6. Marine Sampling Field Manual for Pelagic Stereo BRUVs (Baited Remote Underwater Videos)

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Photograph: Pelagic stereo-BRUV deployed in French Polynesia. Credits: Manu San Felix, National Geographic Society (2014).

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Platform Description

Underwater videography has become a staple of observational studies in both tropical and temperate environments, where the technique offers a robust, non-invasive, and affordable means of monitoring marine species _in situ_ (Mallet & Pelletier 2014). Initially pioneered for applications in the abyssal zone (Priede et al. 1994), benthic BRUVs (see [https://benthic-bruvs-field-manual.github.io/](Chapter 5)) have been extensively used in shallow, inshore environments (e.g. McLean et al. 2011, Langlois et al. 2012, Zintzen et al. 2012, Oh et al. 2017, Juhel et al. 2018).

However, a growing international commitment to expand the world's marine protected area coverage in recent years (Pala 2013) has motivated efforts to adapt BRUVs to pelagic, open ocean habitats away from coasts (Bouchet & Meeuwig 2015) (Table 6.1). Multiple research groups and organisations have concurrently developed several pelagic BRUV designs (Figure 6.1), most of which share similar elements, namely (i) one (monocular) or a pair (stereo) of cameras in appropriate underwater housings, (ii) a base frame on which the camera(s) is/are mounted, (iii) an attractant, usually olfactory in the form of bait, (iv) a synchronisation device (e.g. diode, clapperboard) and (iv) a suspension system (consisting of weights, ropes, and floats).

Pelagic BRUVs retain all the qualities that have made camera-based sampling a flexible and effective approach to non-destructive marine monitoring, as:

- They are suitable in areas where fishing or other extractive activities are prohibited.
- They are straightforward and relatively quick to operate.
- They have little direct impact on wildlife and ecosystems, other than through bait use.
- They present a safety advantage over diver-based methods and overcome some of their limitations and biases (e.g. depth and time constraints, avoidance behaviour in fishes).
- They produce accurate body length measurements when configured in stereo.
- They yield a permanent archive of high-definition footage.
- They generate quantitative data, while also documenting behaviour.
- They are viable in a range of depths, underwater terrains and ocean conditions.

Importantly, the use of one or more attractants substantially increases the likelihood that nearby animals enter the field of view of the cameras for digital capture (Rees *et al.* 2015). Extensive collective experience in the deployment of pelagic BRUVs across a range of habitats, climates, and conditions indicates that the instruments are capable of detecting a large suite of taxonomic groups (including many of interest to fisheries), from teleost fishes to elasmobranchs, marine mammals, molluscs, crustaceans, and reptiles (Figure 6.2).

In spite of their performance, pelagic BRUVs suffer from a number of limitations, many of which apply equally to demersal videography, including:

- Footage quality is affected by high turbidity and low visibility.
- Correct identification of some species can be difficult for small, shy or morphologically similar species and individuals.

- Bait dispersal is a complex, dynamic process likely to fluctuate spatio-temporally. Quantifying the size of the effective area being sampled and its variation remains an unresolved challenge.
- Bait elicits diverse animal behavioural responses whose strength, timing and duration often relate to many unknown parameters (e.g. olfactory performance, prey search strategy, human presence etc.).
- Numerous species may also respond to non-olfactory cues in ways that have seldom been quantified (but see Rees *et al.* 2015).
- The nature and magnitude of observation biases arising from the presence of conspecifics (and other species) are largely unknown (Dunlop *et al.* 2014, Coghlan *et al.* 2017).
- Counts of wildlife on BRUVs reflect measures of *relative* rather than *absolute* abundance and can be biased, e.g. by screen saturation (Lowry *et al.* 2011, Schobernd *et al.* 2013).
- Detection/attraction probabilities likely vary by time of day, habitat, bathome, and species.
- Zero-inflation is common and may undermine the statistical power needed to identify patterns and changes in pelagic communities (Santana-Garcon *et al.* 2014b).
- Benthic "species contamination" can occur wherever the ratio between suspension and seabed depths approaches one (e.g. pelagic BRUVs suspended at 10 m in a total of 15 m of water) (Letessier *et al.* 2013b), but see Clarke *et al.* (2019) for a comparison of benthic and pelagic assemblages and their overlap at different depths.

Further discussion of some of these caveats can be found in Bouchet & Meeuwig (2015), Santana-Garcon *et al.* (2014b) and Espinoza *et al.* (2014), among many others.

Table 6.1 Summary of studies using pelagic video systems in marine monitoring. Orientation refers to the angle of the camera(s), and can be either horizontal (forward-facing) or vertical (downward-facing). Deployments can be conducted with instruments either moored to the seafloor ('anchored'), linked to a vessel via a coaxial cable or similar ('tethered'), or free drifting (as individual units or in a longline configuration). NSW: New South Wales. WA: Western Australia. Due to differences in local supply, it is difficult to identify a standardised type of baitfish. As a rule, small pelagic species with soft, oily flesh are usually recommended. For instance, sardines/pilchards (*Sardinops sagax*) have been a staple of BRUV research in Australia and New Zealand, as evidence suggests they result in consistent numbers of fish among samples (less variation), exhibit higher mean abundance among sites and are more persistent (i.e. longer time to depletion) (Dorman *et al.* 2012). MW = mid-water. P = pelagic. S = Stereo.

Authors	Location	Stereo	Orientation	Method	Attractant type	Bait type	Instrument name
Heagney *et al.* (2007)	Lord Howe Island (NSW, Australia)	□	Horizontal	Anchored	Olfactory (dead bait)	Mixture of minced pilchards, bread and tuna oil (8:1:1), combined in matrix of vegetable meal (falafel) [100g]	MW BRUVs
Letessier *et al.* (2013)	Shark Bay (WA, Australia)	✔	Horizontal	Anchored	Olfactory (dead bait)	Pilchards, squid, and combination (slurry, 1:1)	MW camera rigs
Santana *et al.* (2014a)	Ningaloo Reef (WA, Australia)	✔	Horizontal	Anchored	Olfactory (dead bait)	Mullets (cut in halves) [1kg]	PS BRUVs
Santana *et al.* (2014b)	Coral Bay (WA, Australia)	✔	Horizontal	Anchored	Olfactory (dead bait)	Pilchards [800g]	PS BRUVs

Santana *et al.* (2014c)	Western Australia (several locations)	✔	Horizontal	Anchored	Olfactory (dead bait)	Crushed pilchards [800g]	PS BRUVs
Santana *et al.* (2014d)	Houtman Abrolhos Is. (WA, Australia)	✔	Horizontal	Anchored	Olfactory (dead bait)	Crushed pilchards [800g]	PS BRUVs
Schifiliti *et al.* (2014)	Ningaloo Reef (WA, Australia)	✔	Vertical	Tethered	Olfactory (dead bait)	N/A	RemORA
Bouchet & Meeuwig (2015)	Perth Canyon (WA, Australia)	✔	Horizontal	Drifting	Olfactory (dead bait)	Crushed pilchard heads, guts and tails [2-3kg]	PS BRUVs
Fukuba *et al.* (2015)	Mariana Trench (Western North Pacific)	□	Vertical	Drifting	Olfactory (live bait)	Live matured eels	Una-Cam
Rees *et al.* (2015)	Jervis Bay (NSW, Australia)	□	Horizontal	Anchored	Olfactory, visual, acoustic	<u>Visual:</u> Spearfishing 'swivel flasher'. <u>Acoustic:</u> Playback recording of bait fish. <u>Olfactory:</u> Mixture of white bread and pilchards.	MW RUVs
Scott *et al.* (2015)	Sydney Harbour (Australia)	□	Horizontal	Anchored	Olfactory (dead bait)	Mixture of minced pilchards, bread, and tuna oil, in an (8:1:1) [100g]	P BRUVs
Kempster *et al.* (2016)	Mossel Bay (South Africa)	✔	Vertical	Tethered	Olfactory (dead bait)	Sardines and fish heads [0.5kg]	RemORA
Vargas *et al.* (2016)	Australian east coast (several locations)	□	Horizontal	Drifting	Olfactory (dead bait)	Chopped pilchards and squid [500g]	Surf-BRUVs
Acuña-Marrero *et al.* (2018)	Galapagos Islands, Ecuador	✔	Horizontal	Anchored	Olfactory (dead bait)	Yellow-fin tuna [800g]	P BRUVs
Caselle *et al.* (2018)	Tristan da Cunha (British Overseas Territory)	✔	Horizontal	Drifting	Olfactory (dead bait)	Crushed fish [800g]	MW BRUVs
Ryan *et al.* (2018)	Mossel Bay (South Africa)	✔	Vertical	Tethered	Olfactory (dead bait)	Crushed sardines [0.5kg]	N/A
Clarke *et al.* (2019)	Gulf St Vincent (SA, Australia)	□	Horizontal	Anchored	Olfactory, visual	<u>Visual:</u> flasher. <u>Olfactory:</u> minced sardines [1kg]	P BRUVs

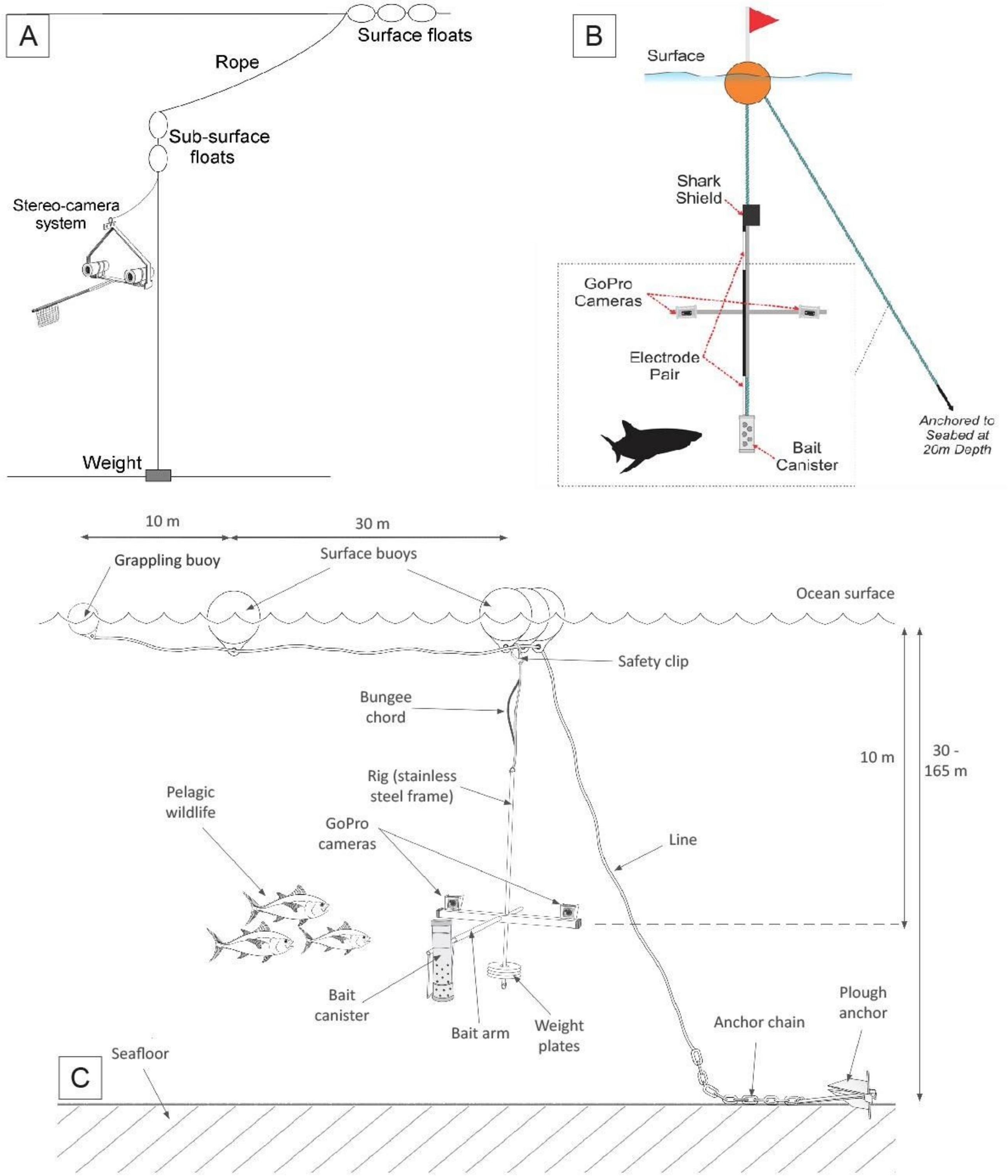

Figure 6.1 Examples of possible deployment configurations for pelagic BRUV sampling. Schematics extracted from or as used in (A) Santana-Garcon *et al.* (2014b), (B) Schifiliti *et al.* (2014) and Kempster *et al.* (2016), (C) Letessier *et al.* (2013b). Cameras can be either forward-facing (A, C) or downward-facing (B). The anchored design shown in C was adapted in Bouchet & Meeuwig (2015) to let BRUV units drift freely.

Figure 6.2 Example species observed on pelagic BRUVs. (A) Bryde's whale *Balaenoptera brydei*, (B) Manta ray *Manta birostris*, (C) Dusky dolphin *Lagenorhynchus obscurus*, (D) Whale shark *Rhincodon typus*, (E) Dolphin fish *Coryphaena hippurus*, (F) Atlantic horse mackerel *Trachurus trachurus*, (G) Blue shark *Prionace glauca*, (H) Shortfin mako shark *Isurus oxyrinchus*, (I) Sea snake *Hydrophiidae sp.*, (J) Green turtle *Chelonia mydas*, (K) Krill *Euphausia sp.*, (L) Loggerhead turtle *Caretta caretta*, (M) Atlantic spotted dolphin *Stenella frontalis*, (N) Longfin yellowtail *Seriola rivoliana*, (O) Sub-Antarctic fur seal *Arctocephalus tropicalis*, (P) Yellowfin tuna *Thunnus albacares*, (Q) Pilot fish *Naucrates ductor,* (R) Blue marlin *Makaira nigricans*, and (S) Unicorn leatherjacket *Aluterus monoceros*.

Scope

This manual relates to gear designed to acquire digital video imagery of macro-organisms living in the ocean's water column, from small zooplankton (Letessier *et al.* 2013a) to marine mega-vertebrates (Letessier *et al.* 2014). A sister chapter on benthic BRUVs is included in the field package and addresses sampling protocols for demersal fish and shark assemblages (Chapter 5). The document aims to span everything from pre-survey planning to equipment preparation, field procedures, and on-board data acquisition to guarantee the efficient and correct use of pelagic BRUVs as monitoring tools in Australian Marine Parks (AMPs) and other Commonwealth waters. Such information is critical for supporting the development of consistent, concise, transparent and standardised guidelines in the collection and processing of pelagic BRUV data that can allow statistically robust comparisons between studies, sites, projects, and institutions.

Here, we consider both mono- and stereo-BRUVs[7]. While the latter can be calibrated to allow measurements of individuals' body lengths and animal positions in three-dimensional space (Letessier *et al.* 2015), the former seems to remain a more prevalent approach in the literature due to lower costs and personnel/labour requirements (Whitmarsh *et al.* 2017). It is worth noting that other imagery-based methods such as mid-water towed video transects (Riegl *et al.* 2001), in-trawl cameras (Underwood *et al.* 2014), drop cameras (Friedlander *et al.* 2014), infrared thermography (Zitterbart *et al.* 2013), unmanned aerial vehicles (Kiszka *et al.* 2016), or diver operated videos (Goetze *et al.* 2015) are also available for monitoring pelagic environments and wildlife. These would each warrant a field manual in their own right (Mallet & Pelletier 2014), and are thus not included here (for further information, see Bouchet *et al.* 2017).

Pelagic BRUVs in Marine Monitoring

The need for pelagic monitoring programmes is becoming increasingly urgent as the diversity and abundance of pelagic species decline and the pressure to meet global conservation targets rises (Letessier *et al.* 2017). While pelagic baited video techniques remain in their infancy, they show promise as efficient and affordable tools for monitoring wildlife communities and characterising biodiversity patterns at a range of spatial and temporal scales. For instance, Letessier *et al.* (2013b) and Heagney *et al.* (2007) were able to detect regional differences in the structure of pelagic fish assemblages, whilst Santana-Garcon *et al.* (2014b) reported changes in species diversity with water depth. Pelagic BRUVs may therefore be useful for providing rapid assessments of the effects of spatial closures, particularly as they are equally as efficient as benthic BRUVS in reducing overall costs and sampling footprint (Clarke *et al.* 2019). Although neither Heagney *et al.* (2007) nor Santana-Garcon *et al.* (2014c) found significant differences in species composition and relative abundance between fished and protected areas within their respective study sites, their data represent valuable baselines for future surveys. Knowledge of pelagic species distributions and habitat preferences are also critical to successful management, and pelagic BRUVs can yield geo-referenced data with sufficient replication to support the development of predictive statistical models (Bouchet & Meeuwig 2015). Lastly, pelagic BRUVs allow cost-effective observations of behaviour in free-ranging animals that might otherwise be difficult to obtain outside laboratory settings (Santana-Garcon *et al.* 2014a, Kempster *et al.* 2016, Ryan *et al.* 2018). Many aspects of the behaviour and basic biological requirements of pelagic fishes remain largely unknown, and pelagic BRUVs can thus be a powerful way of filling these knowledge gaps, for example by documenting biologically important areas like spawning (Fukuba *et al.* 2015) and nursery grounds (A. Forrest, unpublished data).

In brief, BRUV sampling (and by extension pelagic BRUV sampling) generates quantitative, monitoring-relevant data on:

- The extent and magnitude of anthropogenic impacts (e.g. fishing, climate change, oil and gas exploration, novel ecosystems such as man-made structures).
- Temporal and spatial variability in the relative diversity, abundance, and size structure of fish assemblages (when used in stereo).
- Behaviour observed *in situ*.
- Species-habitat relationships.

For a detailed overview of observational methods used in the spatial monitoring of fishes, with notes on baited videography, see Murphy & Jenkins (2010) and Mallet & Pelletier (2014). Struthers *et al.* (2015) offer additional insights into the value and limitations of action camera technology for field studies and education/outreach.

Equipment

It is crucial that equipment be appropriately set up to ensure maximum consistency among surveys and to facilitate gear replacement where/when necessary. Key components for a pelagic BRUV are listed in Table 6.2.

Equipment configurations can vary among terrains, bathomes and as a function of study objectives (Figure 6.1). For instance, Santana-Garcon *et al.* (2014b)'s design is remarkably stable compared to Letessier *et al.* (2013b) but is constrained by the need to moor, which Bouchet & Meeuwig (2015)'s design bypasses. Likewise, bait arm length is usually variable, and may be reduced under turbid conditions to optimise species identification capacity.

Table 6.2 Example packing list. The list reflects the equipment needed to deploy pelagic BRUVs in an adaptation of Bouchet and Meeuwig (2015)'s protocol, whereby 3-5 camera units are tethered to each other on a longline (ca. 250 m) and drift with prevailing currents.

Item description	Quantity
BRUV units	
Rig frames	As required
Rig uprights + lynch pins (stainless steel ~ 5cm) + shackles	1 / rig + spares
Bait arms (stainless steel, 1.8m)	1 / rig + spares
Dumbbells (rubberised 2.5kg)	2 / rig + spares
Bait canisters (PVC tubes ~ 50cm)	1 / rig + spares
Rope (8mm or thicker – silver rope preferable for hauling)	1 / longline
Rubber rope bin	10m / rig / flag buoy + 200m / longline + spare
Double action clips (stainless steel ~10cm)	2 / rig + spares
Shark clips for bait arms (~10cm) + longlines (~7cm)	2 / rig + 1 / longline + spares
Buoys (orange, soft plastic, approx. 300mm x 400mm)	3 / rig
Sub-surface buoys	1-2 / rig
Flag buoys	1 / longline
Bait (pilchards/mulies/bonito whole fish frozen)	~1kg / drop + spare
GPS loggers and VHF transmitter	4
CAMERA EQUIPMENT	

Cameras (e.g. GoPro Hero 3+ Silver)	2 / rig / drop + spares
Camera battery extension packs (e.g. GoPro Battery BacPac)	1 / camera + spares
Spare internal camera batteries	10
Memory cards (e.g. micro SD 64GB)	1 / camera + spares
Camera housings	2 / rig +spares
DATA RECORDING	
Laptops (HP Probook 450 G2 + power cable)	2
Hard drives (2TB Seagate portable hard drives)	~1 / 100 hours of footage + spares
Magnadoodle / slate / white board and marker / pen and paper (metadata recording)	1
Power adapters + power boards	~4
USB hubs	8
USB2 cables	50
SD card adapters	3
Clipboard	1
Waterproof paper (for datasheets) + pencils	1 ream + 1 box
Handheld GPS	1
GENERAL	
Toolbox	1
Socket set	1
Power drill and charger (battery operated)	1
Hot knife (for cutting and sealing rope)	1
Gloves (full fingered sailing gloves for hauling)	1 pair / person
Safety boots	1 pair / person
Air compressor hose and nozzle	1
Tupperware tubs (to store cameras in the field)	2 boxes
Dry bag (to store cameras in wet conditions)	1
Nuts and bolts (Phillips head stainless steel bolts with nylon locking nuts 3/16" x 25mm)	2 / rig + spares
Screwdriver set (assorted flathead and Phillips head)	1
Hex (Allen) key set	1
Wrench set (150mm, 200mm and 250mm adjustable)	1
Spanner set (14mm and 10mm for BRUVS)	1
Wire cutters	1
Cable ties (assorted, for repairs etc.)	500
Packing tape (e.g. duct tape)	10 rolls
Plastic packing film	1 large roll
Laminated packing labels (premade for shipping out and back)	3 / item

Pre-Survey Preparations

Methodology

A statistically robust sampling design must be chosen, allowing for adequate spatial/temporal coverage and replication whilst meeting the overall survey objectives, given available equipment and vessel time. Santana-Garcon *et al.* (2014b) recommend a minimum of 8 replicates per experimental treatment in warm-temperate and tropical coastal environments, although this may be dependent on the geographic distribution and abundance of species. The final design should be communicated to all personnel before the survey to maximise clarity and efficiency during field operations. As a rule, pelagic BRUVs should be deployed a minimum of 200-500 m apart to reduce the likelihood of bait plume overlap and inter-camera animal movements (Santana-Garcon *et al.* 2014b, Bouchet & Meeuwig 2015), but further field testing is required to determine if this separation is sufficient to consistently guarantee independence between replicates when sampling large, mobile vertebrate species. See Chapter 2 for additional details.

The timing and duration ("soak time") of BRUV deployments should be determined. Deployments conducted 30-60 min after sunrise and before sunset should abate the effects of differential crepuscular behaviour in fishes (Axenrot *et al.* 2004, Potts 2009). If BRUVs are only one part of a larger research programme, it is important to think carefully about the timing of BRUV operations, as bait use may bias subsequent observations at that same site (e.g. if diver surveys were to follow). Optimal soaking time is likely to vary across habitats and represent a practical compromise between increasing sample size and making the best use of available vessel time in light of the target level of replication. Previous studies have reported soaking times of 45 min (Rees *et al.* 2015), 120-135 min (Letessier *et al.* 2013b, Santana-Garcon *et al.* 2014c), 165 min (Bouchet & Meeuwig 2015), or 180 min (Santana-Garcon *et al.* 2014b). Santana-Garcon *et al.* (2014b) suggested a soak time of 120 min. In cool-temperate waters, Bouchet & Meeuwig (2015)'s species accumulation curves failed to plateau after 3 hours. Although some attempts have been made to develop a range of plausible bait plume dispersal models (e.g. Olsen & Laevastu 1983; Sainte-Marie & Hargrave 1987), further on bait diffusion in the mid-water is needed to confirm the minimum distance that should be allowed between deployments, estimate the effective sampling area in a range of conditions, and better understand the dynamics bait flushing across different levels of fish activity. Lastly, careful thought must be given to the choice of suspension depth, as different assemblages may vary along depth gradients away from the surface (Santana-Garcon *et al.* 2014b).

Consideration must be given to the location of BRUVs during deployment. Instruments should not be deployed where there is a risk of entanglement (e.g. near fishing gear) or where they are likely to constitute or become a navigational hazard (e.g. inside shipping lanes, where trawlers are operating). At a minimum, deployment and retrieval locations should be recorded, with vessel location monitored at regular time intervals as a back-up. GPS loggers can be mounted on flag poles or buoys when deploying free-drifting BRUVs and are advised for capturing the exact spatial trajectories of the units (Bouchet & Meeuwig 2015). VHF radio beacons are also recommended to avoid gear loss in adverse weather conditions. Geofencing technology could be used (as it has been with fish aggregation devices) should the user need to be alerted when BRUVs exit a predefined area.

Appropriate approvals must be obtained. All research activities within Australian Marine Parks are to be undertaken under permit, and most institutions will also require Animal Ethics approval, even if the proposed methods are non-invasive. All institutional health and safety requirements must also be satisfied (e.g. travel risk assessment, volunteer insurance proposal). See Appendix B for a list of potential permits required at the Commonwealth level).

Appropriate camera settings must be selected (e.g. frame rate, video resolution, field of view mode, action cams vs camcorders, see Table 6.3) in light of their performance relative to the study goals and market availability. Correct date/time settings are particularly crucial for file management during subsequent analyses. When using GoPro cameras, note that standard and dive housings are rated to 40 m and 60 m respectively. Special backdoors must be also fitted if battery packs are considered. All equipment must be carefully checked prior to deployment, including that cameras have been serviced, cleaned, and calibrated (if using stereo-BRUVs). Spares (batteries, memory cards, cameras, Table 6.2) are essential as a contingency plan against equipment failure/damage/loss or adaptive changes in the sampling plan (e.g. additional deployments).

Table 6.3 Example camera settings for a pelagic BRUVs. Values reflect the use of GoPro Hero3 cameras. Options may differ in other camera models.

Settings	Value
Camera	
Resolution	1080
Frame Rate	25 fps
Field of View	Medium
Capture	
Upside Down	Up
Spot Meter	Off
Looping Video	Off
Set up	
Default Mode at Power Up	Video (default)
One Button	Off
NTSC/PAL	PAL
Onscreen Display	ON
Camera Status Lights	2
Sound Indicator	Off
Manual Power Off	Manual

Bait must be ordered ahead of time in sufficient quantities. Sourcing bait locally from factory discards (e.g. fish heads, tails and guts) is an attractive option for reducing costs and the ecological footprint of sampling. For some applications, bait balls comprising minced fish, oil, and/or meal, may also be appropriate, though care should be taken to standardise bait mixtures across deployments. Between 800g-3kg of bait is generally adequate for deployments of up 3 hours (Letessier *et al.* 2013b, Santana-Garcon *et al.* 2014b), though having extra supplies (e.g. 20%) may be useful if extra/longer deployments can/must be undertaken. Ultimately, the choice of bait quantity should be informed by consideration of the desired soaking time, expected flushing rate, and likely level of fish activity. Sufficient freezer space must be made available on-board accordingly. Debate is still ongoing over the most efficient way to prepare bait, although crushed/slurried mixtures seem more likely to disperse well into the water column. Presentation is also important, with wire mesh baskets (Santana-Garcon *et al.* 2014b) and perforated PVC tubes (Bouchet & Meeuwig 2015) being two popular options, despite the lack of comparative studies of their relative efficiencies. Critically, recent research demonstrates that bait alone may be a biased/poor attractant for pelagic fishes, and that consideration should be given to combinations of multiple attractants associated with sight, sound, and scent to help generate more effective abundance estimates for some species (Rees *et al.* 2015).

Rig set up should reflect the chosen BRUV design, and may need to be adapted in response to vessel constraints (e.g. available deck space). It is critical to check that the correct amount of weight, length of ropes, number of buoys etc. are available before the survey begins (Figure 6.1). Spare units and parts are essential in all circumstances.

Sampling gear specifications should always be fully documented to achieve maximum transparency and comparability. Over a third of studies fail to report on basic methodological choices (Whitmarsh *et al.* 2017), including rigging plans, camera orientation, spacing, convergence angle, field of view, inter-BRUV distances, soak time, bait choice and quantity, bait preparation technique, bait dispenser type, suspension depth, deployment configuration (Figure 6.1), number of replicates, among others.

Data storage needs must be anticipated. 2TB portable hard drives will typically provide enough storage space for 100 hours of high-resolution video footage, though this may vary by camera model/make. Equally important is making sure that enough power boards, adapters, USB hubs, data cables, etc. are purchased, and can be configured safely for use at sea, so that data offload and backup following each deployment can occur. Planning for double copies of each hard drive and for offline storage on institutional servers is highly recommended to avoid data loss in the event of hardware failure.

Pre-survey checklist

	Task	Description/comments
☐	Sampling design chosen and coordinates of sampling sites calculated and checked for safety hazards	
☐	Pelagic BRUV design and configuration determined	
☐	Deployment protocol determined, including methods for locating/tracking gear	
☐	Appropriate permits obtained and printed copies made (on waterproof paper if necessary)	
☐	Bait (and/or other attractants) ordered in adequate quantities	
☐	Camera settings determined, and cameras calibrated as appropriate	
☐	Data storage needs identified and hardware purchased accordingly	
☐	Metadata sheet prepared	
☐	Gear shipment arranged	

Field Procedures

A visual summary of the key steps to follow when deploying pelagic BRUVs is shown in Figure 6.3.

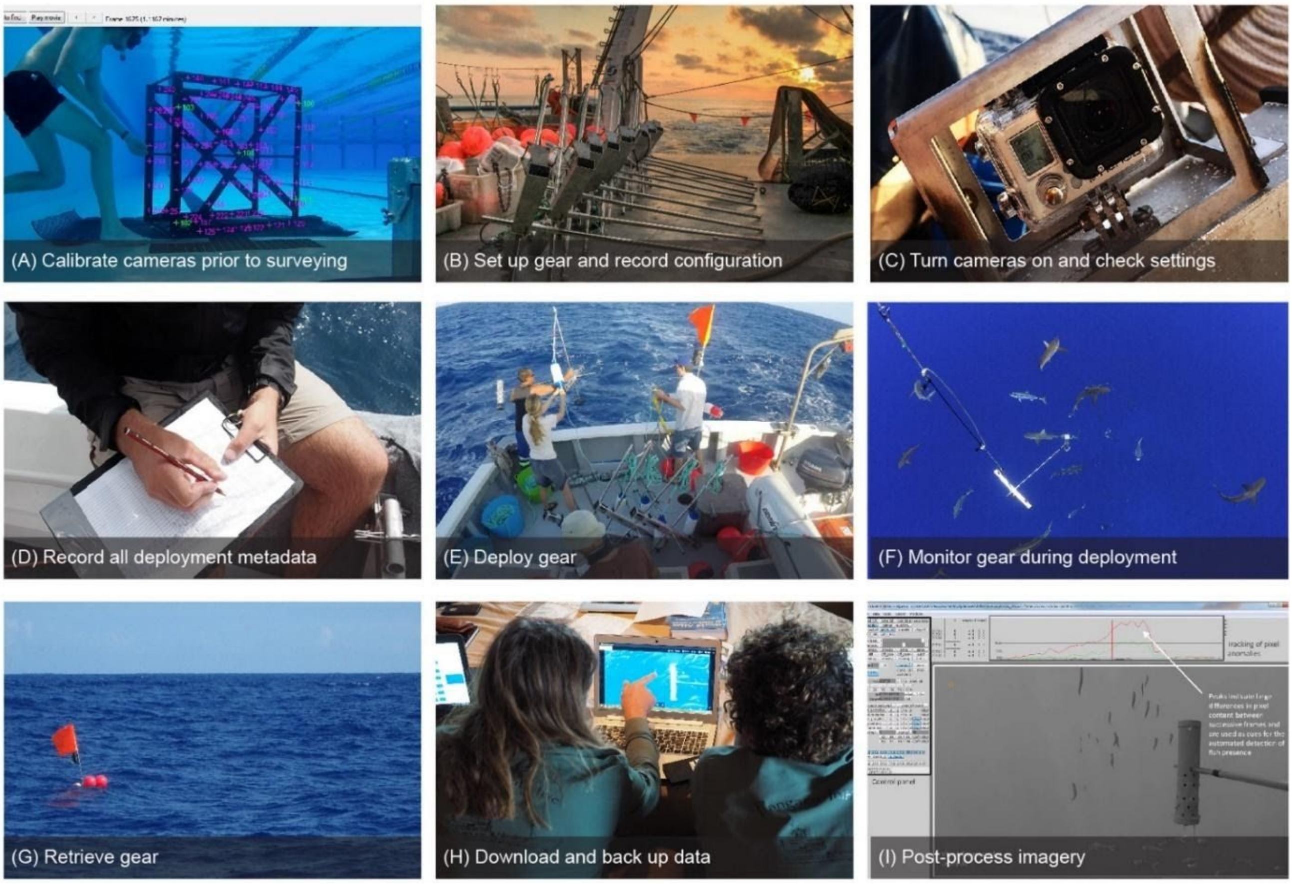

Figure 6.3 Images from key steps involved in the use of pelagic BRUVs for marine monitoring. (A) Using a calibration cube in an enclosed pool environment. (B) Once set up, the gear can be easily stacked and stowed on deck. (C) Example of a GoPro camera turned on before deployment. (D) Relevant metadata can be recorded on waterproof paper. (E) Pelagic BRUVs are versatile and can be deployed manually from a variety of platforms ranging in size from small rigid inflatables to large research vessels. (F) Maintaining visual contact with the gear is key to avoiding equipment loss. Should the deployment vessel need to leave the site (e.g. to support additional activities), a VHF transmitter can be used to re-locate the gear. (G) Flags and brightly coloured buoys help locate the equipment for recovery. (H) Videos are typically downloaded and backed up at the end of each sampling day. (I) Processing and analysis of the imagery occur in a computer lab post-survey.

Calibrations

Stereo-BRUVs require calibration to ensure accurate length measurements. Calibration frequency will ultimately depend on the hardware used and recommendations from the manufacturer. Calibrations are best carried out prior to surveying and commonly take place in enclosed pool environments. Additional post-survey calibrations are also advantageous, particularly following long sampling campaigns where the risk of camera displacement during operation or transport is higher. The calibration process takes into account the base separation, camera angle and lens distortion, all of which are unique to each BRUV (Harvey & Shortis 1998), meaning that individual units must hence be calibrated separately, and cameras should not be swapped between units. In addition, if a camera is damaged or knocked out of position during field work, calibrations will need to be repeated post-survey. While some studies show that purpose-built three-dimensional calibration cubes yield maximum accuracy (Boutros *et al.* 2015), recent evidence suggests that planar checkerboards may be equally accurate, at a fraction of the cost (Delacy *et al.* 2017). Where possible, carrying out 'mock deployments' of a single unit may be useful to ensure the BRUV units sit correctly and consistently in the water column.

SeaGIS have long been the primary provider of third-party calibration hardware and software, yet alternative open-source packages have now also begun to emerge, including the MATLAB Calibration Toolbox or the StereoMorph R package (Olsen & Westneat 2015, Díaz-Gil *et al.* 2017).

Arrival on site

1. Unpack equipment and check for any damage that may have occurred during transport.
2. Check that all camera settings are correct (Table 6.3), batteries are full and memory cards formatted.
3. If not already done, number each individual camera and memory card using a permanent marker, and make a note of which card is used in which camera on the data sheet. It may be useful to also number batteries and battery extension packs, to facilitate the troubleshooting of any hardware malfunctions.
4. Lubricate the cameras' O-rings and check them for cuts or nicks. Replace damaged O-rings as appropriate.
5. Set up pelagic BRUV unit(s) (see Table 6.4 for an example). Attach bait containers to bait arms and securely stack/stow equipment on deck.
6. Discuss deployment and safety plans with captain/crew/team and deliver a copy of sampling site coordinates to the skipper.

Table 6.4 Example instructions for setting up a pelagic BRUV. Note that BRUV components are often made of stainless steel to prevent rusting in the marine environment. All replacement parts (e.g. spare bolts, nuts etc.) must therefore also be marine grade stainless (316).

Order	Action
Rigs	
Step 1	Attach camera housings to the mounts on the crossbar using a stainless steel nylon locking nut and bolt (Phillips head 3/16" approx. 25mm). Ensure they are tightly in place and will not move if bumped. **Do not remove** after attachment to ensure calibration accuracy.
Step 2	Place the upright through the hole in the centre of the rig and secure with locking nut.
Step 3	Weight rigs by placing 2 x 2.5kg dumbbell weights (rubber coated preferable) on the base of the vertical pole in the centre and secure with a stainless steel lynch pin.
Step 4	Place the loop of the 10m rig line into the shackle on the top of the rig upright, and ensure the shackle is done up tight (use mousing wire to ensure the shackle does not come loose with the movement of the rig in situ).
Step 5	Fix the bait arm in place with a shark clip.
Bait canisters	
Step 6	Take a ~50 cm length of PVC pipe, glue a cap on one end and a screw cap on the other. Once dry, use a power drill to drill small ~1-2 cm holes in the end without the screw cap and one large hole all the way through in the centre to allow the bait arm to fit through. Drill small holes in the cap at the holey end and cable tie a dive weight to the inside of the canister.
Lines	
Step 7	Equip each rig with 10 m of rope. Note: The length of rope can be adapted depending on the suspension depth relevant to the project.
Step 8	At one end of the loop, make a small (~15cm) eye by splicing the rope back on itself. This end will be attached to the rig upright.
Step 9	At the other end, pass the line through the eyelet of a double action clip and splice it back on to itself to create a loop with the clip on the end. This will be attached to the longlines and buoys.

Step 10	Close to the top of this line (~2 m down), tie on a short length of shock cord (~1 m), to create a D-shape with the shock cord making the short side. At the top of this tie using a small length of line to attach a small buoy.
Step 11	Cut four 200 m lines for each set of 5 rigs (or 9 for sets of 10) to act as the long lines between rigs.
Step 12	Splice small loops at the ends of each of these lines (~15 cm).
Step 13	Store on a winch clipped together with shark clips to make one line. If a winch is not available coil the lines into separate nelly or rubber rope bins, keeping the ends free and easily accessible for deployment.
Buoys	
Step 14	Inflate buoys using a compressor and needle.
Step 15	Take a length of line (1.5-2 m works well) and thread through the eyelets of three buoys and splice it back on to itself, leaving about 1 m free.
Step 16	Pass the free end through the eyelet of a double action clip and splice it back on itself to create a small loop with the clip on the end. You should be left with a loop with the three buoys and a 1m length with a clip at the end. **Note:** Smaller sub-surface buoys can also be added to the suspension line and will generally help stabilise the rig, thereby facilitating species identification and length measurements.
Step 17	To deflate the buoys at the end of the expedition, simply unscrew the bung (some are flat head and some are Phillips head).
Step 18	Inflation and deflation of buoys should be considered for storage and mobilisation (i.e. whether an air compressor is on board the work vessel and what attachment is required).
Cameras	
Step 19	Two [insert model name, e.g. GoPro Hero 3] are required per rig plus spares. The night before field work is conducted, ensure that the camera settings are correct (Table 6.3) and that the cameras and battery packs are charged (power-boards, USB hubs and USB2 cords are the easiest way to do this) NOTE: adapters may be required if working overseas.
Step 20	Once the cameras and battery packs are charged, store them in a Tupperware container lined with a layer of foam padding above and below (or a specifically fitted Pelican case) to keep them from moving around in transit.
Step 21	Store in a cool dry place until needed.
Step 22	Camera housings should be attached to rigs permanently. Consider the depth ranges being sampled and choose housing types accordingly. Standard GoPro housings are rated to 40 m while dive housings are rated to 60 m. This may vary amongst manufacturers and brands. External battery packs must be used to ensure that the cameras run for the required time.
Flag/GPS/VHF buoy	
Step 23	Assemble using socket and spanner sets.
Step 24	Make sure tension wires are tight.
Step 25	Splice a 10 m length of line to the buoy, pass the opposite end through the eyelet of a double action clip and splice back on itself to fix in place.

Deployment

7. Take bait out of the freezer before sampling and place it in a rubber bin (empty or filled with seawater) to allow it to thaw. This can be done anywhere between 1 and 12 hours beforehand. Note that in tropical countries, bait loses texture and quality if thawed too early. It is also generally easier and cleaner to crush half-frozen bait than bait that has thawed fully.
8. When on route to the drop location, rigs can be laid out in order with the first rig to be deployed closest to the stern (along with corresponding lines if a winch is not being used).
9. Prepare bait (e.g. mince, slice or crush) and fill bait bags/canisters with desired weight.
10. Seal bait canister (e.g. tighten screw caps) and store upright in a plastic container until use.
11. Check that metadata sheets are ready (see Table 6.5). These sheets should be printed on waterproof paper before leaving for the expedition. Fill in drop numbers, camera numbers and memory card numbers when preparing cameras for the day's work. Follow this in the field and fill in the other information as available.
12. Attach lights and sensors, if available.
13. If using a VHF transmitter, remove the magnet and note the device's frequency, checking it is working correctly and a signal can be heard/detected. Place it in a small pelican case attached to the flag buoy, along with one GPS logger (turned on by holding down the middle button) and close tightly.
14. Insert cameras into housings and check that the housings are dry and sand-/hair-free, without any other objects obstructing the O-rings to ensure a good seal.
15. Turn the cameras on (e.g. for GoPros, by pressing the front button until the red light starts flashing and the timer starts), check there is battery and storage space available.
16. Place the data sheet (or Magnadoodle/slate/white board/paper sheet) showing drop number, date, rig number and location in front of each camera and in the centre over the bait arm so that it is clearly seen in the fields of view of both cameras. Verbal logs are an alternative/complementary option, as modern cameras are usually sufficiently sensitive to record spoken instructions/information.
17. Attach a diode to the bait arm if using stereo-BRUVs. If a diode is not available, clap slowly 3-4 times in front of the cameras (using a clapperboard or bare hands) over the bait arm in clear view to allow synchronisation during video analysis.
18. Attach the flag pole, one cluster of buoys and the first of the rigs to be deployed to the end of the first longline via double action clips. Ensure the rope is free, coiled, and facing the correct direction to un-coil without hindrance
19. At the captain's go-ahead (i.e. vessel in position and stationary), drop the flagpole into the water.
20. Once the flagpole is clear, push or throw the first rig so that it clears the side of the boat, ensuring all lines are clear of feet and untangled. Drop the cluster of buoys over first, followed by the rig ensuring not to drop the rig on any of the other lines in the water. This works best if one person handles the buoys and another the rig. Note that this sequence differs slightly for moored BRUVs, which require the ballast/anchor to be dropped first, followed by the rig and the floats in this order.

21. Mark a GPS waypoint when the unit is deployed and record both deployment time and site coordinates on the data sheet, which will have been pre-populated with location, rig number, camera numbers, memory card numbers etc. Include comments where necessary e.g. issues, weather conditions.
22. For single-rig designs, travel to the next site. For multi-rig designs, repeat until all units are in the water, making sure the captain moves forward slowly to pay out the lines.

Table 6.5 Example metadata sheet for pelagic stereo-BRUV fieldwork. Left and right memory card numbers must be recorded for each camera pair.

Date	ID	Rig	Left cam	Left card	Right cam	Right card	Time in	Location in	Time out	Location out	Comments (e.g. wildlife, behaviour, habitat etc.)
2017-10-25	SITE-A	15	12	05	10	02	08:00	(115.1252E; 32.5437S)	10:15	(115.2411E; 32.5008S)	Seabird aggregation observed near deployment site

Retrieval

23. Manoeuvre the vessel alongside the flag/grappling buoy, heading upwind of the current towards the BRUV.

24. Either gaff or grapple the rope joining to flag buoy to the first cluster of buoys.
25. Haul the line in and retrieve the flag buoy, taking care not to knock the tension wires on the stern of the boat. Remove and store the VHF transmitter and GPS logger when convenient. Wear gloves when hauling and coiling. Pelagic BRUVs are relatively light so manual handling is generally possible, however use a winch or pot hauler if available and warranted.
26. Unclip buoys and coil rope to facilitate future deployments.
27. Turn off the cameras, rinse them with freshwater, dry the seals around the housings with a towel and carefully remove the cameras from their housings when convenient. If conducting surveys over multiple days, it is good practice to clean and re-grease the O-rings with silicone at regular intervals.
28. Store the rig and buoys out of the way.
29. Repeat until all units are retrieved.
30. Remove memory cards.
31. If required, charge or change camera batteries.
32. Either setup the equipment for redeployment or securely stow on deck.

Post-Survey Procedures

Data management and quality assurance/control are crucial for monitoring and comparisons between studies within a given area. Following simple steps and using easily understandable and transferable metadata (see Table 6.5) will enable efficient harmonisation between studies.

Data management

Store used cards separately from unused cards.

33. Download the video data onto a portable hard-drive using a card reader or equivalent.
34. Save the files from each camera in a separate folder named using the unique site/drop identifier and L for left side or R for right side (e.g. CH001L).
35. Use multiple laptops or extra card readers to speed up the process.
36. During downloads, check that the videos are of good quality and note any interesting species etc. If any issue occurred with a camera, rig etc. attempt to rectify the issue before the next day's sampling.
37. At the end of each day, make a backup of the day's videos to two hard-drives stored in separate locations.
38. Transcribe the data from the data sheets into an expedition spreadsheet updated and backed up daily. The spreadsheet should also include the hard drive number where each sample is saved.

<u>Note:</u> It is important that all hard drives be clearly labelled – e.g. with the date, project name, contents and hard drive number. Ideally, files should also be labelled according to a standardised and unambiguous naming convention. All memory cards should be stored in waterproof containers. They should not be re-used or reformatted until data has been download and a backup created.

Pelagic BRUVs typically generate large volumes of data, including video imagery, field data sheets and software outputs. Consistently labelling folders and files is therefore essential to easily locating information and simplifying analyses. An example folder name is "176022_Groote_Island_stereo-BRUV_HD1", which concatenates the deployment date, study location/name, and hard drive number. Similarly, an appropriate file name could reflect the following structure: OpCode_year_month_day_study_cam1_cam2_L (folders on hard drives should follow a naming convention so that programs like Bulk Rename Utility can be easily used to rename all files with OpCode and camera number in the correct format). Template folder/file structures and further details on data management and quality control are provided in Chapter 5.

At this stage, there are no online video file storage databases, however the GlobalArchive platform has been created to store metadata (see Section 6.7.4). Refer to the software's website for instructions on metadata and data recording instructions.

Quality control

Quality assurance/quality control (QAQC) is an equally vital but potentially time-consuming undertaking for organisations and individual researchers. Following straightforward steps and using easily understandable and transferable metadata will enable harmonisation between studies.

It is important that any data corrections are made within the original annotation files to ensure consistency over time. Four complementary QAQC approaches are recommended:

- Analysts should first be adequately trained by processing videos for which species composition and density are known, and to which their results can be compared.
- Once the first annotation (fish counts and lengths) 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 2017).

Importantly, any corrections should be made to the annotation files before data are exported to GlobalArchive or other repositories.

Video processing

Trained analysts/fish biologists/taxonomists must be engaged to ensure that all footage can be appropriately processed and species can be correctly identified. Care must be taken to ensure that a consistent nomenclature is used, with FishBase, the World Register of Marine Species (WoRMS) and the Codes for Australian Aquatic Biota (CAAB) being popular, authoritative sources of taxonomic information. Undescribed or unnamed species (e.g. defined operational taxonomic units, OTUs) must also be meticulously documented. Archives of reference images from previous sampling campaigns have been established by numerous agencies across Australia and can serve as a useful benchmark for problematic sightings. The Collaborative and Annotation Tools for Analysis of Marine Imagery and Video (CATAMI) Project offers a framework for the cataloguing, annotation, classification and analysis of underwater imagery (Althaus et al. 2015).

A number of software tools are currently available for image analysis, with SeaGIS EventMeasure being arguably the most widespread but also the costliest. Advanced packages such as Image-Pro Plus, SigmaScan, or simpler programmes such as ScreenCalipers can also be used to make measurements calibrated by scale bars. The StereoMorph R package (Olsen & Westneat 2015) is an open-source alternative that additionally allows the reconstruction of 3D objects. Irrespective of the approach chosen, it is critical that any output be produced in a format comparable to other studies to facilitate comparison of data between campaigns and organisations.

Overestimates of abundance can occur as a result of double counting, for instance when the same individual/s is/are viewed at different time points throughout a deployment. To overcome this challenge, counts of the maximum number (MaxN) of individuals of any one species seen over the recording period have been used. In a monitoring context, comparative studies have suggested that the use of MaxN may be "hyper-stable" (i.e. underrepresents the magnitude of changes in true abundance) when fish abundance is high due to saturation of the field of view (Schobernd *et al.* 2013) and have suggested alternative metrics (e.g. MeanCount). However, MaxN remains the most widely accepted metric, and provides the best option for standardisation between sampling programs.

The essential information produced by annotation software should include three main outputs:

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

Point information is typically used to calculate MaxN values, while length and 3D point information is used to calculate length and biomass metrics. EventMeasure-Stereo has established queries built-in that produce a number of chosen metrics over a user defined period within the footage. In addition, EventMeasure-Stereo annotation datasets held within GlobalArchive can be queried in a similar fashion to produce such metrics. While there are a number of relative abundance metrics available, MaxN is the most widely accepted (Harvey *et al.* 2007).

The type of fish length measured (e.g. fork length or total length for fish and disc length for rays) should be clearly indicated as part of the annotation information for each sampling campaign.

Data release

GlobalArchive is a centralised repository for fish image annotation data, particularly those collected using Baited Remote Underwater Video (mono- and stereo-BRUVs) and Diver Operated Video (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 be harvested by the Australian Ocean Data Network in the future, and the metadata will accordingly be available on their national portal (and possibly on partner portals, such as the web interface of the Integrated Marine Observation System, IMOS). Until this is done, metadata should be published on both GlobalArchive and AODN to ensure data discoverability *[Recommended]*.

There is currently no national repository for BRUV imagery so we recommend following agency-specific protocols to ensure public release.

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

39. Immediate post-trip reporting should be completed by creating a metadata record documenting the purpose of the BRUV sampling campaign, the survey design, 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.

40. Publish metadata record to GlobalArchive and the Australian Ocean Data Network (AODN) catalogue as soon as possible after metadata has been quality controlled (see section 6.7.2).

    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 GlobalArchive upload page and the AODN Data Submission Tool. Note that user registration is required, but this is free and immediate.

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

41. Annotate video (fish counts and length) using EventMeasure or similar software.
42. Upload annotation data and any associated calibration, taxa and habitat data to GlobalArchive.
43. 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).
44. 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.
45. Produce a technical or post-survey report documenting the purpose of the survey, sampling design, sampling locations, sampling equipment specifications, annotation protocol, and any challenges or limitations encountered. Provide links to this report in all associated metadata. See Appendix C *[Recommended].*

Forthcoming developments

The development of novel methods combining pelagic BRUVs with ancillary data streams from other sampling platforms is currently underway. This includes, for instance, the integration of species size distributions as observed on BRUVs with active acoustics (echosounder data at 38 kHz) as a means of improving estimates of fish biomass. See the following publication for more details:

Letessier TB, Proud R, Meeuwig JJ, Cox M, Cattaneo Fernandes M, Brierley AS. (Submitted) A protocol for estimating fish biomass using echosounders and baited stereo-videography. Methods in Ecology & Evolution.

Field Manual Maintenance

In accordance with the universal field manual maintenance protocol described in Chapter 1 of the Field Manual package, this manual was updated in 2020 as Version 2. 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 6 (field manual for pelagic 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

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References

Althaus, F., N. Hill, R. Ferrari, L. Edwards, R. Przeslawski, C. H. Schönberg, R. Stuart-Smith, N. Barrett, G. Edgar, and J. Colquhoun. 2015. A standardised vocabulary for identifying benthic biota and substrata from underwater imagery: the CATAMI classification scheme. PLoS ONE 10:e0141039.

Axenrot, T., T. Didrikas, C. Danielsson, and S. Hansson. 2004. Diel patterns in pelagic fish behaviour and distribution observed from a stationary, bottom-mounted, and upward-facing transducer. ICES Journal of Marine Science: Journal du Conseil 61:1100-1104.

Bouchet, P. J. and J. J. Meeuwig. 2015. Drifting baited stereo-videography: A novel sampling tool for surveying pelagic wildlife in offshore marine reserves. Ecosphere 6:art137.

Bouchet, P. J., J. J. Meeuwig, Z. Huang, C. Phillips, S. D. Foster, and R. Przeslawski. 2017. Comparative assessment of pelagic sampling platforms: Final report., Canberra, Australia.

Boutros, N., M. R. Shortis, and E. S. Harvey. 2015. A comparison of calibration methods and system configurations of underwater stereo-video systems for applications in marine ecology. Limnology and Oceanography: Methods 13:224-236.

Coghlan, A., D. McLean, E. Harvey, and T. Langlois. 2017. Does fish behaviour bias abundance and length information collected by baited underwater video? Journal of Experimental Marine Biology and Ecology 497:143-151.

Clarke, T., S. K. Whitmarsh, P. G. Fairweather, and C. Huveneers. 2019. Overlap in fish assemblages observed using pelagic and benthic baited remote underwater video stations. Marine and Freshwater Research. DOI: 10.1071/MF18224 Coghlan, A., D. McLean, E. Harvey, and T. Langlois. 2017. Does fish behaviour bias abundance and length information collected by baited underwater video? Journal of Experimental Marine Biology and Ecology 497:143-151.

Delacy, C. R., A. Olsen, L. A. Howey, D. D. Chapman, E. J. Brooks, and M. E. Bond. 2017. Affordable and accurate stereo-video system for measuring dimensions underwater: A case study using oceanic whitetip sharks *Carcharhinus longimanus*. Marine Ecology Progress Series 574:75-84.

Díaz-Gil, C., S. L. Smee, L. Cotgrove, G. Follana-Berná, H. Hinz, P. Marti-Puig, A. Grau, M. Palmer, and I. A. Catalán. 2017. Using stereoscopic video cameras to evaluate seagrass meadows nursery function in the Mediterranean. Marine Biology 164:137.

Dorman, S. R., E. S. Harvey, and S. J. Newman. 2012. Bait effects in sampling coral reef fish assemblages with stereo-BRUVs. PLoS ONE 7:e41538.

Dunlop, K. M., E. Marian Scott, D. Parsons, and D. M. Bailey. 2014. Do agonistic behaviours bias baited remote underwater video surveys of fish? Marine Ecology 36:810-818.
Espinoza, M., M. Cappo, M. R. Heupel, A. J. Tobin, and C. A. Simpfendorfer. 2014. Quantifying shark distribution patterns and species-habitat associations: Implications of marine park zoning. PLoS ONE 9:e106885.
Friedlander, A. M., J. E. Caselle, E. Ballesteros, E. K. Brown, A. Turchik, and E. Sala. 2014. The real bounty: Marine biodiversity in the Pitcairn Islands. PLoS ONE 9:e100142.
Fukuba, T., T. Miwa, S. Watanabe, N. Mochioka, Y. Yamada, M. Miller, M. Okazaki, T. Kodama, H. Kurogi, S. Chow, and K. Tsukamoto. 2015. A new drifting underwater camera system for observing spawning Japanese eels in the epipelagic zone along the West Mariana Ridge. Fisheries Science 81:235-246.
Goetze, J., S. Jupiter, T. Langlois, S. Wilson, E. Harvey, T. Bond, and W. Naisilisili. 2015. Diver operated video most accurately detects the impacts of fishing within periodically harvested closures. Journal of Experimental Marine Biology and Ecology 462:74-82.
Harvey, E. S., M. Cappo, J. J. Butler, N. Hall, and G. A. Kendrick. 2007. Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. Marine Ecology Progress Series 350:245-254.
Harvey, E. S. and M. R. Shortis. 1998. Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision. Marine Technology Society Journal 32:3-17.
Heagney, E. C., T. P. Lynch, R. C. Babcock, and I. M. Suthers. 2007. Pelagic fish assemblages assessed using mid-water baited video: Standardising fish counts using bait plume size. Marine Ecology Progress Series 350:255-266.
Juhel, J. B., L. Vigliola, D. Mouillot, M. Kulbicki, T. B. Letessier, J. J. Meeuwig, and L. Wantiez. In press. Reef accessibility impairs the protection of sharks. Journal of Applied Ecology.
Kempster, R. M., C. A. Egeberg, N. S. Hart, L. Ryan, L. Chapuis, C. C. Kerr, C. Schmidt, C. Huveneers, E. Gennari, K. E. Yopak, J. J. Meeuwig, and S. P. Collin. 2016. How close is too close? The effect of a non-lethal electric shark deterrent on white shark behaviour. PLoS ONE 11:e0157717.
Kiszka, J. J., J. Mourier, K. Gastrich, and M. R. Heithaus. 2016. Using unmanned aerial vehicles (UAVs) to investigate shark and ray densities in a shallow coral lagoon. Marine Ecology Progress Series 560:237-242.
Langlois, T. J. 2017. Habitat-annotation-of-forward-facing- benthic-imagery: R code and user manual version 1.0.1.
Langlois, T. J., E. S. Harvey, and J. J. Meeuwig. 2012. Strong direct and inconsistent indirect effects of fishing found using stereo-video: Testing indicators from fisheries closures. Ecological Indicators 23:524-534.
Letessier, T., S. Kawaguchi, R. King, J. Meeuwig, R. Harcourt, and M. Cox. 2013a. A robust and economical underwater stereo video system to observe Antarctic krill (*Euphausia superba*). Open Journal of Marine Science 3:148-153.
Letessier, T., J. Meeuwig, M. Gollock, L. Groves, P. Bouchet, L. Chapuis, G. Vianna, K. Kemp, and H. Koldewey. 2013b. Assessing pelagic fish and shark populations: The application of demersal techniques to the mid-water. Methods in Oceanography 8:41-55.
Letessier, T. B., P. J. Bouchet, and J. J. Meeuwig. 2017. Sampling mobile oceanic fishes and sharks: Implications for fisheries and conservation planning. Biological Reviews 92:627-646.
Letessier, T. B., P. J. Bouchet, J. Reisser, and J. J. Meeuwig. 2014. Baited videography reveals remote foraging and migration behaviour of sea turtles. Marine Biodiversity:DOI 10.1007/s12526-12014-10287-12523.
Letessier, T. B., J.-B. Juhel, L. Vigliola, and J. J. Meeuwig. 2015. Low-cost small action cameras in stereo generates accurate underwater measurements of fish. Journal of Experimental Marine Biology and Ecology 466:120-126.
Lowry, M., H. Folpp, M. Gregson, and R. Mckenzie. 2011. A comparison of methods for estimating fish assemblages associated with estuarine artificial reefs. Brazilian Journal of Oceanography 59:119-131.
Mallet, D. and D. Pelletier. 2014. Underwater video techniques for observing coastal marine biodiversity: A review of sixty years of publications (1952–2012). Fisheries Research 154:44-62.
McLean, D. L., E. S. Harvey, and J. J. Meeuwig. 2011. Declines in the abundance of coral trout (*Plectropomus leopardus*) in areas closed to fishing at the Houtman Abrolhos Islands, Western Australia. Journal of Experimental Marine Biology and Ecology 406:71-78.
Murphy, H. M. and G. P. Jenkins. 2010. Observational methods used in marine spatial monitoring of fishes and associated habitats: A review. Marine and Freshwater Research 61:236-252.
Oh, B. Z., A. M. Sequeira, M. G. Meekan, J. L. Ruppert, and J. J. Meeuwig. 2017. Predicting occurrence of juvenile shark habitat to improve conservation planning. Conservation Biology 31:635-645.
Olsen, A. M. and M. W. Westneat. 2015. StereoMorph: an R package for the collection of 3D landmarks and curves using a stereo camera set-up. Methods in Ecology and Evolution 6:351-356.
Olsen, S., and T. Laevastu. 1983. Fish attraction to baits and effects of currents on the distribution of smell from baits. Northwest and Alaska Fisheries Center Processed Report 83-05. National Marine Fisheries Service, 64 p.
Pala, C. 2013. Giant marine reserves pose vast challenges. Science 339:640-641.
Potts, G. 2009. Crepuscular behaviour of marine fishes. Pages 221-228 *in* P. J. Herring, A. K. Campbell, M. Whitfield, and L. Maddock, editors. Light and Life in the Sea. Cambridge University Press, Cambridge, UK.
Priede, I. G., P. M. Bagley, A. Smith, S. Creasey, and N. R. Merrett. 1994. Scavenging deep demersal fishes of the Porcupine Seabight, Northeast Atlantic-observations by baited camera, trap and trawl. Journal of the Marine Biological Association of the UK 74:481-498.
Rees, M., N. A. Knott, G. Fenech, and A. R. Davis. 2015. Rules of attraction: Enticing pelagic fish to mid-water remote underwater video systems (RUVS). Marine Ecology Progress Series 529:213-218.

Riegl, B., J. L. Korrubel, and C. Martin. 2001. Mapping and monitoring of coral communities and their spatial patterns using a surface-based video method from a vessel. Bulletin of Marine Science 69:869.
Ryan, L. A., L. Chapuis, J. M. Hemmi, S. P. Collin, R. D. McCauley, K. E. Yopak, E. Gennari, C. Huveneers, R. M. Kempster, C. C. Kerr, C. Schmidt, C. A. Egeberg, and N. S. Hart. 2018. Effects of auditory and visual stimuli on shark feeding behaviour: The disco effect. Marine Biology:DOI 10.1007/s00227-00017-03256-00220.
Sainte-Marie, B., and B. T. Hargrave. 1987. Estimation of scavenger abundance and distance of attraction to bait. Marine Biology 94:431–443.
Santana-Garcon, J., J. M. Leis, S. J. Newman, and E. S. Harvey. 2014a. Presettlement schooling behaviour of a priacanthid, the Purplespotted Bigeye *Priacanthus tayenus* (Priacanthidae: Teleostei). Environmental Biology of Fishes 97:277-283.
Santana-Garcon, J., S. J. Newman, and E. S. Harvey. 2014b. Development and validation of a mid-water baited stereo-video technique for investigating pelagic fish assemblages. Journal of Experimental Marine Biology and Ecology 452:82-90.
Santana-Garcon, J., S. J. Newman, T. J. Langlois, and E. S. Harvey. 2014c. Effects of a spatial closure on highly mobile fish species: An assessment using pelagic stereo-BRUVs. Journal of Experimental Marine Biology and Ecology 460:153-161.
Santana-Garcon, J., M. Braccini, T.J. Langlois, S.J. Newman, R.B.., McAuley, E.S. Harvey, E.S., 2014d. Calibration of pelagic stereo-BRUVs and scientific longline surveys for sampling sharks. Methods in Ecology and Evolution 5, 824-833.
Schifiliti, M., D. McLean, T. Langlois, M. Birt, P. Barnes, and R. Kempster. 2014. Are depredation rates by reef sharks influenced by fisher behaviour? PeerJ PrePrints 2:e708v701.
Schobernd, Z. H., N. M. Bacheler, and P. B. Conn. 2013. Examining the utility of alternative video monitoring metrics for indexing reef fish abundance. Canadian Journal of Fisheries and Aquatic Sciences 71:464-471.
Scott, M.E., J.A. Smith, M.B. Lowry, M.D. Taylor, I.M. Suthers, I.M., 2015. The influence of an offshore artificial reef on the abundance of fish in the surrounding pelagic environment. Marine and Freshwater Research 66, 429-437.
Struthers, D. P., A. J. Danylchuk, A. D. Wilson, and S. J. Cooke. 2015. Action cameras: Bringing aquatic and fisheries research into view. Fisheries 40:502-512.
Underwood, M. J., S. Rosen, A. Engås, and E. Eriksen. 2014. Deep vision: An in-trawl stereo camera makes a step forward in monitoring the pelagic community. PLoS ONE 9:e112304.
Vargas-Fonseca, E., A.D.. Olds, B.L. Gilby, R.M. Connolly, D.S. Schoeman, C.M. Huijbers, G.A. Hyndes, and T.A. Schlacher. 2016, Combined effects of urbanization and connectivity on iconic coastal fishes. Diversity and Distributions, 22: 1328–1341.
Whitmarsh, S. K., P. G. Fairweather, and C. Huveneers. 2017. What is Big BRUVver up to? Methods and uses of baited underwater video. Reviews in Fish Biology and Fisheries 27:53-73.
Zintzen, V., M. J. Anderson, C. D. Roberts, E. S. Harvey, A. L. Stewart, and C. D. Struthers. 2012. Diversity and composition of demersal fishes along a depth gradient assessed by baited remote underwater stereo-video. PLoS ONE 7:e48522.
Zitterbart, D. P., L. Kindermann, E. Burkhardt, and O. Boebel. 2013. Automatic round-the-clock detection of whales for mitigation from underwater noise impacts. 2013. PLoS One 8(8):e71217.

[7] Mono-BRUVs consist of a single camera usually mounted directly behind or above the bait arm (Whitmarsh *et al.* 2017). Stereo-BRUVS consist of two cameras mounted at specific angles (ca. 7-8 degrees) either side of the bait arm.