fish/organisms off the transect. Also avoid disturbing the substratum as sediment clouds will obscure the image (Hitchin et al. 2015). However, if elevation is too high then fish observations are likely to be reduced. These factors need to be informed by the 'survey question', camera type and performance, illumination type and output power, etc.
4. Ask the vessel's Master to follow the ROV during transects. If current/wind is too strong then the vessel may need to anchor. A sea anchor or drop/clump weight can be used to reduce the effects of vessel and tether drag, respectively. If survey designs require live-boat procedures it is more likely that operations would cease if weather conditions deteriorate too much, unless there was an alternate survey objective that could be accomplished at anchor.

5. Make sure that the tether is kept away from vessel propellers at all times. A crew member must maintain tether management at all times. Clear and uninterrupted communication between ROV pilot, tether crew and vessel master must be maintained at all times.

6. Monitor weather forecast conditions prior to and during deployment to maintain a safe working environment. Consider aborting operations if local weather and forecast conditions are marginal.

7. Vessel/ROV maneuvering is a nuanced topic, with most work class ROV teams having their own protocols. Importantly, planning a transect in a fashion that avoids positioning the ROV between the vessel and known entanglement risks (ledges, pinnacles, fishing gear, etc) is the most important general protocol. The goal being to avoid a situation where the vessel drags the tether into the entanglement because the vessel is typically less maneuverable and has less situational awareness of the terrain. Current direction and speed become forces that influence how easy this is to accomplish but many other factors may dictate how a team chooses to mitigate this risk. Before each transect operators should discuss with the vessel master if the entrapment risks associated with the seafloor are low enough for the transect to be completed successfully.

ROV retrieval

1. When the transect is complete or if the transect is being aborted, advise the vessel Master of the intention to retrieve the ROV.

2. Watch for the ROV to resurface, ensuring only required personnel are near open transom. Avoid approaching the ROV looking into the sun as this increases the risks of collision.

3. Use a grapple hook to connect the lift line to the ROV for retrieval. Depending on the size of the ROV, at least three personnel should be present with hooks to avoid the ROV colliding with the vessel *[Recommended]*.

4. Shut down the ROV. (Dis)connect relevant tether or data transfer cables.

5. For the last transect of the day, if available, wash down the ROV with freshwater and unplug the USBL.

6. Raise the USBL transducer (if pole mounted) before moving the vessel to the next location.

Procedures for seabed entanglement or loss of communications with ROV

Potential entanglement of the ROV is always a possibility. The following procedures should be followed upon entanglement/loss:

1. Log the last known position of the ROV.

2. If the ROV appears entangled (i.e. not moving) try to maneuver the vehicle so as to be able to follow back along the tether to see if and where the tether has become snared. If the ROV is trapped under a ledge/cave, or ensnared in a fishing line or kelp, a dive team or additional ROV may be required. It may be required that the tether is disconnected from the vessel before recovery equipment is launched. In such circumstances, the tether end should be

temporally sealed and attached to surface floats which will reduce water damage to the tether.

3. Ensure the vessel is maintaining position and is not adding increased tension to entangled tether.
4. Ensure that you check ROV thoroughly for damage before redeployment.

Completion of operations

Prior to any vessel movement or engine start-up, operators should check the following:

- All equipment is clear of the water, including the USBL transducer pole.
- ROV is shut down.
- All gear is safely stowed.
- All power and data cables are (dis)connected.
- External cameras are turned off.
- An "All Clear to Move" command is given to the vessel Master when the ROV team is satisfied it is OK for the vessel to move on.

Onboard data processing and storage

5. Once the ROV transect is complete, it is good practice to download associated raw imagery and associated positional data. Imagery and associated positional data should be checked to ensure no failures have occurred, including but not limited to the following:
    - Miss-timing between image capture and strobes (i.e. dark/black imagery)
    - Failure of one of the stereo cameras
    - Failure of positional logging
2. Name data files according to established conventions. File naming conventions are vital for ensuring both efficient and effective management of field data and its integration into appropriate data management repositories. It is important to note that these conventions will differ among agencies and academic institutions. Examples of stereo imagery naming conventions are provided in Chapter 5 for benthic stereo-BRUVs.
3. Ensure accurate recording of metadata. Metadata are descriptive data sources composed of information that may be used to process the images or information therein and for archiving data on data portals (Durden et al. 2016). While it is important to follow agency specific protocols for capturing metadata, it is also essential that metadata are sufficient enough in detail to satisfy conformance checks for subsequent data release via AODN. Minimum data for each transect should contain as follows:

- Campaign (i.e. Survey identifier)
- Station/event number
- Platform
- Latitude and longitude (WGS 1984 in decimal degrees with a minimum of 6 decimal places *[Recommend]*)
- Altitude in m
- Depth in m
- Time and date stamp in UTC
- AUV orientation (roll, pitch, heading) in degrees
- Precision details (e.g. type of navigation system used and its associated errors)
- Data provenance

4. Backup data. This is necessary to ensure all data collected in the field is safely returned and securely backed-up at host facilities, prior to quality control and public release. Onboard copies of data should be made as soon as practical following acquisition. When operating external to a network, it is recommended that all data be backed up on a RAID or a NAS that contain built-in storage redundancy in case of hard-drive failure. A duplicate copy of all data can be copied onto external hard drives for transportation back to host facilities *[Recommended]*.

Post-Survey Procedures

Imagery collected by ROV can be either in the form of video footage or still imagery. What type of imagery is collected and annotated is dependent on the aims or hypothesis. Each has its advantages and disadvantages. Below outlines the workflow for both video and still imagery.

Processing and annotation of video footage

The annotation of ROV imagery will vary according to survey aims and hypotheses, as well as availability of staff and time for this activity. Below we provide standards for annotating ROV imagery for fish based on stereo imagery and habitat and communities based on downward-facing stills.

ROV based stereo-video should be treated similar to stereo-DOV footage (Goetze et al. 2019). Where possible and in line with survey aims and hypotheses, species composition, abundance and length data for all species should be recorded.

For studies focussing on fish or overall community composition, every fish along a transect should be measured (where possible). However, fish that occur in large schools, and are of similar size, can be attributed to binned length measurement using the Number field associated with each length in EventMeasure (or equivalent if analysed using other softwares). It is important to document the range from camera as this is likely to change between regions/ecosystems. This information is included in the standard outputs of EventMeasure and is imported by default into GlobalArchive (see below).

There are several software packages available, but it is important that the output from the analysis of data is in the same or similar formats to facilitate comparison of data between campaigns, studies, and organisations. The most commonly used annotation software is EventMeasure from SeaGIS (https://www.seagis.com.au). If afforded, then the EventMeasure software is recommended, unless your organisation already has an alternative established stereo-video annotation workflow (e.g. AIMS). The essential information produced by such annotation software includes three main outputs:

- Point information
- Length measurements
- 3-D point information

Point information is typically used to calculate abundance values, while length and 3D point information is used to calculate length and biomass metrics. EventMeasure has established queries built-in to produce typical metrics over a user defined period within the footage. Periods can be used to define the start and end transects if multiple are conducted in the same deployment. In addition, EventMeasure annotation datasets held within GlobalArchive (http://globalarchive.org/) can be queried in a similar fashion to produce such metrics (see the manual for GlobalArchive).

Type of fish length (e.g., fork length or total length for fish and disc length for rays) should be clearly indicated as part of the adequate annotation information for each transect/campaign.

Processing and annotation of downward facing still imagery

A general workflow for processing and annotating epibenthos still imagery can be found in Williams et al. (2012). Key requirements for raw image processing and positional data are as follows:

- It is recommended that at least one of the stereo images is in colour and enhanced following similar procedures as outlined by Bryson et al. (2016).
- Ideally all stereo images should be georectified similar to Williams et al. (2012). If not stereo then processing routines can be found in Morris et al. (2014).
- Positional data should be post-processed. This could include using Simultaneous Localisation and Mapping (SLAM) as demonstrated in (Barkby et al. 2009) and (Palomer et al. 2013) for AUV imagery.

Annotation of individual images can be done using a number of annotation software tools. Examples include, Transect Measure, BenthoBox, Coral Point Count, CoralNet and Squidle+. For national consistency Squidle+ (http://squidle.org) is recommended as it is free and allows for different approaches in image subsampling (such as a spatially balanced selection), which is important to minimise spatial autocorrelation and influence inferences from data (Monk et al. unpublished data), as well as stratified and random point count distribution on images. Squidle+ will also automatically import the ROV data once it is linked to a data portal (such as IMAS data repository) making it ready for analysis. Squidle+ also has tools for exploring survey data as well as analysis. In addition, it supports multiple annotation schemes, and will provide consistency through translation between schemes, which is an important point that differentiates Squidle+.

There are three approaches recommended for annotating imagery from ROVs:

- Annotation of individual images
- Annotation of photomosaics
- Extracting structural complexity from orthomosaics

A how-to guide about setting up annotation media sets within Squidle+ is provided at https://squidle.org/wiki. Annotation of individual images or photomosaics can be undertaken using three methods:

- Full assemblage scoring of imagery across space and time. It is important to note that this is a time-consuming process, requiring a lot of replicate images to be scored to enable sufficient power to detect biologically meaningful change as most morphospecies cover < 10 % of an image. This approach appears to be good for delineating bioregional and cross-shelf patterns at a morphospecies (Monk et al. unpublished data) and CATAMI (Althaus et al. 2015) level (Monk et al. 2016, James et al. 2017). This approach will no doubt be effective in choosing an initial suite of indicators for national level monitoring and reporting.

  As a general guideline, and dependent on the survey question, we recommend that 25 random points per image from at least 50 images per transect are a good starting point for recording most morphospecies present within images (based on Perkins et al. 2016). It is important to note that the properties of the organism themselves will also influence the number of points/images to score. Obviously morphospecies that are less abundant require more effort, but also the 'clumpiness' of species will affect the scoring effort needed (Perkins et al. 2016). (Van Rein et al. 2011) and Perkins et al. (2016) suggest that, while a higher number of points per image can increase the detection rate of more organisms within an image, increasing the number of scored images using fewer points is likely to have a similar (or greater) effect. Ideally, increasing both the number of images scored and the number of points scored within an image would result in greater power (Roelfsema et al. 2006), but preference is usually for increasing the number of images (Perkins et al. 2016). Unfortunately, the adoption of this approach is likely to result in substantial increases in processing time and thus cost.

- Targeted scoring of indicators or proxies (such as grouping fine level morphospecies into broader level CATAMI classes; Monk et al. unpublished data). This approach has been shown to work very well at an indicator morphospecies level for detecting change at a regional level (e.g. AUV imagery used by Perkins et al. 2017) as well as for detecting invasive species trends (Whitfield et al. 2007). Since this approach requires substantially less effort to score each image, more images (i.e. often all images) can be scored and, thus, increasing statistical power. The drawback is that a narrower understanding of the environment is produced.

- Automated analysis of imagery potentially provides a cost-effective alternative to annotating imagery from ROVs. It is important to note that automated imagery analysis is a relatively new, and largely developmental, way of annotating images. Despite this, some studies suggest that coral and macroalgae can be reliably identified using automated image analysis (Table 4.1 in Chapter 4 AUV). In 2023, Squidle+ implemented automated annotation tools for the detection of urchins and the classification of *Ecklonia radiata*, canopy-forming macroalgae, mud/sand, hard-coral, seagrass and sponges.

- The last approach to annotating ROV imagery involves the extraction of 3D structural information from stereo images using structure from motion techniques (Marcon 2014). This approach works particularly well for sessile species to track changes in growth form through time at a fine scale (Price et al. 2019). It also has application for vertical structure such as reef walls or artificial structures (Robert et al. 2017).

Data curation and quality control

Data quality control at both the collection and annotation stage is critical. For fish datasets we suggest that the same protocols outlined in section 5.7.3 in Chapter 5 (benthic stereo-BRUVs) be followed, whereby strict training of new annotators is undertaken and thorough checks of species IDs are done by trained taxonomists. It is crucial to include the salary or in-kind contribution of taxonomists into project budgets. For epibenthic sessile communities we recommend that the same protocols outlined in section 4.6.3 in Chapter 4 (AUV) be followed, with, most importantly, the annotation schema needs to be consistent between studies. Where possible morphospecies and associated CATAMI parent classes should be used *[Recommended]*. An initial morphospecies catalogue for southeastern shelf waters is currently held and maintained at the Institute for Marine and Antarctic Studies (IMAS) (contact Assoc. Prof. Neville Barrett or Dr Jacquomo Monk). Clearly, other annotation schemas are available and can be applied. Where existing protocols prevent the adoption of this approach the alternative schema must be mapped to CATAMI so that comparisons can be made with previous studies or between regions. Translations between schema can be readily applied within Squidle+. Squidle+ has a built-in QAQC interface to ensure the consistency of annotations with exemplars managed by schema custodians. The quality control of all annotations of epibenthic sessile organisms undertaken by novice scorers should be assessed against an experienced analyst or machine learning algorithm (e.g. using confusion matrices; see Figure 4.4 in Chapter 4). Similarly, all datasets annotated by multiple people, even skilled scorers, should be tested for observer bias. If there are significant differences among annotators it is important to correct discrepancies. This can be done by re-examining the images to ensure an agreement can be reached between annotators. Alternatively, if an agreement cannot be reached, then the miss-classified item could be potentially grouped into a higher level CATAMI class.

Data release

Many national marine observing programs (for example IMOS through the Australian Ocean Data Network (AODN), or the Marine Geoscience Data System (MGDS) in the USA) routinely store imagery online in an openly accessible location. Squidle+ is a centralised online platform for standardised analysis and annotation of georeferenced imagery and video. Squidle+ operates based on flexible distributed data storage facilities (i.e. imagery can be stored anywhere in an openly accessible online location) to reduce data duplication and inconsistencies, and provides a flexible annotation system with the capability to translate between different annotation schemes.

Following the steps listed below will ensure the timely release of imagery and associated annotation data in a standardised, highly discoverable format.

1. Create a metadata record describing the data collection. Provide as much detail as possible on the deployment (either directly in the metadata record itself, or in the form of attached field sheets as .csv, .txt or similar). Details of minimum metadata requirements are provided in the On-board Data Storage section above. Publish metadata record(s) to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QC-d. This can be done in one of two ways:

   - If metadata from your agency is regularly harvested by the AODN, follow agency-specific protocols for metadata and data release.
   - Otherwise, metadata records can be created and submitted via the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate. As of January 2024, this tool is under maintenance, and metadata submissions should be sent to info@aodn.org.au until it is again active.

   Lodging metadata with AODN in advance of annotation data being available is an important step in documenting the methods and location of acquired imagery and enhancing future discoverability of the data.

2. Upload raw imagery from the survey to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository).

3. Create a Squidle+ campaign as soon as possible after imagery is uploaded, choose the most appropriate annotation schema, and commence annotation of imagery.

4. Add links to the location of the Squidle+ campaign to the previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the record.

5. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation schema (e.g. morphospecies, CATAMI, etc.), and any challenges or limitations encountered. Provide links to this report in all associated metadata *[Recommended]*.

Data analysis

The breadth of research questions precludes any detailed advice on the analysis of data from ROV transects. However, one common attribute of the image-based data that will have to be considered for all analyses is spatial proximity. The closeness of images, within and sometimes between transects (for example if triangle or clover-leaf transect designs or subsets of longer transects are used), means that image data are unlikely to be independent (due to spatial autocorrelation). Yet, this is an assumption that many statistical methods rely upon. The failure to meet this assumption means that the inferences from the statistical analysis may be: (i) over-confident, e.g. having a p-value that is too small; (ii) biased, i.e. the estimates do not reflect the truth; (iii) both, or; (iv) no effect. Obviously, the fourth category is what a researcher hopes for, but it is improbable and must be validated. However, if it is known that the study organism exhibits particularly low autocorrelation then the analysis need not consider it explicitly.

Methods to analyse data, accounting for autocorrelation are available. These include geostatistical models (Foster et al. 2014). However, in certain situations subsampling images will help (Mitchell et al. 2017), but not necessarily alleviate completely. Further, if the study is for a broad area, where transects are small and are well-separated, then amalgamating data to transect level may also be appropriate. The issues of spatial auto-correlation should also be considered if longer transects are being broken up into smaller sections for analysis (as is commonly done in the oil and gas sector).

Some effort should be made to estimate sources of error inherent in navigational (USBL) systems (and/or other geo-referencing methods) and understand how these errors affect the overall target parameter estimation and variability (see Karpov 2006, Rattray et al., 2017, Mitchell et al. 2017).

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2 and in 2024 as Version 3.In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 20204 as Version 23. Updates reflect user feedback and new developments. There is currently no long-term plan or support for future updates. See Chapter 1 (Introduction to field manual package) for further details.

The version control for Chapter 10 (field manual for ROVs) is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, external reviewer as listed Acknowledgements.	25 May 2020
1	There was no ROV manual included in Version 1 of the field manual package	n/a
2	Publicly released as Chapter 10 on www.nespmarine.edu.au through online portal	July 2020
3	Minor updates	March 2024

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