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5. A Field and Video-annotation Guide for Baited Remote Underwater stereo-video Surveys of Demersal Fish Assemblages

Tim Langlois*, Jordan Goetze[1], Todd Bond[2], Jacquomo Monk[3], Rene Abesamis, Jacob Asher, Neville Barrett, Anthony Bernard, Phil Bouchet, Matthew Birt, Mike Cappo, Leanne Currey-Randall, Damon Driessen, David Fairclough, Laura Fullwood, Brooke Gibbons, David Harasti, Michelle Heupel, Jamie Hicks, Thomas Holmes, Charlie Huveneers, Daniel Ierodiaconou, Alan Jordan, Nathan Knott, Hamish Malcolm, Dianne McLean, Mark Meekan, David Miller, Peter Mitchell, Stephen Newman, Ben Radford, Fernanda Rolim , Benjamin Saunders, Marcus Stowar , Adam Smith, Michael Travers, Corey Wakefield, Sasha Whitmarsh, Joel Williams & Euan Harvey

*tim.langlois@uwa.edu.au, [1]jordan.goetze@dbca.wa.gov.au, [2]todd.bond@uwa.edu.au, [3]jacquomo.monk@utas.edu.au

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Introduction

Our understanding of fish ecology and ability to manage populations require accurate data on species occurrence, abundance, body-size distribution and behaviour. Remote video-based sampling methods are increasingly being adopted due to: (i) their non-destructive nature, (ii) ability to sample rare species (Harvey *et al.* 2018; Goetze *et al.* 2019), over broad depth ranges (Heyns-Veale *et al.* 2016; Wellington *et al.* 2018), (iii) provision of a permanent record that can be reviewed to reduce interobserver variability (Cappo *et al.* 2009), (iv) ability to collect concomitant data on habitat (Bennett *et al.* 2016; e.g. epibenthic cover and substrate, Collins *et al.* 2017), and (v) provision of images for science communication. Remote underwater video sampling methods are not subject to diver safety restrictions, nor do they suffer from the behavioural biases resulting from diver presence (Lindfield *et al.* 2014; Gray *et al.* 2016). Multiple remote systems can be deployed in the field consecutively to make efficient use of field time and enable spatially-extensive sampling (Langlois *et al.* 2012c).

The use of bait with remote underwater video (BRUV) systems increases the relative abundance and diversity of fishes observed, particularly species targeted by fisheries, without precluding the sampling of fishes not attracted to bait (Harvey *et al.* 2007; Coghlan *et al.* 2017; Speed *et al.* 2019). Biases associated with bait use have been discussed in various studies (Dorman, Harvey & Newman 2012; Hardinge *et al.* 2013; Goetze *et al.* 2015; Coghlan *et al.* 2017). Variation in bait plume dispersal and the sensitivity of different fish species to bait is unknown (Harvey *et al.* 2007), and likely species-specific, with cryptic and sedentary species potentially under-represented (Watson *et al.* 2005; Stat *et al.* 2019). Despite these limitations, BRUVs have been shown to provide relative measures of species richness and abundance for a range of species in a diverse array of conditions and habitats (Cappo, Harvey & Shortis 2006).

Platform Description

Stereo-BRUV systems consist of two convergent video cameras inside waterproof housings, attached to a base-bar (Figure 1b), held in a frame (Figure 1a), with some form of baited container in front of the cameras (Figure 1e). Systems are generally tethered by rope to surface buoys (Figure 1c). Ballast can be added to frames for use in deep-water or areas of strong current (Figure1f).

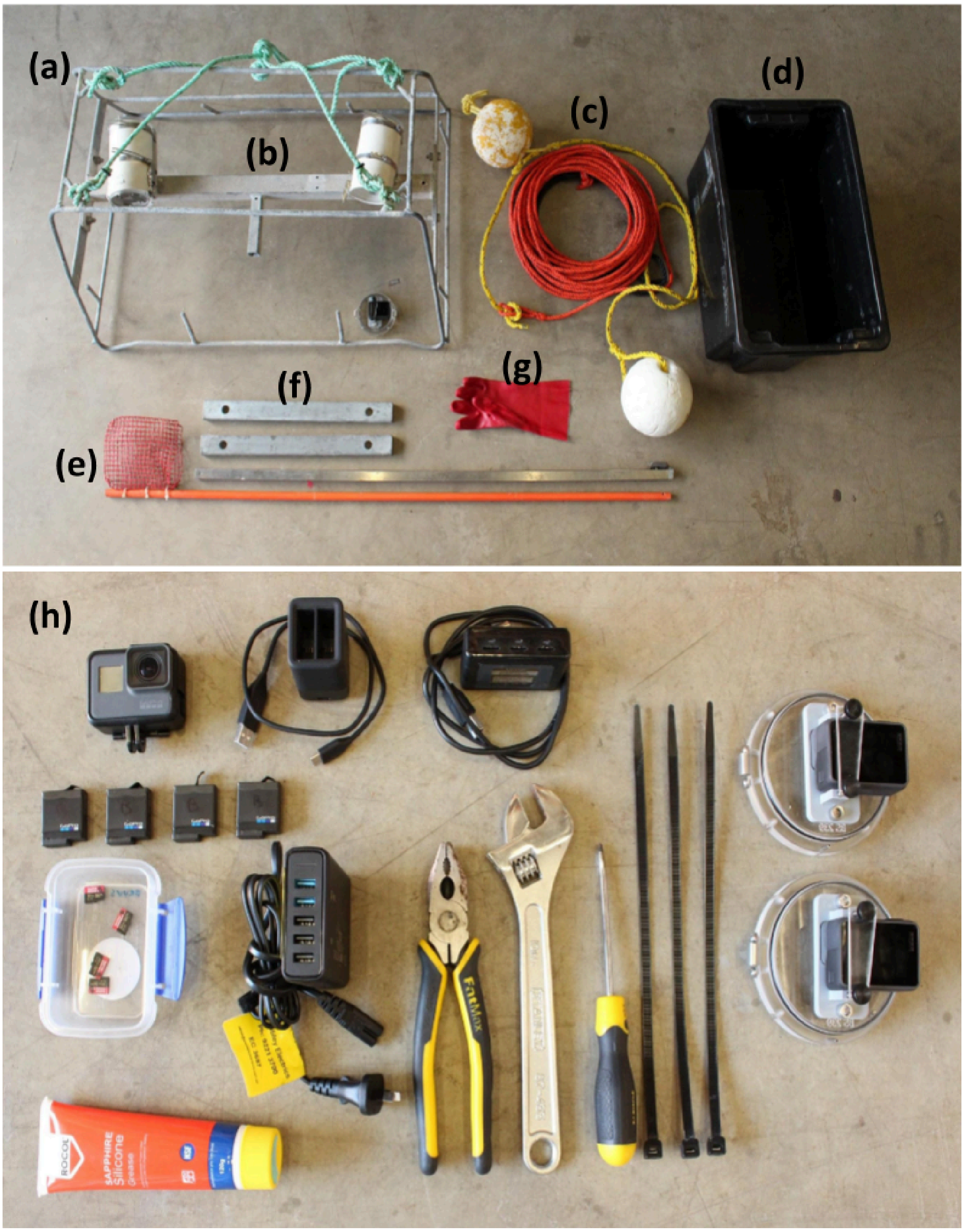

Figure 1: Equipment required for stereo-BRUV surveys, including (a) mild-steel galvanised frame and bridle, (b) stereo base-bar and camera housings, (c) rope with detachable float line and two floats, (d) storage container for equipment and bait, (e) PVC bait arm (reinforced with fibreglass rod) with mesh bait bag and supporting metal diode arm, (f) metal weights for deep-water or strong current, (g) long-armed glove for handling bait, and (h) dry kit including calibrated cameras fixed to face plates, spare cameras, spare batteries, battery charger, micro-sd card reader, micro-sd cards, standard tools, cable ties to secure bait bags, and silicone grease for o-rings.

Cameras and photogrammetry

We recommend cameras with full, high-definition resolution of at least 1920 x 1080 pixels (Harvey et al. 2010) and a capture rate of at least 30 frames per second (note some models of action cameras can overheat at high resolution e.g. 4K). Higher camera resolution will improve identification of fish, and the pixel selection required for measurement. 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 (Shortis, Harvey & Abdo 2009; Boutros, Shortis & Harvey 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 (8 m) from the cameras, Boutros et al. (2015) suggested a separation < 500 mm will result in a decrease in the accuracy of measurements, with measurement precision being a function of 1/(camera separation). Cameras are fixed to a rigid base bar to preserve the stereo-calibration required to calculate accurate length and range measurements (Harvey & Shortis 1995, 1998; Shortis & Harvey 1998; Shortis et al. 2009; Boutros et al. 2015). The system pictured in Figure 1 uses GoPro Hero 5 Black cameras, with camera housings separated by 700 mm with 7° convergence angle on a steel base bar, although 500 mm with a 5° convergence angle is also common.

Stereo-calibrations must be made both prior to and following a field campaign. Given the required tolerances involved with stereo-BRUV construction, we recommend seeking manufacture and calibration advice from recognised providers or adhering to strict specifications. Any changes in camera positioning (e.g. if a camera is dismounted during battery replacement) will disrupt the stereo-calibration, resulting in measurement error. For this reason, most "off-the-shelf" housings remain unsuitable for stereo-BRUVs. Figure 1h provides an example of a camera that is secured to the housing faceplate to ensure stability. Each housing and camera should be uniquely identified, ensuring the latter are only used on the system they are calibrated for. A flashing LED may be added to the end of the diode arm to aid synchronisation of imagery from the left and right cameras when submerged (Figure 1).

Bait

As a general rule, locally sourced, sardine-type oily bait is recommended (Dorman et al. 2012), as the oil disperses to attract fish. Sourcing sardine bait locally from factory discards (e.g. fish heads, tails and guts) will reduce the survey's ecological footprint, cost of sampling and potential for disease translocation. We recommend 0.8 - 1 kg of roughly crushed bait, positioned between 1.2 m and 1.5 m in front of the cameras with the mesh bait bag as close to the benthos as possible. Positioning outside of this range will reduce the ability to identify and measure individuals.

Deployment time

Benthic stereo-BRUVs should be deployed for a standard duration. We recommend deployments of 60 min, to allow species detection (Currey-Randall et al. 2020), and facilitate comparison with historical data. Deployments of 30 minutes have been demonstrated to be sufficient for sampling particular species of finfish on shallow temperate reefs (Bernard & Götz 2012; Harasti et al. 2015).

Scope

BRUV systems with stereo-video cameras (stereo-BRUVs) enable precise measurements of body size (Harvey, Fletcher & Shortis 2001), which surpass estimates made by divers (Harvey et al. 2001). Both length and biomass distribution data are recognised as essential metrics for biodiversity conservation and fisheries management reporting (Langlois, Harvey & Meeuwig 2012b). Importantly, stereo-BRUVs provide comparable body-size distribution data to fisheries-dependent methods such as trawls (Cappo, Speare & De'ath 2004), hook and line (Langlois et al. 2012a), and trap fishing (Langlois et al. 2015). Despite being considered unsuitable for estimating density, stereo-BRUVs provide a cost-effective and statistically powerful method to detect spatio-temporal changes in the relative abundance, length, and biomass distribution of fish assemblages (Harvey et al. 2013; Malcolm et al. 2015; Bornt et al. 2015). However, in over 260 studies using stereo-BRUVS for a range of objectives (Supp. 1), Whitmarsh, Fairweather & Huveneers (2017) found widespread variation in methodology, which may prevent interoperability of the data.

Survey Planning

Although BRUVs are a non-destructive technique, permits may still be required for deployment in certain areas (e.g. marine protected areas, Indigenous Protected Areas). Prior to undertaking any marine survey, researchers are responsible for ensuring appropriate applications for permission are lodged, with subsequent relevant approvals obtained and documented. More information regarding legislation and permitting can be found on the AusSeabed website (www.ausseabed.gov.au/resources/permit).

Additionally, researchers should engage with local communities, including Traditional Owners, to understand their research priorities and share knowledge. See Indigenous Partnerships and Engagement in Chapter 1 for further details.

Sampling Design

Sampling strategies should be designed to ensure valid inferences and interpretations of resulting data (Smith, Anderson & Pawley 2017). We recommend spatially balanced statistical routines, such as R package MBHdesign (Foster et al. 2019), which can incorporate environmental information and legacy sites to create sampling designs with known inclusion probabilities (Foster et al. 2017, 2018). Due to the need to revisit each site to retrieve stereo-BRUVs after deployment, spatially balanced designs may be inefficient for sampling large regions (>10 minutes transit time between samples), and clustered sampling designs may be preferred (Hill et al. 2018).

Individual stereo-BRUV samples should be separated to reduce the likelihood of non-independence due to individuals being concurrently sampled by adjacent stereo-BRUVs. Separation distance will depend on the mobility of the species and the habitat being studied, for typical demersal fish assemblages a minimum of 400 m for one-hour deployments is recommended (Bond et al. 2018b) or 250 m for 30 minute deployments (Cappo, Speare & Wassenberg 2001).

Field Logistics

Vessels fitted with a swinging davit arm, or pot-tipper and winch are ideal for deploying and retrieving stereo-BRUVs in deeper waters (Fig 2), however, light-weight stereo-BRUVs (Fig 4) can be retrieved by hand. Comparable trap fishing retrieval methods are generally the most efficient. Each retrieval design remains dependent on the type of vessel used, stereo-BRUV weight and size, and prevailing sea conditions. Local fishers familiar with a study location can provide valuable advice on sampling logistics. Multiple stereo-BRUVs can be deployed concurrently, with ~10 stereo-BRUV systems providing optimum logistical efficiency for 60 minute deployment times. Crepuscular periods should be avoided due to demonstrated changes in fish behaviour during these times (Myers et al. 2016; Bond et al. 2018a). When sampling in low light conditions, both blue (450-465 nm) and white (550–560 nm) lights can be used. White can provide the best imagery for identification (Birt et al. 2019), but blue has been found to avoid potential behavioural biases and reduce backscatter from plankton at night (Fitzpatrick, McLean & Harvey 2013). Field methodology checklists are provided below.

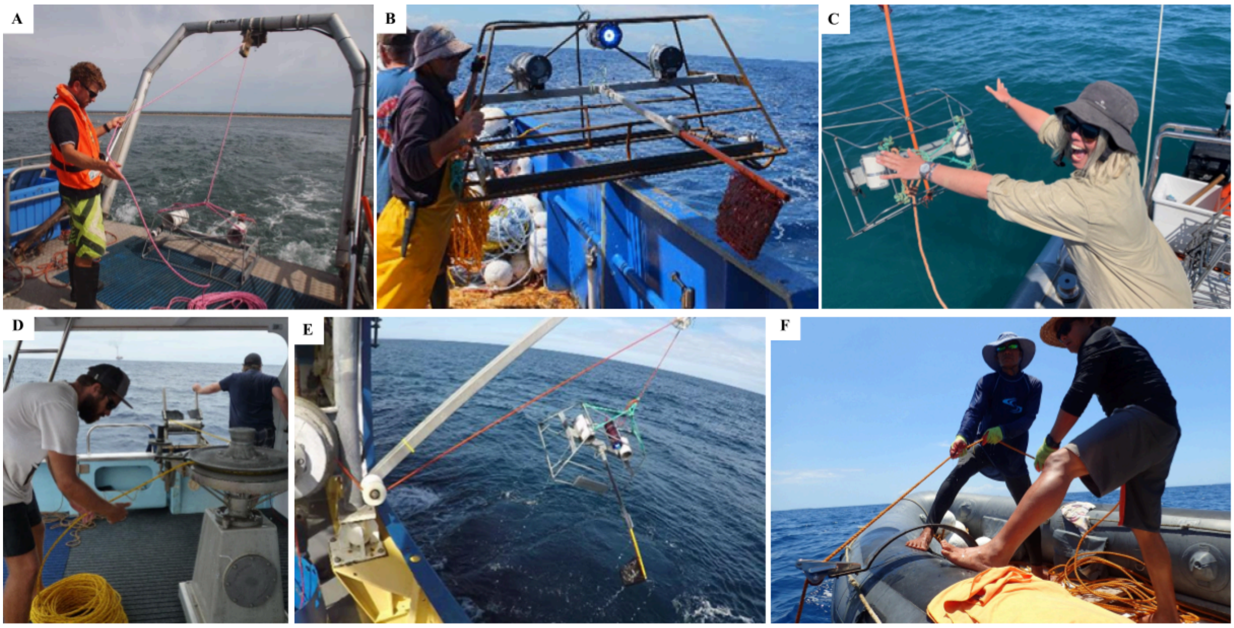

Figure 2: Methods to safely deploy and retrieve BRUVs from different size vessels using different equipment. A: deploying a stereo-BRUV using an A-frame and pulley at the vessel's stern; B: deploying a stereo-BRUV with weights and a light from the side of a vessel; C: deploying light-weight stereo-BRUV from a small rigid inflatable (see Fig 4); D: using a 'pot winch' and 'pot tipper' to quickly retrieve stereo-BRUVs in deep water; E: retrieving a stereo-BRUV using a davit arm from the side of a vessel; F: retrieving stereo-BRUVs by hand using an repurposed anchor hauler in the Philippines.

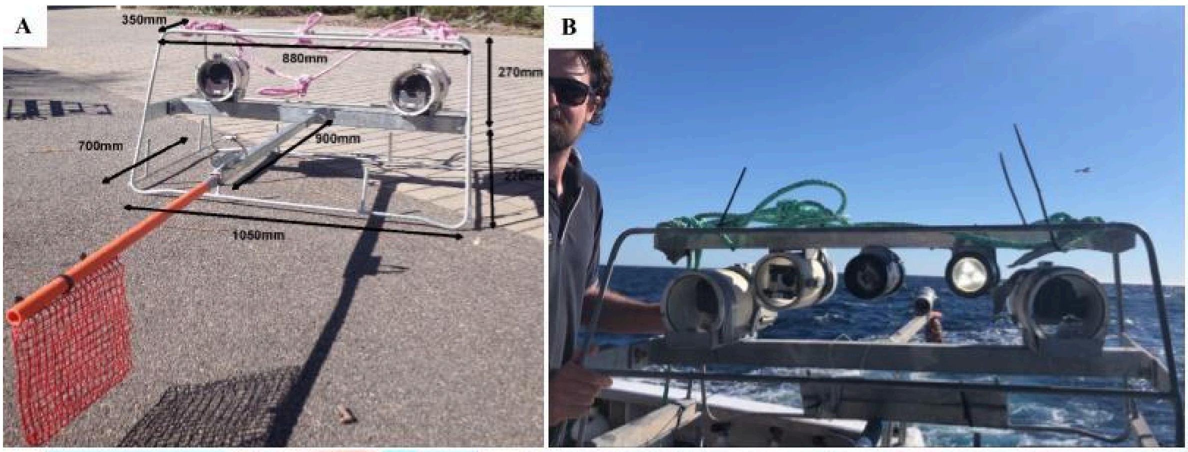

Figure 3: Stereo-BRUV systems, including (A) standard dimensions, and (B) addition of weights for deeper water deployment and added forward and rear facing lights and rear facing stills camera to collect habitat imagery.

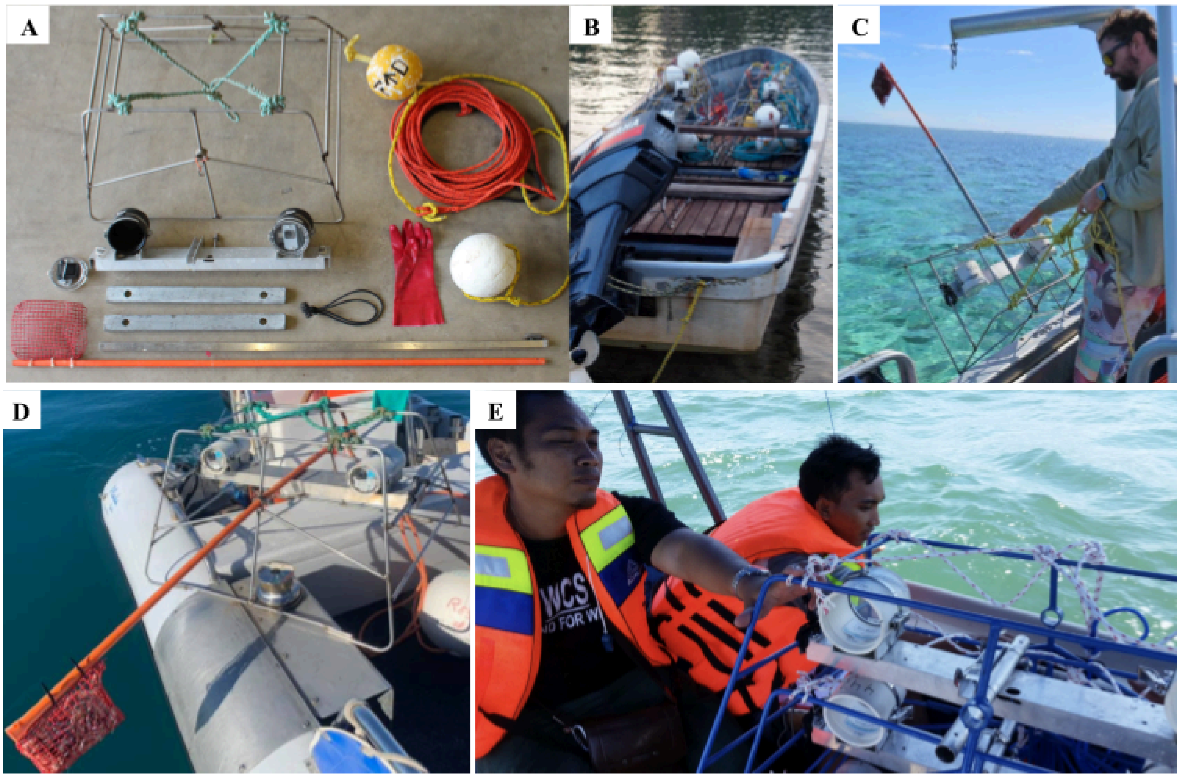

Figure 4: Light weight stereo-BRUV. (A) Frame made of thin gauge stainless steel. Diode arm is passed through the back and front of the frame and not attached to the base bar. This reduces strain to the base bar during retrieval and allows the base bar to be made of light-weight hollow aluminium rectangular section (D). Base bar uses hooks and bungee cords to attach to the frame. The separation of cameras has been reduced to 500mm, with camera convergence of 5 degrees, to decrease the size of systems and making them easier for (B) travel with and use on smaller vessels and can be (C) hand-hauled. For research projects led by partners without expertise in stereo calibrations, (E) frames can be manufactured locally and pre-calibrated light-weight base bars can be sent to the study site. See this video example of [deploying light weight stereo-BRUV](#).

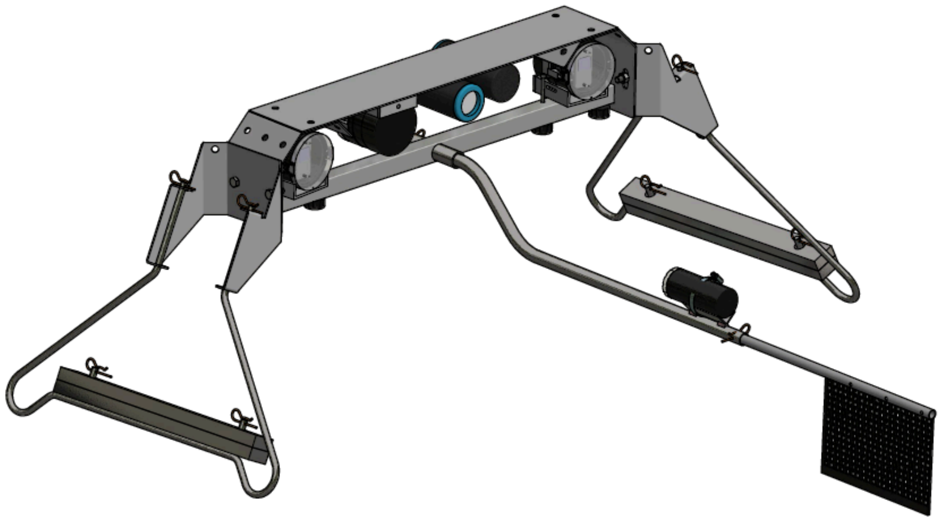

Figure 5: Stereo-BRUV systems developed by the Australian Institute of Marine Science (AIMS). Designed to be easily assembled and packed down with detachable legs that occupy minimal space when shipping. The cameras are inwardly converged at 5 degrees and separated by 650mm. Camera cradles are precision machined and have a locating pin that aligns with the back of the camera housing which allows for housings to be easily removed from the frame (for battery change, downloading etc.) and put back in the exact same position, maintaining camera calibration. A plate across the top of the frame allows for additional backward facing cameras or lights to be attached. The lack of rails along the front and back of the frame footing reduces potential for seabed snags and minimises contact with seabed habitats.

Table X. Packing Checklist

Gear	
☐	Rope
☐	Floats
☐	Frames
☐	Base bars
☐	Bait arms
☐	Bait bags
☐	Weights
☐	Light & backwards camera base bars (if required)
☐	Housings
☐	Bait bin
Tools/consumables	
☐	Drill
☐	Impact driver
☐	Socket adaptors
☐	Sockets
☐	Adjustable spanners
☐	Cable ties
☐	Rope gloves
☐	Bait gloves
☐	Spare o-rings
☐	Hose clamps
☐	Tape
☐	Silicone grease

☐	Microfibre cloths
☐	Towels
☐	Pencils/Pens
☐	Clipboard
☐	Whiteboard and markers (for showing cameras metadata)
☐	Shark clips
☐	Bungee cord or nuts and bolts to fasten base bar to frame
☐	Hot knife
☐	Inox
☐	Wire cutters
☐	Bottle of isopropyl alcohol to soak any salt damaged electronics - not batteries
Electronics	
☐	Cameras & spares
☐	Camera chargers & spares
☐	Camera batteries & spares
☐	Camera battery chargers & spares
☐	Lights & spares
☐	Light batteries & spares
☐	Light chargers & spares
☐	Magnets (if required to turn on lights)
☐	SD cards
☐	Box for used SD cards
☐	SD card readers
☐	Quick computer to download videos (Laptop or NUC)
☐	Mouse
☐	Keyboard

☐	USB hubs
☐	Hard drives, back-ups & spares
☐	Tablet/Laptop for recording metadata
☐	Paper copies of metadata recording data sheets
☐	GPS
☐	GPS charger
☐	Extension cords
☐	Powerboards
☐	Planned sampling locations formatted for the vessels plotter (on a device the plotter can read e.g. USB drive or SD card)
Paperwork	
☐	Animal ethics
☐	Field work risk assessments
☐	Any permits required for undertaking work within Marine Parks etc.
☐	Hard copy sampling map if any locations are pre planned

Field Methodology Checklist

Pre-field work

Check equipment as shown in Figure 1 and Table X.

1. Conduct 3D calibration of stereo-camera pairs. 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.
2. Ensure sampling design can be imported to the research vessel navigation system, or bring a standalone navigation and sounding system for the skipper.
3. Ensure sufficient data storage capacity for downloading all video imagery collected, and for back-up copies.
4. Ensure sufficient spares for stereo-BRUVs (Figure 1).
5. Purchase bait and ensure it can be stored appropriately for the duration of fieldwork.

6. Create a metadata sheet or preferably using a capture device (e.g. Collector for ArcGIS or QGIS, tablet computer with GIS) to record the sample, stereo-camera pair and memory card unique identifier in addition to other essential field data (Table 1 and Table 2). By capturing metadata digitally transcription errors and post-field work time are reduced.

Table 1. Suggested columns for the sample metadata. Transposed (rows for columns) for formatting convenience.

Column name	**Format**	**Column required for GlobalArchive and CheckEM**
opcode	String	✔ *if opcodes were used to define a sample. DON'T include this column if it is not required to define a sample.*
period	String	✔ if periods were used to define a sample. *DON'T include this column if it is not required to define a sample.*
latitude_dd	Decimal degrees. Must be between -90 to 90.	✔
longitude_dd	Decimal degrees. Must be between -180 to 180.	✔
date_time	YYYY-MM-DDThh:mm:ssTZD YYYY = four-digit year MM = two-digit month (01=January, etc.) DD = two-digit day of month (01 through 31) T being a required literal character. hh = two digits of hour (00 through 23) mm = two digits of minute (00 through 59) ss = two digits of second (00 through 59) TZD = time zone designator (Z or +hh:mm or -hh:mm)	✔
site	String. The scale of sites are up to the user to define.	✘
location	String. The scale of locations are up to the user to define.	✘
status	MPA status (must be Fished, No-take, I, II, III, IV, V, VI)	✔
depth_m	Floating point number (metres)	✔
left_cam_number	String.	✘
right_cam_number	String.	✘
left_memcard_number	String.	✘
right_memcard_number	String.	✘
successful_count	Was the sample annotated for count and will that data be included in any analysis? String ("Yes", "No" or blank).	✔
successful_length	Was the sample annotated for length and will that data be included in any analysis?	✔

	String ("Yes, "No" or blank).	
observer_count	String (Full name of analyst). Only required if successful_count = “Yes”	✔
observer_length	String (Full name of analyst). Only required if successful_length = “Yes”	✔
visibility_m	Floating point number (metres)	✘
inclusion_probability	Floating point number. The probability of including that sample in a spatially balanced sampling design.	✘
observer_habitat_forward	String (Full name of analyst)	✘
observer_habitat_backward	String (Full name of analyst)	✘
observer_habitat_downward	String (Full name of analyst)	✘
successful_habitat_forward	String ("Yes" or "No")	✘
successful_habitat_backward	String ("Yes" or "No")	✘
successful_habitat_downward	String ("Yes" or "No")	✘

Table 2. An example of the first five rows of a $_Metadata.csv file.

This is an example for a stereo-BRUVs campaign with additional backwards facing cameras for habitat annotation where the sample is defined using the opcode column only.

opcode	latitude_dd	longitude_dd	date_time	left_cam_number	right_cam_number	left_memcard_number	right_memcard_number	site	location	status	depth_m	successful_count	successful_length	observer_count	observer_length	successful_habitat_forward	successful_habitat_backward	observer_habitat_forward	observer_habitat_backward
35	-34.1315	114.9236	2023-03-15T07:36:19+08:00	L21	R22	01	02	Site 1	South-west Corner	No-take	39.6	Yes	Yes	Hannah Williams	Gidget Mirrabelle	Yes	Yes	Hannah Williams	Hannah Williams
5	-34.1295	114.9292	2023-03-15T07:49:41+08:00	L23	R24	03	04	Site 1	South-west Corner	No-take	42.7	Yes	Yes	Hannah Williams	Gidget Mirrabelle	Yes	Yes	Hannah Williams	Hannah Williams
26	-34.1272	114.9284	2023-03-15T07:54:35+08:00	L25	R26	05	06	Site 1	South-west Corner	No-take	36	Yes	Yes	Gidget Mirrabelle	Hannah Williams	Yes	Yes	Hannah Williams	Hannah Williams
23	-34.1283	114.9189	2023-03-15T08:01:12+08:00	L21	R22	01	02	Site 2	South-west Corner	Fished	41	Yes	Yes	Gidget Mirrabelle	Hannah Williams	Yes	Yes	Hannah Williams	Hannah Williams
29	-34.1229	114.9105	2023-03-15T08:07:51+08:00	L23	R24	03	04	Site 2	South-west Corner	Fished	42.6	Yes	Yes	Levi Peters	Gidget Mirrabelle	Yes	Yes	Hannah Williams	Hannah Williams

Pre-deployment

1. Set up stereo-BRUVs, including ropes and floats.
2. Check camera batteries are charged and memory cards are formatted.
3. Check the batteries in lights and synchronising devices if applicable.
4. Defrost enough bait the night before sampling.
5. Discuss deployment, retrieval procedures and safety with skipper and crew.

Deployment

See this video example of [deploying light weight stereo-BRUV]

1. Fill bait containers with ~1 kg of crushed bait.
2. Turn cameras on and ensure there is sufficient battery life and storage space.
3. Check camera settings are consistent.
4. Film the metadata sheet or capture device with each camera so information can be attributed to the video footage.
5. Check the camera housings are dry and clean before aligning and inserting cameras. Check o-rings are not pinched or dirty.
6. Attach the bait arm and turn on exterior lights (if applicable).
7. Ensure a means of synchronising cameras such as a flashing diode, a stopwatch, slow clapper board or hand clap is recorded within view of both cameras simultaneously.
8. Once on site, and at the command of the master, experienced personnel or deck hands should physically deploy stereo-BRUV, ropes, and floats clear of the vessel. Ropes and floats may need to be streamed in advance if operating in deepwater.
9. It is important the vessel remains directly over the site whilst deploying. In shallow water, it may be necessary to arrest the deployment of the stereo-BRUV above the bottom to ensure it maintains orientation. In water depths >30 m and when using ballast, rope drag through the water is often enough to maintain orientation and the system can be left to freefall from the surface.
10. When the stereo-BRUV lands on the seafloor a waypoint should be taken.
11. Ensure all field metadata and comments are collected (as in Table 1 and Table 2).

Retrieval

1. Once deployment (sampling) time is complete, vessels should manoeuvre alongside the surface floats heading upwind or upcurrent.
2. Crew gaff or grapple the rope between the floats and retrieve slack rope as the vessel manoeuvres over the system.
3. Stereo-BRUVs should only be retrieved once the vessel is directly above the deployment site. Stereo-BRUVs retrieved at an angle are prone to being dragged and caught on the benthos.
4. Once the stereo-BRUV is on deck, dry the housings and remove cameras and their memory cards and change bait. Check battery life is sufficient for another deployment and turn the cameras off to preserve battery life.
5. Ensure all field metadata and comments are collected (as in Table 1 and Table 2).

End of day checks

Review, download, and backup all footage during or at the end of each day. Save separate samples in a folder structure with clear naming conventions (see Jordan S. Goetze et al. 2019). Format memory cards for the next day once the videos have been checked, downloaded, and backed-up. Ensure all field metadata and comments are collected (as in Table 1 and Table 2).

Image Annotations

Software

Software specifically designed to annotate and measure fish from stereo-video will substantially increase the cost-efficiency and consistency of image annotation (Gomes-Pereira et al. 2016). For stereo-video the challenge is not the annotation by the calibration of imagery to provide accurate length and range measurement. Annotation software and packages with measurement capabilities include Vision Measurement System (Harman, Harvey & Kendrick 2003), NIH Image (Dunbrack 12/2006), SEBASTES package in Python (Boldt et al. 2018), StereoMorph package in R (Olsen & Westneat 2015), and EventMeasure from SeaGIS (seagis.com.au). We recommend EventMeasure due to its established workflow, ability to create 3-D stereo-calibrations, and active development, which enables cost-effective and consistent point and stereo annotation of video imagery. Manual image annotation and measurement can be time consuming, but the emerging field of automated image annotation provides promise of increased cost efficiency and collection of novel metrics (Marini et al. 2018).

Annotation metadata

Field metadata (Table 1) should be used to populate a unique sample code for each sample and annotation set. Time on the seabed should be annotated to provide a start time for the stereo-BRUV deployment period. It is important that the link between annotations and imagery are maintained.

Abundance estimates

We recommend all fish be identified to the lowest taxonomic level possible. The standard metric of abundance is MaxN, the maximum number of individuals of a given species present in a single video frame (Priede et al. 1994). MaxN is widely used for BRUVs (Whitmarsh et al. 2017) conservative, and ensures that no individual is counted more than once (Schobernd, Bacheler & Conn 2013) It has frequently been suggested that MaxN underestimates both small and large-bodied individuals, whereas the only study so far to evaluate this has found MaxN provides a representative sample of size-distributions (Coghlan et al. 2017). Synchronise left and right cameras to allow the analyst to determine the range of fish in the field of view and ensure they are within a predefined distance from the cameras. Typically, fish are counted within a maximum distance of 8 m, beyond which length estimates are likely to be inaccurate unless specialist calibrations have been conducted. Annotations of the current MaxN may be updated when individual fish are more clearly visible, and therefore easier to measure, by taking photogrammetric measurements of individual body length at the last MaxN annotated. Please see the Annotation guides on the CheckEM website for a step by step guide.

Body-size measurements

Synchronised and calibrated stereo-video streams are used to accurately measure body size. All individuals of each species should be measured at their MaxN. We recommend measuring fork length rather than total length, as it is more easily definable across a range of species. Biomass estimates typically rely on total length, but fork length to total length conversions can be used to complete these calculations (Froese & Pauly 2019). For species where total length can be unreliable or there is no definable fork, body size is estimated using other measures (e.g. disk length for rays). Photogrammetric length measurements are typically made with some degree of error, which can be minimised by measuring individuals when they are as close to cameras as possible with both the nose and the tail-fork clearly visible, still or slowly moving, at an angle less than 45° perpendicular to the cameras. Defining cut-offs for measurement error across projects will help to maintain accurate and precise body-size estimates, we provide recommended stereo-measurement length rules for EventMeasure in Table 3. If fish cannot be measured within these parameters, a '3D point' may be used for annotation, which records the 3D location of the fish to ensure it is within the sampling area (Harvey et al. 2004). To create a relative abundance metric standardised to a consistent sample area, abundance should be summed from the lengths and 3D points at the MaxN for each species. For biomass estimates, 3D points provide a basis for extrapolating a median length value to fish that could not be measured (Wilson et al. 2018). When large tightly packed schools are encountered, fish that cannot be measured should have 3D points. When lengths or 3D points are not possible for every fish, multiple individuals can be assigned to a single length or 3D point, but care should be taken to represent the range of body sizes within a school. Please see the Annotation guides on the CheckEM website for a step by step guide.

Table 3. Recommended Stereo-measurement Length Rules for EventMeasure.

Name	Data	Units
Use lengths rules	True	Boolean
Apply range rule	True	Boolean
Minimum range	0.0000	mm

Maximum range	8000.0000	mm
Apply RMS rules	True	Boolean
Maximum RMS	20.0000	mm
Apply precision to length ratio rules	True	Boolean
Maximum precision to length ratio	10.0000	%
Apply precision rule	False	Boolean
Maximum precision	10.0000	mm
Apply direction rule	False	Boolean
Maximum direction	45.0000	Degrees
Apply horizontal direction rule	False	Boolean
Maximum horizontal direction	45.0000	Degrees
Apply vertical direction rule	False	Boolean
Maximum vertical direction	45.0000	Degrees
Apply x coordinate range rule	False	Boolean
Minimum x coordinate	-2500.0000	mm
Maximum x coordinate	2500.0000	mm
Apply y coordinate range rule	False	Boolean
Minimum y coordinate	-2500.0000	mm
Maximum y coordinate	2500.0000	mm

Behaviour

A range of behavioural observations, including time of first arrival, time to first feed, and minimum approach distance may also be calculated (Goetze et al. 2017; Coghlan et al. 2017).

Interoperable and reproducible annotations

Video imagery enables annotators to work collaboratively to ensure identifications are consistent. A library of reference images, such as that supported by EventMeasure, will assist with identification and training. It is acknowledged that some genera cannot be consistently identified to species level from imagery, so individuals are recorded at genus-family levels (e.g. flathead: *Platycephalus spp*). For unidentified individuals, a common convention is that fish that are potentially identifiable at a later date are annotated to Genus sp1–10, this permits a batch-rename at a later stage if the species is successfully identified. Individuals that are clearly unidentifiable to species are annotated as *Genus sp*.

Habitat classification

Information on relief, habitat types, and benthic composition (e.g. percent cover of benthos types) should be recorded from each deployment (Bennett et al. 2016; Collins et al. 2017), to facilitate investigation of fish-habitat relationships and to enable the sampling field of view to be standardised or controlled for in subsequent data analysis (McLean et al. 2016). It is important that these data are annotated consistently and it is recommended that they are mapped to the CATAMI classification scheme (Althaus et al. 2015) and a 0-5 estimate of benthic relief (Polunin & Roberts 1993; Wilson, Graham & Polunin 2007). Forward facing imagery can be annotated in a range of software, including TransectMeasure from SeaGIS (seagis.com.au), BenthoBox (https://benthobox.com), CoralNet (https://coralnet.ucsd.edu/), and Squidle+ (https://squidle.org). Please see the CheckEM website for the standard operating procedures and QAQC scripts. An example of habitat composition and relief annotation schema are also provided.

Quality control and data curation

Quality control and data curation are vital to ensure FAIR data workflows (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 "training" videos where species IDs and MaxN are known and can be used to assess competency.

- A different annotator should complete the MaxN and length measurement annotations to provide an independent check of the species identifications.

- Quality assurance should be carried out by a senior video analyst or researcher and involve a random review of 10% of annotated videos and data within a project. If accuracy is below 95 % for all identifications and estimates of MaxN, reannotation should be undertaken.

- Unique identifiers of annotators and dates of when imagery was annotated should be maintained to provide a data checking trail (see Table 1 and Table 2).

R workflows and functions are provided on the CheckEM website available at (https://globalarchivemanual.github.io/CheckEM/) to enable validation with regional species lists and likely minimum and maximum sizes for each species. A web based application is also available at (https://marine-ecology.shinyapps.io/CheckEM/) for those who are not familiar with R.

Data storage, discoverability and release

We encourage open data policies and recommend archiving and sharing stereo-BRUV annotations on global biodiversity data repositories, such as OBIS (Ocean Biogeographic Information System), GBIF (Global Biodiversity Information Facility) and the recently developed GlobalArchive (globalarchive.org). GlobalArchive is a centralised repository that allows open access and private sharing of fish image annotation data from stereo-BRUVs or similar imagery-based sampling techniques. GlobalArchive allows users to store data in a standardised and secure manner and makes meta-data discoverable, thus encouraging collaboration and synthesis of datasets within the community of practice. We recommend all quality controlled annotation data and any associated calibration, taxa and habitat data should be uploaded to GlobalArchive and we encourage that all data should be made publicly available via the public data option. As an example, the Australian standards for data management, discoverability and release are provided below.

Australian Standards for Data Management, Release, and Discoverability of Stereo-BRUV Data

Quality control and data curation

Quality control and data curation are vital, but are potentially time consuming. These time considerations (and associated costs) should be considered during the survey planning stages.

All data corrections should be made within the original annotation files (i.e. within EventMeasure) to ensure data consistency over time. Four complementary approaches for QAQC of data are recommended:

- Analysts should first be adequately trained by completing deployments for which a species composition and density are known to which they can be compared.
- Once the first annotation for a deployment is completed, a different analyst should view each MaxN annotation to double check the species ID and abundance estimates.
- Footage from any previously unrecorded (i.e. range or depth extensions) or unidentifiable species should be sent to the project taxonomist for formal ID. It is important to send footage clip rather than still images.
- R workflows are provided on the CheckEM website to enable comparison with regional species lists and likely minimum and maximum sizes for each species).

It cannot be stressed enough that any corrections should be made to the annotation files before data is exported to GlobalArchive or other repositories (i.e. only QA/QC and validation annotations should be publicly released).

A national stereo-BRUV steering group has been set up to oversee a nationally coordinated BRUV monitoring program (Table 4). Any new stereo-BRUV deployments should be discussed with this steering group to ensure that, where possible, they can be integrated within the national program.

Table 4. Australian National BRUV Working Group, as of May 2020.

Name	State	Organisation
Euan Harvey*	Western Australia	Curtin
Tim Langlois	Western Australia	UWA
Neville Barrett	Tasmania	IMAS
Jacquomo Monk	Tasmania/Victoria	IMAS
Nathan Knott	New South Wales	NSW DPI

Hamish Malcolm	New South Wales	NSW DPI
Daniel Ierodiaconou	Victoria	Deakin
Charlie Huveneers	South Australia	Flinders University
Daniel Brock	South Australia	SA DEWNR
Leanne Currey	Queensland	AIMS

* Chair

Data release

GlobalArchive (www.globalarchive.org) is a centralised repository for stereo- and single-camera image annotation of mobile fauna, in particular from Baited Remote Underwater stereo-Video (stereo-BRUVs) and Diver Operated stereo-Video (stereo-DOVs). A user manual for GlobalArchive is available in an open-access GitHub repository. Metadata should be made publicly available via GlobalArchive as soon as possible after survey completion and data QA/QC and validation. This should include positional data, as well as the purpose of the sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered. Annotations can also be uploaded once complete. Spatial metadata from GlobalArchive data will in the future be harvested by the Australian Ocean Data Network, and the metadata will accordingly be available on their national portal. Until this is done, metadata should be published on both GlobalArchive and AODN to ensure data discoverability.

There is currently no national repository for BRUV imagery so we recommend following agency-specific protocols to ensure public release. A national marine imagery repository (including for BRUV imagery) will be scoped in 2020 and updates provided in this field manual.

If desired by the researcher or requested by the funding agency all quality controlled annotation data and any associated calibration, taxa and habitat data should be uploaded to GlobalArchive (www.globalarchive.org) and made publicly available via the public data option. Other funding agency requirements may apply.

Immediate post-trip reporting should be completed by creating metadata records. This can be done far in advance of annotation (scoring) of raw video which is time-consuming and often does not occur for some time following completion of sampling.

ISO 19115 records should be generated at both the Project[1] and Campaign(s)[1] level. For Project records, the ScopeCode element should be set to "fieldSession". Accompanying Campaign metadata record(s) should use the ScopeCode element "dataset" and be linked to the Project record by adding the Project record identifier (the UUID) into the parentIdentifier element of the Campaign record. An example of a Project record with linked Data records (equivalent to Campaign records) in

AODN is here. This approach improves discoverability, provides context to datasets, and aligns with the schema used by services like Research Data Australia.

The Project metadata record should document the project name, purpose, description, location, dates/times, and relevant contacts. The Campaign metadata record(s) should document the purpose of the BRUV sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered.

[1] See Global Archive definitions here.

Data discoverability

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

1. Immediate post-trip reporting should be completed by creating a metadata record documenting the purpose of the BRUV sampling campaign, the survey design, all sampling locations, equipment specifications, and any challenges or limitations encountered. This can be done far in advance of annotation (scoring) of raw video which is time-consuming and often does not occur for some time following completion of sampling.

2. Publish metadata record to the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been QA/QC. 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.

Lodging metadata with AODN in advance of annotation data being available is an important step in documenting the BRUV campaign and enhancing future discoverability of the data.

1. Annotate video (fish counts and length) using EventMeasure or similar software.

2. Upload annotation data and any associated calibration, taxa and habitat data to GlobalArchive.

3. Upload raw video data to a secure, publicly accessible online repository (contact AODN if you require assistance in locating a suitable repository for large video collections).

4. Add links to GlobalArchive campaign and raw video storage location to previously published metadata record. You may also wish to attach or link a copy of the annotation data directly to the published metadata record.

5. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation schema, and any challenges or limitations encountered. Provide links to this report in all associated metadata.

Conclusion

Globally, stereo-BRUVs usage is spreading rapidly. The standardisation of stereo-BRUVs surveys and annotation will facilitate the synthesis of comparable data over continental and global scales, and provide rich and interoperable data to inform natural resource management. Variation in methodology has constrained the interoperability of this data to date (Whitmarsh et al. 2017), we encourage researchers to standardise and share technical improvements and issues via an established on-line forum.

Achieving consistent field methodology and FAIR annotation, with data archiving and sharing protocols, provide the greatest barrier to the globally consistent uptake and impact of stereo-BRUV. We provide a standardised protocol that will reduce methodological variation among researchers and encourage the use of FAIR workflows to increase the ability to synthesise datasets and answer a range of ecological questions.

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 2a and again in 2024 as Version 3. 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 5 (benthic BRUVs is below:

Version Number	Description	Date
0	Submitted for review (NESP Marine Hub, GA, external reviewers as listed Appendix A.	22 Dec 2017
1	Publicly released on www.nespmarine.edu	28 Feb 2018
2	Minor corrections, updates and clarifications	July 2020
3	Minor updates	March 2024

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