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

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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).

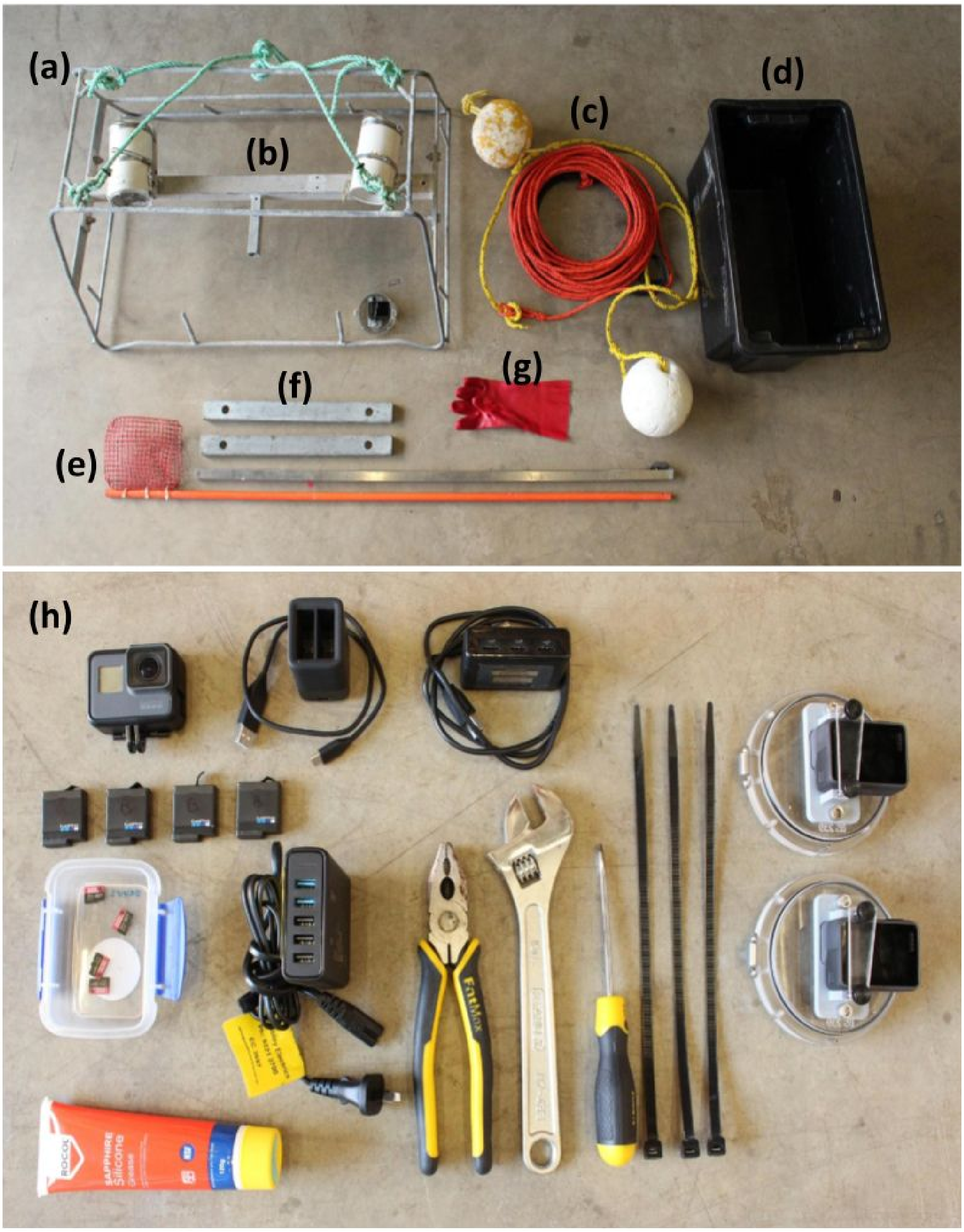

Figure 1: Equipment required for stereo-BRUV surveys, including (a) mild-steel galvanized frame and bridle, (b) stereo base-bar and camera housings, (c) rope with detachable float line and two floats, (d) storage container for equipment and

bait, (e) PVC bait arm (reinforced with fiberglass 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.

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 (Supp. 2) 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 in Supp. 3.

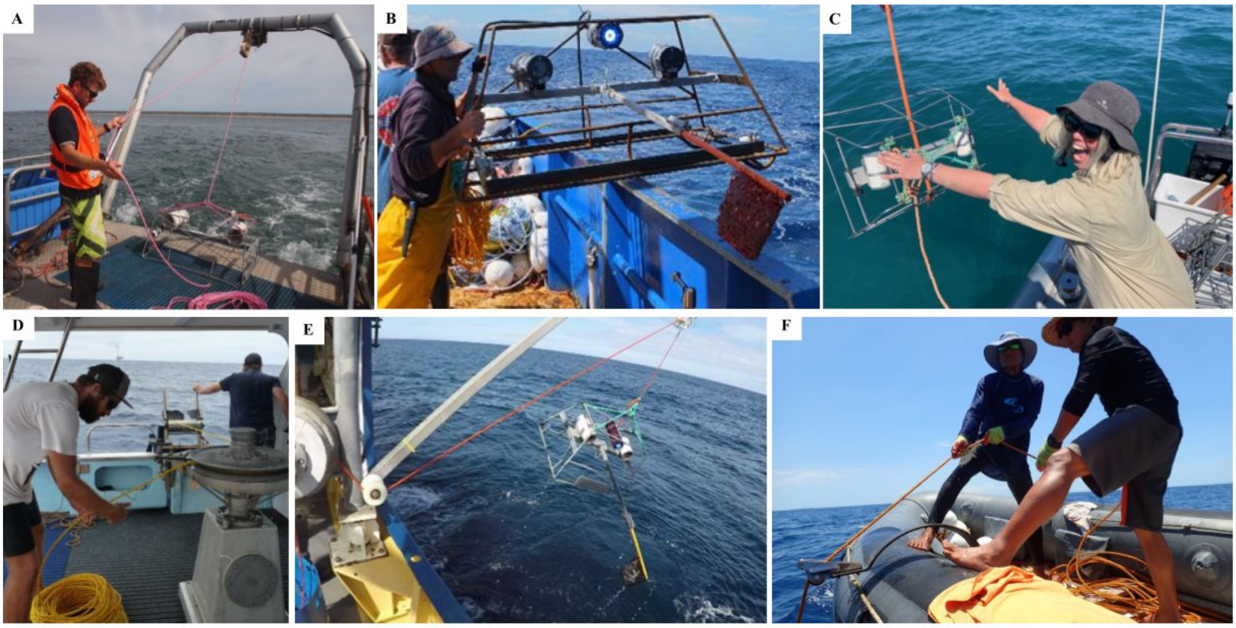

Figure 2: Methods to safely deploy and retrieve BRUVs from different size vessels using different equipment. A: deploying a stereo-BRUV using an A-frame and pulley at the vessel's stern; B: deploying a stereo-BRUV with weights and a light from the side of a vessel; C: deploying light-weight stereo-BRUV from a small rigid inflatable (see Supp. 2); 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.

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 (Supp. 4) 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). Syncronise 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.

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 Supp. 5. 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.

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). An example of habitat composition and relief annotation schema are provided in a GitHub repository (Langlois 2017). 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).

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 Supp. 4).

R workflows and function packages are provided in a GitHub repository (github.com/GlobalArchiveManual/globalarchive-query) to enable validation with regional species lists and likely minimum and maximum sizes for each species.

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 in Supp. 6.

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Supp. 1: BRUV Studies by Topic.

Appendix II: 259 studies found using baited underwater cameras showing the purpose of the study. Papers were included in the analysis if published in peer-reviewed literature, bait was used in one or more replicates and if video footage was used rather than still images. The last search (finding 254 studies) was conducted on the 27/05/2019 using the keywords 'baited' and 'video' or 'BRUVS', on Google Scholar, Scopus, Proquest (Aquatic Sciences and Fisheries Abstracts), Biological Abstracts. Extra studies known to the authors were added. The Other category includes studies focusing on anthropogenic stressors, artificial structures, and diurnal changes. Number below show the total number of studies in that category. Individual studies may be included in more than one category.

Behavioural (63 studies) (Ellis & DeMartini 1995; Willis & Babcock 2000; Willis, Millar & Babcock 2000; Collins *et al.* 2002; Denny, Willis & Babcock 2004; Jamieson *et al.* 2006; Bailey *et al.* 2007; Stoner, Laurel & Hurst 2008; Jamieson *et al.* 2009; Broad *et al.* 2010; Fujii *et al.* 2010; McLean *et al.* 2010; Ryer, Laurel & Stoner 2010; Brooks *et al.* 2011; Dunstan, Ward & Marshall 2011; Gutteridge *et al.* 2011; McLean, Harvey & Meeuwig 2011; Robbins, Peddemors & Kennelly 2011; Zintzen *et al.* 2011; Bond *et al.* 2012; Misa *et al.* 2013; White *et al.* 2013; Barord *et al.* 2014; Dunlop *et al.* 2014; Espinoza *et al.* 2014; Harasti *et al.* 2014; Klages *et al.* 2014; Santana-Garcon *et al.* 2014b; Udyawer *et al.* 2014; Barley *et al.* 2015; Bornt *et al.* 2015; D'Onghia *et al.* 2015b; De Vos *et al.* 2015; Malcolm *et al.* 2015; Ryan *et al.* 2015; Stobart *et al.* 2015; Terres *et al.* 2015; Harasti *et al.* 2016; Kempster *et al.* 2016; Spaet, Malcolm HA 2016; Nanninga & Berumen 2016; Acuña-Marrero *et al.* 2017; Cullen & Stevens 2017; Duffy, Letessier & Irving 2017; Kilfoil *et al.* 2017; Roberson *et al.* 2017; Wellington, Wakefield & White 2017; Alós *et al.* 2018; Benjamins *et al.* 2018; Devine, Wheeland & Fisher 2018; Fetterplace *et al.* 2018; Hammerschlag *et al.* 2018; Harasti *et al.* 2018b; Irigoyen *et al.* 2018; Jabado *et al.* 2018; Mensinger, Putland & Radford 2018; O'Connell *et al.* 2018; O'Driscoll *et al.* 2018; Radford, Putland & Mensinger 2018; Sherman *et al.* 2018; Chapuis *et al.* 2019; Juhel *et al.* 2019; Rolim, Rodrigues & Gadig 2019; Thompson, Bouchet & Meeuwig 2019)
Fishing impacts (80 studies): (Willis & Babcock 2000; Willis, Millar & Babcock 2000; Westera, Lavery & Hyndes 2003; Cappo, Speare & De'ath 2004; Denny & Babcock 2004; Denny, Willis & Babcock 2004; Cappo, De'ath & Speare 2007; Heagney *et al.* 2007; Malcolm *et al.* 2007; Watson *et al.* 2007; Kleczkowski, Babcock & Clapin 2008; Svane & Barnett 2008; Svane, Roberts & Saunders 2008; Watson *et al.* 2009; McLean *et al.* 2010; Goetze *et al.* 2011; McLean, Harvey & Meeuwig 2011; Bernard & Götz 2012; Bloomfield *et al.* 2012; Bond *et al.* 2012; Dorman, Harvey & Newman 2012; Harvey *et al.* 2012b; Langlois, Harvey & Meeuwig 2012; Fitzpatrick, McLean & Harvey 2013; Gardner & Struthers 2013; Goetze & Fullwood 2013; Moore *et al.* 2013; Poulos *et al.* 2013; Rees *et al.* 2013; Sackett *et al.* 2013; White *et al.* 2013; Wraith *et al.* 2013; De Vos *et al.* 2014; Dunlop, Barnes & Bailey 2014; Espinoza *et al.* 2014; Hill *et al.* 2014; Kelaher *et al.* 2014; Lindfield, McIlwain & Harvey 2014; Peters *et al.* 2014; Rizzari, Frisch & Connolly 2014; Santana-Garcon *et al.* 2014c; Stevens *et al.* 2014; Whitmarsh *et al.* 2014; Bornt *et al.* 2015; Bouchet & Meeuwig 2015; Coleman *et al.* 2015; Fitzpatrick *et al.* 2015; Goetze *et al.* 2015; Harasti *et al.* 2015; Howarth *et al.* 2015; Kelaher *et al.* 2015a; Kelaher *et al.* 2015b; Malcolm *et al.* 2015; McLaren *et al.* 2015; Roberson *et al.* 2015; Schultz *et al.* 2015; Stobart *et al.* 2015; Tanner & Williams 2015; Terres *et al.* 2015; Colefax, Haywood & Tibbetts 2016; Gilby, Tibbetts & Stevens 2016; Heyns-Veale *et al.* 2016; Jaiteh *et al.* 2016; Ochwada-Doyle, Johnson & Lowry 2016; Parker *et al.* 2016; Walsh, Barrett & Hill 2016; Barley, Meekan & Meeuwig 2017a; Díaz-Gil *et al.* 2017; Harasti *et al.* 2017; Tickler *et al.* 2017; Goetze *et al.* 2018; Harasti *et al.* 2018b; Hill *et al.* 2018; Juhel *et al.* 2018; Malcolm *et al.* 2018; Mensinger, Putland & Radford 2018; Rees *et al.* 2018; Speed, Cappo & Meekan 2018; Harasti *et al.* 2019; Henderson *et al.* 2019; Juhel *et al.* 2019; Ortodossi *et al.* 2019; Prior *et al.* 2019
Spatial and habitat associations (79 studies): (Cappo, De'ath & Speare 2007; Heagney *et al.* 2007; Malcolm *et al.* 2007; Gomelyuk 2009; Watson & Harvey 2009; Westera *et al.* 2009; Chatfield *et al.* 2010; McLean *et al.* 2010; Moore, Harvey & Van Niel 2010; Ryer, Laurel & Stoner 2010; Cappo *et al.* 2011; Jeffreys *et al.* 2011; Malcolm, Jordan & Smith 2011; McIlwain *et al.* 2011; Merritt *et al.* 2011; Moore, Van Niel & Harvey 2011; Colton & Swearer 2012; Fitzpatrick *et al.* 2012; Harvey *et al.* 2012a; Harvey *et al.* 2012c; Langlois *et al.* 2012b; Schultz *et al.* 2012; Zintzen *et al.* 2012; Harvey *et al.* 2013; Poulos *et al.* 2013; Rees *et al.* 2013; Espinoza *et al.* 2014; Morton & Gladstone 2014; Schultz *et al.* 2014; Bacheler & Shertzer 2015; Pearson & Stevens 2015; Schultz *et al.* 2015; Scott *et al.* 2015; Tanner & Williams 2015;

Andradi-Brown *et al.* 2016; Gilby *et al.* 2016; Hesse, Stanley & Jeffs 2016; Heyns-Veale *et al.* 2016; Lindfield *et al.* 2016; McLean *et al.* 2016; Vargas-Fonseca *et al.* 2016; Vergés *et al.* 2016; Walsh, Barrett & Hill 2016; Yates *et al.* 2016; Asher, Williams & Harvey 2017; Babcock *et al.* 2017; Barley, Meekan & Meeuwig 2017a; Benzeev, Hutchinson & Friess 2017; Borland *et al.* 2017; Ford, Stewart & Roberts 2017; Galaiduk *et al.* 2017a; Galaiduk *et al.* 2017b; Galaiduk *et al.* 2017c; Henderson *et al.* 2017; Lavaleye *et al.* 2017; Linley *et al.* 2017; Logan *et al.* 2017; Oh *et al.* 2017; Schmid *et al.* 2017; Tickler *et al.* 2017; Zintzen *et al.* 2017; Abesamis *et al.* 2018; Alós *et al.* 2018; Esteban *et al.* 2018; Ferrari *et al.* 2018a; Ferrari *et al.* 2018b; Ford & Roberts 2018; Galaiduk, Radford & Harvey 2018; Goetze *et al.* 2018; Hammerschlag *et al.* 2018; Harasti *et al.* 2018a; Irigoyen *et al.* 2018; Kiggins, Knott & Davis 2018; Rees, Knott & Davis 2018; Wellington *et al.* 2018; Bach *et al.* 2019; Clarke *et al.* 2019; Gilby *et al.* 2019; Hale *et al.* 2019; Reis-Filho *et al.* 2019; Schultz *et al.* 2019; Williams *et al.* 2019)
Methods (within BRUVS)(40 studies): (Watson *et al.* 2005; Harvey *et al.* 2007; Stobart *et al.* 2007; Lowry, Folpp & Gregson 2011; Bernard & Götz 2012; Dorman, Harvey & Newman 2012; Gladstone *et al.* 2012; Harvey *et al.* 2012a; Ebner & Morgan 2013; Fitzpatrick, McLean & Harvey 2013; Hardinge *et al.* 2013; Letessier *et al.* 2013; Taylor, Baker & Suthers 2013; Wraith *et al.* 2013; De Vos *et al.* 2014; Hannah & Blume 2014; Santana-Garcon, Newman & Harvey 2014; Unsworth *et al.* 2014; Anderson & Santana-Garcon 2015; Campbell *et al.* 2015; Harasti *et al.* 2015; Letessier *et al.* 2015; Rees *et al.* 2015; Stobart *et al.* 2015; Tanner & Williams 2015; Trobbiani & Venerus 2015; Ghazilou, Shokri & Gladstone 2016b; Ghazilou, Shokri & Gladstone 2016a; Misa *et al.* 2016; Walsh, Barrett & Hill 2016; Watson & Huntington 2016; Cundy *et al.* 2017; Kilfoil *et al.* 2017; Schmid *et al.* 2017; Trave *et al.* 2017; Benjamins *et al.* 2018; Sherman *et al.* 2018; Whitmarsh, Huveneers & Fairweather 2018; Clarke *et al.* 2019; Whitmarsh, Fairweather & Huveneers 2019; Wong *et al.* 2019)
Methods (comparisons to other methods)(45 studies): (Ellis & DeMartini 1995; Willis & Babcock 2000; Willis, Millar & Babcock 2000; Cappo, Speare & De'ath 2004; Watson *et al.* 2005; Stobart *et al.* 2007; Colton & Swearer 2010; Langlois *et al.* 2010; Watson *et al.* 2010; Brooks *et al.* 2011; Lowry *et al.* 2011; Pelletier *et al.* 2011; Colton & Swearer 2012; Harvey *et al.* 2012c; Langlois *et al.* 2012a; Lowry *et al.* 2012; Ebner & Morgan 2013; Gardner & Struthers 2013; Wakefield *et al.* 2013; Rizzari, Frisch & Connolly 2014; Santana-Garcon *et al.* 2014a; Ebner *et al.* 2015; Goetze *et al.* 2015; Langlois *et al.* 2015; McLaren *et al.* 2015; Stobart *et al.* 2015; Andradi-Brown *et al.* 2016; Ochwada-Doyle, Johnson & Lowry 2016; Parker *et al.* 2016; Pejdo *et al.* 2016; Spaet, Nanninga & Berumen 2016; Bacheler *et al.* 2017; Barley, Meekan & Meeuwig 2017b; Bosch *et al.* 2017; Bradley, Papastamatiou & Caselle 2017; Galaiduk *et al.* 2017a; Logan *et al.* 2017; Roberson *et al.* 2017; Boussarie *et al.* 2018; Davis, Larkin & Harasti 2018; Enchelmaier, Babcock & Hammerschlag 2018; Goetze *et al.* 2018; Hale *et al.* 2019; Stat *et al.* 2019; Wong *et al.* 2019)
Other (e.g. diel variation)(41 studies): (Yau *et al.* 2002; Smale *et al.* 2007; Svane & Barnett 2008; Svane, Roberts & Saunders 2008; Bassett & Montgomery 2011; Craig *et al.* 2011; Marouchos *et al.* 2011; McIlwain *et al.* 2011; Aguzzi *et al.* 2012; Birt, Harvey & Langlois 2012; Harvey *et al.* 2012a; Harvey *et al.* 2012b; Fitzpatrick, McLean & Harvey 2013; Folpp *et al.* 2013; Ruppert *et al.* 2013; Anderson & Bell 2014; Lowry *et al.* 2014; Peters *et al.* 2014; Unsworth *et al.* 2014; Anderson & Santana-Garcon 2015; D'Onghia *et al.* 2015a; Kelaher *et al.* 2015a; Kelaher *et al.* 2015b; Scott *et al.* 2015; Ghazilou, Shokri & Gladstone 2016b; Griffin *et al.* 2016; Roberts, Pérez-Domínguez & Elliott 2016; Vargas-Fonseca *et al.* 2016; Benzeev, Hutchinson & Friess 2017; Díaz-Gil *et al.* 2017; Nagelkerken *et al.* 2017; Bond *et al.* 2018; Florisson *et al.* 2018; Irigoyen *et al.* 2018; Mensinger, Putland & Radford 2018; Olds *et al.* 2018; Radford, Putland & Mensinger 2018; Reynolds *et al.* 2018; Chapuis *et al.* 2019; Henderson *et al.* 2019; Whitmarsh, Fairweather & Huveneers 2019)

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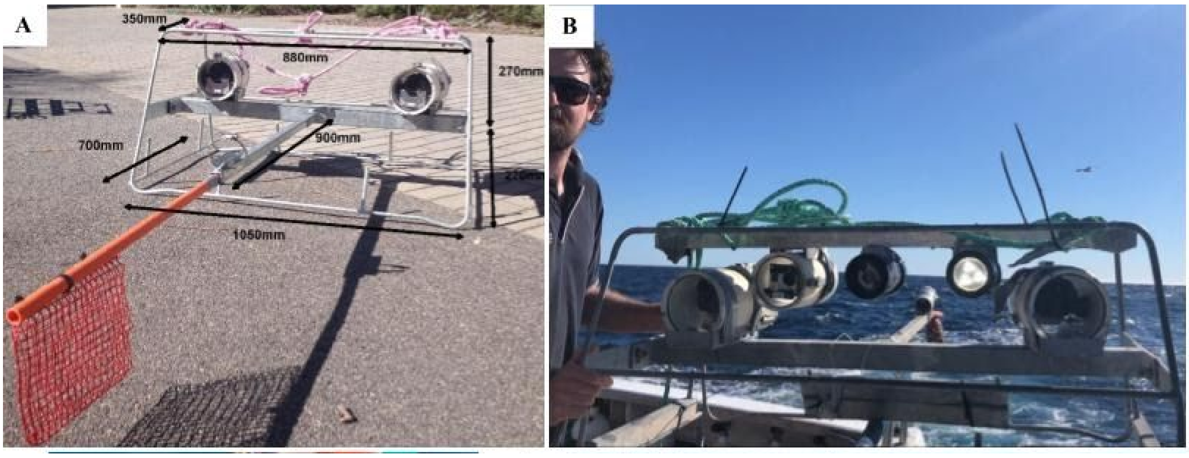
Zintzen, V., Anderson, M.J., Roberts, C.D., Harvey, E.S., Stewart, A.L. & Struthers, C.D. (2012) Diversity and composition of demersal fishes along a depth gradient assessed by baited remote underwater stereo-video. *PLoS ONE,* **7,** e48522.

Zintzen, V., Roberts, C.D., Anderson, M.J., Stewart, A.L., Struthers, C.D. & Harvey, E.S. (2011) Hagfish predatory behaviour and slime defence mechanism. *Sci. Rep.,* **1**.

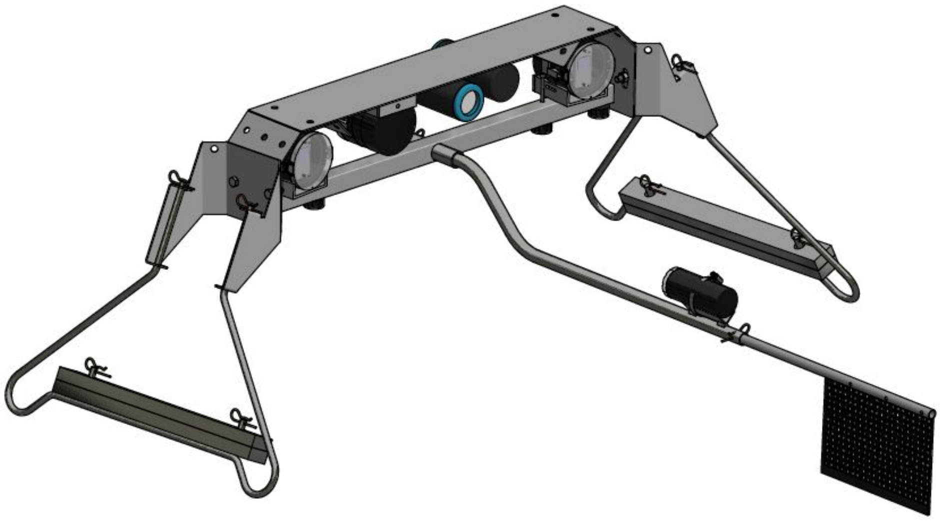
Supp 2: Stereo-BRUV Design Variations



Supp 2 Figure 1: 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.

Supp Figure 2: 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 aluminum 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 study site. See this video example of deploying light weight stereo-BRUV

Supp Figure 3: 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.



Supp 3: Field Methodology Checklist

Pre-field work

Check equipment as shown in Figure 1.

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 (Supp. 4). By capturing metadata digitally transcription errors and post-field work time are reduced.

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 Supp 4).

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 Supp 4).

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 Supp 4).

Sample	Date	Time	Time.out	Depth	Location	Site	Status	Latitude	Longitude	Waypoint	Left.mem.card	Right.mem.card	Left.cam	Right.cam	Field.notes	Raw.hdd.number	Con.hdd.number	Observer	Maxn.complete.yyyymmdd	Maxn.checker	Successful.count	Length.analyst	complete.date.yyy	Successful.length	abitat.image.forwa	Analysis.notes
POC11001	20181022	07:48	09:06	99.7	Rottnest Island	1	Fished	-19.06074981	117.9939425	W101	84	68	377	378	Clear skies, less than 1 m swell, no wind, slack high	RAW1	CON1	Fernanda Rolim	20181106	Matt Hammond	Yes	Michael Brooker	15/11/2018	Yes	Yes	
POC11002	20181022	08:06	09:26	101	Rottnest Island	1	Fished	-19.05631981	117.9932366	W102	121	73	373	374		RAW1	CON1	Brooke Gibbons	20181107	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	
POC11003	20181022	08:16	09:40	99	Rottnest Island	1	Fished	-19.06097751	117.9983176	W103	83	91	375	376		RAW1	CON1	Michael Brooker	20181106	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	
POC11004	20181022	08:29	09:58	99.5	Rottnest Island	1	Fished	-19.06528606	117.9935499	W104	78	88	367	368	Shark on drop at surface	RAW1	CON1	Michael Brooker	20181106	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	
POC11005	20181022	08:40	10:12	100	Rottnest Island	1	Fished	-19.06093706	117.9886542	W105	111	95	371	372	Shark went straight for bait at surface	RAW1	CON1	Fernanda Rolim	20181106	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	
POC12001	20181022	12:06	13:17	114	Rottnest Island	2	No-take	-19.02441154	118.0508807	W106	13	28	371	372		RAW1	CON1	Michael Brooker	20181107	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	
POC12002	20181022	12:14	13:33	115	Rottnest Island	2	No-take	-19.02766095	118.0432022	W107	10	112	367	368		RAW1	CON1	Fernanda Rolim	20181107	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	Big tiger shark
POC12003	20181022	12:23	13:50	106	Rottnest Island	2	No-take	-19.03227934	118.0487416	W108	106	118	375	376		RAW1	CON1	Matt Hammond	20181107	Michael Brooker	Yes	Michael Brooker	16/11/2018	Yes	Yes	
POC12004	20181022	12:34	14:06	104	Rottnest Island	2	No-take	-19.03632717	118.0435769	W109	122	116	373	374		RAW1	CON1	Fernanda Rolim	20181108	Matt Hammond	Yes	Fernanda Rolim	15/11/2018	Yes	Yes	Lots of fish
POC12005	20181022	12:41	14:20	113	Rottnest Island	2	No-take	-19.03208903	118.0386256	W110	72	76	377	378		RAW1	CON1	Matt Hammond			No			No	Yes	Camera system turn over 30 mins in.

Cells highlighted orange are mandatory for uploading data into GlobalArchive. See https://globalarchivemanual.github.io/metadata-file

Sample	Unique identifier for each deployment. (From field recording sheet).
Date	Date of deployment. (From field recording sheet).
Time	Time (local) the BRUV landed on the seafloor. (From field recording sheet).
Time.out	Time (local) the BRUV was retrieved. (From field recording sheet).
Depth	Depth of deployment. (From field recording sheet).
Location	Name of the location where BRUV was deployed.
Site	Name of site within a location. For example, Thompson Bay at Rottnest Island.
Status	Protection status (must be Fished, No-take, I, II, III, IV, V, VI)
Latitude	Latitude of the deployment. Decimal degrees (WGS 1984) is the recommended format with at least 6 decimal places
Longitude	Longitude of the deployment. Decimal degrees (WGS 1984) is the recommended format with at least 6 decimal place
Waypoint	Waypoint number if collected in the field. (From field recording sheet).
Left.mem.card	Memory card number used in the left camera. (From field recording sheet).
Right.mem.card	Memory card number used in the reft camera. (From field recording sheet).
Left.cam	Left camera number. (From field recording sheet).
Right.cam	Right camera number. (From field recording sheet).
Field.notes	Notes transcribed from the field labsheet.
Raw.hdd.number	Name of the hard drive the raw video files have been downloaded onto.
Con.hdd.number	Name of the hard drive that raw videos have been converted onto.
Observer	Full name of person analysing the video for MaxN.
Maxn.complete.yyyymmdd	Date MaxN analysis was completed. Only enter this date once the video has been completed.
Maxn.checker	Full name of person checking the IDs.
Successful.count	Was the MaxN analysis successfull and can it be used? (Yes/No)
Length.analyst	Full name of the person who measured the fish at MaxN.
Length.complete.date.yyyymmdd	Date length analysis was completed. Only enter this date once all lengths have been measured.
Successful.length	Was the length analysis successfull and can it be used? (Yes/No)
Habitat.image.forward	Has a forward facing habitat image been captured from video footage?
Habitat.image.rearward	Has a rearward facing habitat image been captured from video footage?
Analysis.notes	Notes on the analysis.

Supp 5: 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

Supp. 6: 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 in a GitHub repository to enable comparison with regional species lists and likely minimum and maximum sizes for each species (Langlois et al. 2017).

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 (Supp. 7). 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.

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.

Supp. 7: 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

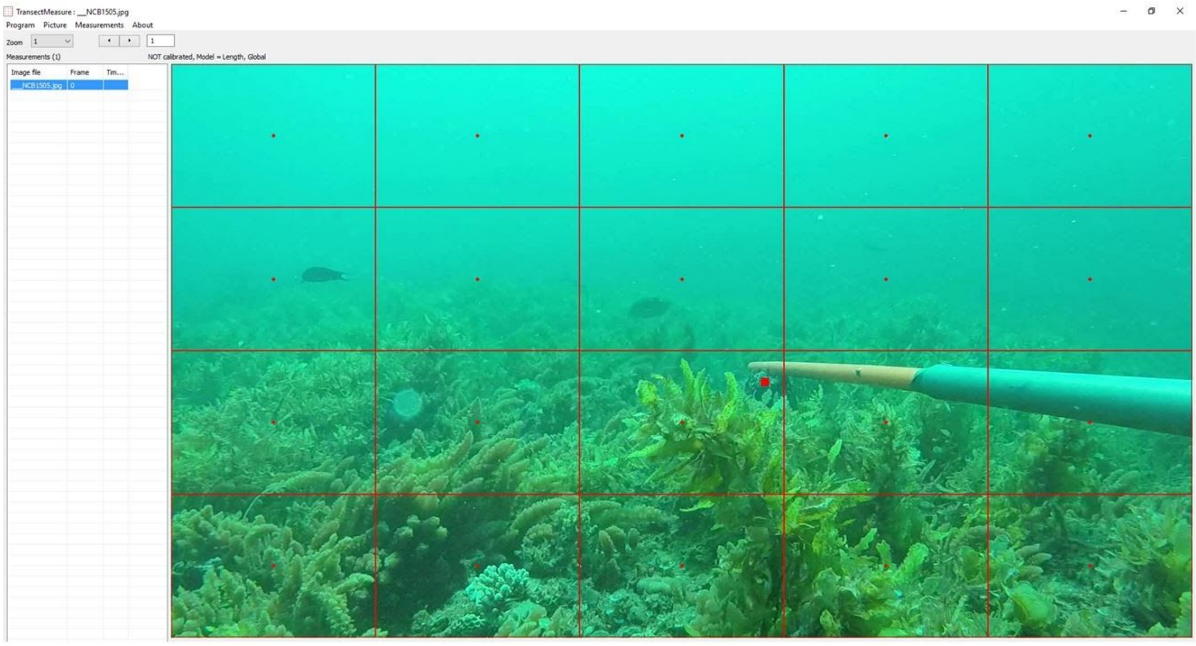
Supp. 8: Habitat Annotation of Stereo-BRUV Imagery

We have developed a simple approach to characterise the composition and complexity of habitats from stereo-BRUV imagery, adapting existing standardised schema for benthic composition (CATAMI classification scheme) and benthic complexity, with the addition of a class to quantify the percent cover of benthos versus open water within the horizontally facing image.

The annotation approach is rapid and produces percent composition and mean and standard deviation estimates of complexity, which enable flexible modelling of habitat occurrence and fish-habitat relationships.

Methods

To simplify the annotation process and still represent multiple scales of habitat in stereo-BRUV imagery, a 5 x 4 grid is overlaid on a high definition image (Supp 8 Figure 1). Each of the 20 'rectangle's are annotated for dominant *Benthic Composition*, *FieldOfView* and *Relief*. See this github repository for examples of annotations.



Supp 8 Figure 1: Screen capture from TransectMeasure (seagis.com.au)

Benthic composition

The annotation schema is made up of nested *Benthic Composition* classes taken from the CATAMI schema ("*BROAD*" > "*MORPHOLOGY*" > "*TYPE*", e.g. "Macroalgae" > "Erect coarse branching" > "Brown").

For detailed information on the particular taxonomic levels within the "*BROAD*" > "*MORPHOLOGY*" > "*TYPE*" classifications provided in this annotation schema, please consult the CATAMI visual guide.

To the "*BROAD*" class, we have added additional levels of "Open water" (to calculate the percentage of benthos within each image) and "Unknown" (to account for the frequent issues of limited visibility typical for forward facing imagery).

NOTE: Any 'rectangle' that has some form of habitat visible should be classified for *Benthic Composition* (even if open water makes up the majority of the grid).

Field of view

The *FieldOfView* class assesses how the BRUV is positioned when it lands on the substrate. Definition of *FieldOfView* options:

- Facing Down: No open water visible and the system is facing the benthos. This deployment would most likely be removed from analysis due to atypical field of view.
- Facing Up: No substrate visible and the system is facing towards the surface. This deployment would most likely be removed from analysis due to atypical field of view.

- Limited: BRUV landed on its side, upside down or the field of view is badly obstructed by benthos or substrate within ~1m of the camera that would limit the number of individuals observed. This deployment may be removed from analysis due to atypical field of view.
- Open: BRUV landed upright and level on the substrate and there is an adequate amount of habitat available for classification.

Relief

The Relief class uses a 0-5 quantification of relief and includes an "Unknown" level to account for 'rectangle's with limited visibility. *Relief* class is representative of complexity or the height and angle of substrate.

When the *Benthic Composition* is "Open Water", *Relief* should be classified as "Unknown". Distinct categories have been adapted from Wilson et al. (2006):

0. Flat substrate, sandy, rubble with few features. ~0 substrate slope.
1. Some relief features amongst mostly flat substrate/sand/rubble. <45 degree substrate slope.
2. Mostly relief features amongst some flat substrate or rubble. ~45 substrate slope.
3. Good relief structure with some overhangs. >45 substrate slope.
4. High structural complexity, fissures and caves. Vertical wall. ~90 substrate slope.
5. Exceptional structural complexity, numerous large holes and caves. Vertical wall. ~90 substrate slope.

NOTE: Any 'rectangle' that has some form of habitat visible should be classified for Relief (even if open water makes up the majority of the grid).

Recommended approaches

For standard (rapid) assessment of *Benthic Composition*, *FieldOfView* and *Relief* we recommend using ONLY the: "*BROAD*" classification within the *Benthic Composition* and *FieldOfView* and *Relief*. An experienced analyst would be able to annotate this schema to over 200 images a day.

OR

For detailed assessment of *Benthic Composition* (where coral bleaching or macroalgae composition was of interest), *FieldOfView* and *Relief* we recommend using all the classes in *Benthic Composition* ("*BROAD*" > "*MORPHOLOGY*" > "*TYPE*" and *FieldOfView* and *Relief*. An experienced analyst would be able to annotate this schema to over 120 images a day.

Forward facing imagery can be annotated in a range of software, including TransectMeasure from SeaGIS (seagis.com.au), ReefCloud (reefcloud.ai), CoralNet (coralnet.ucsd.edu), and

Squidle+ (squidle.org). See this github repository for an example of how to annotate imagery using TransectMeasure (github.com/GlobalArchiveManual/forward-facing-habitat-annotation).

Annotation summary and quality control

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:

- Check that *FieldOfView*, *Relief* and *Benthic Composition* have been entered for every grid that contains habitat (see R script below).
- Check that the image names match the metadata sample names (see R script below).
- Check all successful deployments have habitat data (see R script below).

See this github repository for an example R script to check and summarise annotations (github.com/GlobalArchiveManual/forward-facing-habitat-annotation).