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Short communication

The BRUVs workshop – An Australia-wide synthesis of baited remote underwater video data to answer broad-scale ecological questions about fish, sharks and rays

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A R T I C L E I N F O

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A B S T R A C T

Many marine fish populations have declined due to the individual or cumulative impacts of increasing water temperatures, ocean acidification, overfishing and other human-induced impacts such as land run-off, dredging and habitat alteration. Some solutions may be offered by ecosystem-based fisheries and conservation management. However, understanding their effectiveness relies on the availability of good quality data on the size distributions and abundance of fish populations and assemblages, collected at appropriate temporal and spatial scales. Since the early 2000s, baited remote underwater video systems (BRUVs) have become a popular tool for collecting data on fish assemblages across a range of depths and habitats. In Australia, this technique has been adopted by many different agencies and institutions, creating a unique opportunity to compile a continental-scale synthesis of fish data using a standardised sampling technique. Key Australian researchers and managers were invited to contribute to a synthesis workshop on baited underwater video in Albany, Western Australia between the 4th and 8th of February 2018. Data from 19,939 BRUVs deployments, collected between 2000 and 2017 around Australia, were compiled using GlobalArchive (globalarchive.org). The workshop identified and prioritised several key research themes that would contribute to the conservation and sustainable management of focal species and broad assemblages. Our goal is to describe where and when the data were collected, the type of equipment used and how the imagery was analysed. We also discuss the types of questions that can be addressed by analysing these standardised datasets and the potential benefits to conservation and fisheries management.

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1. Introduction

Underwater video technology is constantly evolving and being adapted for the collection of scientific data on fish populations. The development and use of remote underwater video sampling was driven by the need for a safe, non-destructive and fishery-independent means of collecting data on diverse fish populations across a range of depths and habitats with minimal biases. Critical to the success and uptake of remote video sampling has been the ability to provide accurate and precise length measurements using stereo-video [1–3], a feature essential for understanding the biology and ecology of most fish populations [4]. The advantages and potential biases of baited remote underwater video systems (BRUVs) with single or stereo configuration are now well researched and understood [5–8] and the technique is widely employed by research institutions and governmental natural asset managers in many countries [7,8].

BRUVs are used for a variety of purposes [9], but most commonly for describing spatial and temporal patterns in fish communities [10–15]. They have also been used for assessments of fish activity patterns [16–19], behaviour [20,21], assemblage structure in pelagic systems [22–24], responses to protected areas and anthropogenic pressures and in fisheries-independent surveys to support targeted species stock assessments [25,26]. They are also showing real potential as a survey technique for sharks [27]. BRUVs data also have the potential to collect information on taxa not originally targeted by surveys. For example, BRUVs data have recently been used to document the behaviour of sea turtles [28], the effects of fishing on the cephalopod *Nautilus* sp. [29] and distribution patterns of sea snakes [30]. BRUVs can also provide useful information on the composition and complexity of habitats with these data facilitating assessments of fish-habitat associations and an improved understanding of the drivers of fish distributions [14,31–33]. As the use of BRUVS is now widespread across the globe, and in particular around Australia [7,8], there is an opportunity for datasets to be pooled among studies to provide large-scale spatial (1000 s km) and temporal (months–years) assessments of fish populations to inform our understanding of population dynamics and ecological processes to optimise management strategies [27].

Utilising this opportunity, Australian managers and researchers who were experienced in the development and use of BRUVs gathered at a workshop with the goal of compiling, refining and subsequently analysing BRUVs data to answer broad ecological questions at a continental scale. This introductory paper provides a brief description of how workshop participants selected data, identified methodological differences, and implemented quality control measures to ensure the resulting data were suitable for answering key ecological questions that facilitate improved management of aquatic animal resources at a jurisdictional and national scale.

2. GlobalArchive

Access to a continental-scale BRUVs dataset was enabled through GlobalArchive (https://globalarchive.org/). GlobalArchive is a centralised repository that allows open access and private sharing of fish image annotation data from BRUVs or similar imagery-based sampling techniques. It allows users to store data in a standardised and secure manner, makes meta-data discoverable, and has the functionality to request data from other users, encouraging collaboration and synthesis of datasets within the community of practice. GlobalArchive was used to compile a comprehensive BRUVs dataset, including 19,939 deployments in depths from 0.5 to 600 m (Fig. 1), both in areas open to fishing (n = 15,509) and in no-take marine reserves (n = 4,430), spanning the six marine regions of Australia (Fig. 2) [34]. Over 60% of the BRUVs were deployed in depths that are difficult to survey using diver-based methods, following Australian work health and safety guidelines (>20 m). The dataset included observations of over 1.1 million individual fishes (sum of MaxN) and more than 1,450 species, providing the essential foundation for a workshop tasked with examining broadscale assessments of distribution and habitat use by finfish, sharks and rays.

3. Workshop goals and objectives

Key managers and scientists using BRUVs to collect fish data from around Australia were invited to a workshop in Albany, Western Australia (WA) between the 4th and 8th of February 2018. Participants were invited based on their publications, collaborations, access to data, provision of data and experience using BRUVs for research outputs. Participants included managers and scientists from state-based fisheries and conservation departments (Department of Primary Industries and Regional Development (Government of WA), Department of Biodiversity Conservation and Attractions (Government of WA), New South Wales (NSW) Department of Primary Industries), Commonwealth Government (Australian Federal Government) research institutions (Australian Institute of Marine Science, Commonwealth Scientific and Industrial Research Organisation (CSIRO)) and universities (The

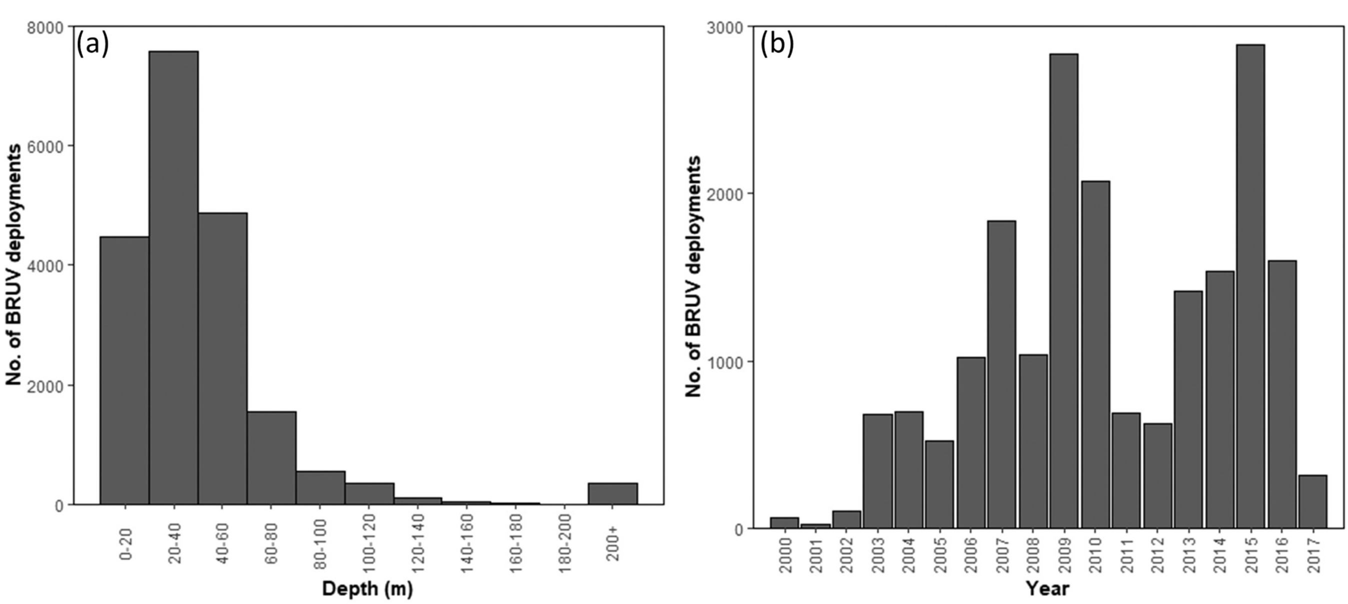

Fig. 1. Number of BRUVs deployments across (a) 20 m depth increments and (b) years, that were extracted from GlobalArchive to facilitate ecological research.

University of Western Australia, Curtin University, University of Tasmania, Flinders University and Deakin University).

Before datasets could be synthesised, differences in BRUVs methodology (e.g. soak time, camera configuration and data extraction) across sampling campaigns were recorded in GlobalArchive as a part of meta-data requirements so that these could be considered and potentially accounted for in future analyses. An additional, but important outcome, of the workshop was identifying and rectifying anomalies in the dataset through investigations into data quality and data collectors.

3.1. Variations in BRUVs methodology

Despite the diversity of managers and scientists and the ecological questions posed when the BRUVs data were collected, a number of factors were consistent across the entire dataset due to the development of standard operating procedures [6,9]. These included bait type and consistency (crushed pilchards, *Sardinops* spp.), the method of recording abundance (MaxN), and fish being identified to the finest taxonomic level possible (species level). There were several variations in the way BRUVs were constructed (see *BRUVs Design*), how they were used to achieve sampling goals (*Experimental Design*) and how and what data were extracted from the videos (*Video Analysis*) (Table 1). Variations in these factors were treated in three ways; 1) they were removed from the final dataset if found to occur for a small proportion of replicates (e.g. pelagic BRUVs), 2) they were retained if the variation could be discounted as a problem in peer-reviewed literature, or 3) they were recommended for inclusion in statistical models to account for variation.

Table 1
A summary of the differences in methodology between datasets included in the synthesis.

Variation in method	Category	Variable (% of studies used)
BRUVs design	Mono/Stereo	Mono (4.4%), Stereo (95.6%)
	Cameras	2000 - 2005 Hi8 Camcorder (0.7%) 795 ×596 pixels 2003 - 2010 MiniDV Camcorder (31%) 720 ×576 pixels 2008 - 2016 Digital HandyCam (46.1%) 1920 ×1080 pixels 2008 - 2017 Action Cam (22.2%) 1920 ×1080 pixels
	Bait Quantity	500 g (7.9%), 800 g (67.6%), 1 kg (24.5%)
Experimental design	Deployment Duration	30 mins (11.8%), 45 mins (4.2%), 60 mins (83%), 90 mins (0.03%), 120 mins (0.04%), 180 mins (0.03%)
	Replicate Separation	150 m (5.8%), 200 m (17.1%), 250 m (73.6%), 500 m (3.6%)
Video analysis	Software Used	Non-specialised (0.4%), AIMS BRUVS database (13.8%), EventMeasure (85.8%)
	Taxa Identified and Counted	All fish (99.2%), sharks and rays (0.8%)
	Taxa Measured	All fish (89%), targeted species (10%), sharks and rays (1%)
	Length type	Fork Length (83.3%), Total Length (16.7%)
	Max Range Annotated	2 m (0.6%), 4 m (2.4%), 5 m (4.1%), 8 m (24.1%), 10 m (5.3%), Not Specified (63.5%)

3.2. BRUVs design

Both stereo and single camera BRUVs (all forward facing) were used to collect data on species richness and relative abundance and were combined for analyses (Table 1). Length-based analyses were limited to datasets collected using stereo-BRUVs (95.6% of all samples, Table 1). As technology developed from 2000 to 2017, the recording capacity of cameras went from tape-based media analogue video (Hi8) and digital video (MiniDV), to digital handy-cams and action-cams capable of recording at full high definition (1080p @ 25–60 frames per second) on memory cards (Table 1). Given the increase in video quality over the years and potential increased capacity to identify fishes to species level, we recommend that camera type is included in statistical models. The quantity of bait used in each BRUVs deployment varied between 500 g and 1 kg (Table 1). The differentiation between some quantities (e.g. 800 g and 1 kg), is primarily due to an estimation of what will fit within the wire mesh bags that are used to contain the bait, given the weight of bait is rarely measured for each individual deployment. Given Hardinge et al. [35] found no significant difference in abundance or species richness when testing a more extreme differentiation between 200 g and 2 kg, we recommend that the variation in bait quantity within this dataset is discounted.

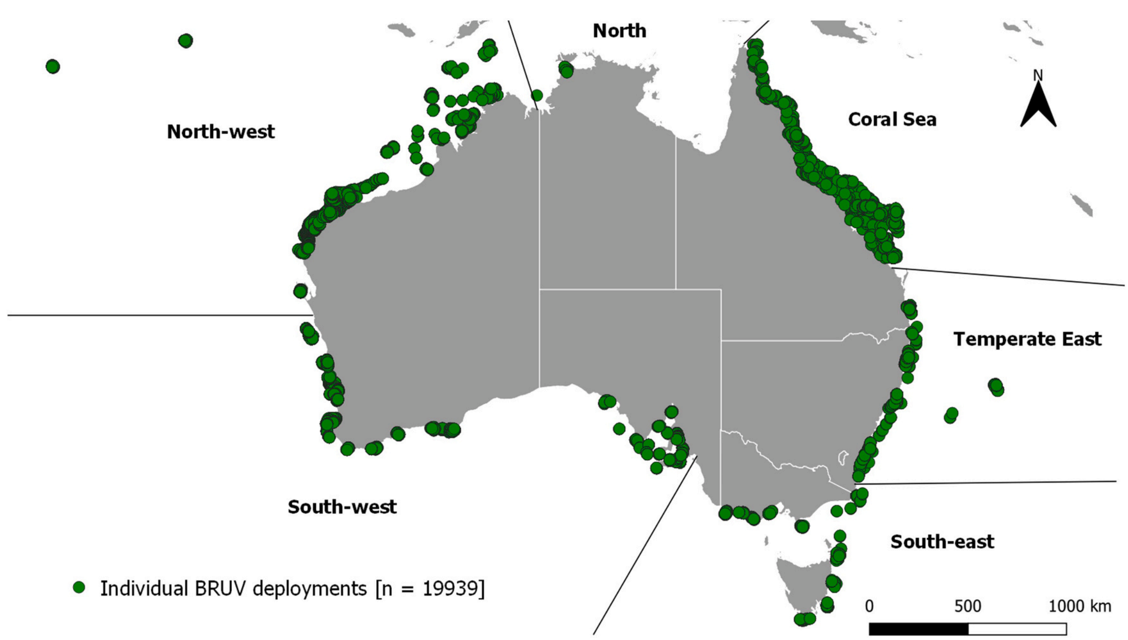

Fig. 2. Extent of the baited remote underwater video dataset across Australia and the six marine regions.

3.3. Experimental design

BRUVs were deployed between 2000 and 2017, although 90% of the data were collected post 2005 (Fig. 1). Deployment duration varied between 30 and 180 min (Table 1). For deployments > 60 min, data from the first 60 min were retained (this was possible where MaxN [36,37] was recorded for all species), or they were removed from the final dataset given they made up less than 1% of the sum of MaxN. [46] compared the influence of sampling duration on counts of species and their abundance in temperate, subtropical, and tropical locations. For broad-scale studies that spanned temperate and tropical locations, a 60-minute sampling duration was recommended [46]. Localised assessments could potentially utilise shorter deployment periods (30 min) where practicable, however, this depends on the diversity of fishes present, and if time and costs allow, the full 60-minute deployment duration is recommended to facilitate research such as that presented here. Deployment time should be included as a covariate when modelling or analysing this dataset. Finally, separation between individual BRUVs deployments varied from 150 to 500 m (Table 1). Although there have been no studies examining the impacts of differences in the spatial separation of replicate BRUVs, scientists often take a precautionary approach, separating BRUVs by distances thought to minimise individuals travelling between replicates for the species, group or community of interest [38]. The distance between replicates should be included within models to account for spatial autocorrelation and replicates deployed over the same time with less than 250 m separation removed [38].

3.4. Video analysis

Three different software programs have been used since 2000 to count and identify fishes from video; a) Microsoft Excel (2000–2002 only), b) the Australian Institute of Marine Science (AIMS) BRUVS database and c) EventMeasure from SeaGIS (seagis.com.au; Table 1). By using the AIMS BRUVS database and EventMeasure, metrics of interest were recorded in a standardised way that minimises user error (e.g. predefined species lists). More details on video analysis procedures can be found in Langlois et al. [9]. All length measurements were made in EventMeasure Stereo, or its predecessor PhotoMeasure. The majority of datasets contained counts of all species of fish present, and those that did not were only retained to answer questions on focal groups (i.e. sharks and rays; Table 1). Similarly, some datasets only contained measurements of the length of individuals in focal groups (i.e. species targeted by fisheries) and were only used for analyses of these groups. Most length measurements were fork length. When total lengths were recorded, they were converted to fork length using length to length equations [39]. Finally, the maximum distance in front of the cameras from which fish were recorded varied from 2 to 10 m, primarily reflecting limitations of the capabilities of older cameras to yield accurate length measurements beyond 8 m [3] and sampling in turbid waters. This factor will need to be incorporated into models given it may cause variation in the recorded abundance and the ability to identify fish to species level. Information on benthic relief (using a 0–5 estimate [40,41] and benthic biotic composition (based CATAMI classification scheme; [42]) was collected from each deployment [52,53] using TransectMeasure from SeaGIS (seagis.com.au) or Benthobox (benthobox.com). In addition to this information on the benthic relief and biotic composition, spatially-explicit covariates covering the continental shelf region of Australia were extracted for each deployment. These spatially-explicit covariates were collated, or generated from a wide variety of sources, including published and state/national government geodatabases. They also varied in spatial (c. 0.3–44 km) and temporal (e.g. monthly, annual, decadal) resolutions (Supplementary Material Table 1). These covariates were selected as they are are likely to influence the distribution and abundance of fish, shark and ray assemblages, including protection (i.e., no-take reserve), seabed structure and habitat (e.g. seabed aspect), connectivity (e.g. distance to reef), oceanography (e.g. water temperature, currents, nutrients), natural disturbance events (e.g. cyclone frequency) and human pressures (e.g. human access, light pollution) (Supplementary Material Table 1).

4. How can BRUVs and the data they generate contribute to aquatic natural resource management outcomes?

Effective management of the marine environment and its natural resources requires an understanding of the ecology of key fish populations and how they change through time. Thus, it is essential that management is underpinned by ongoing research and monitoring. BRUVs are a useful tool as they provide data on the distribution, relative abundance, length diversity, and habitat associations of fish important to fisheries and conservation management, without many of the inherent restrictions and inconsistencies associated with other common survey methods. BRUVs are especially good for obtaining a signal on carnivorous taxa, but have also been used to identify cryptic taxa of ecological and fishery significance [43]. The ability of BRUVs to record carnivore abundance is particularly relevant in Australia given most species targeted by fishers are carnivorous. For this reason, BRUVs are increasingly used to monitor fish assemblages in marine reserves and across mosaics of varying fishing intensity [8,9]. As many of the BRUV systems also use stereo-video, valuable information can be obtained on the length distributions and biomass of fishes [44] and fish behaviour, an area that is yet to be fully explored using BRUVs data.

Although management and analyses of marine data typically occur at the local scale, the collation of BRUVs datasets at a national level will allow trends to be explored over broad environmental gradients. Spatially extensive data are, for example, essential for informing species distribution modelling and identifying environmental variables that likely influence patterns in species abundance and assemblage attributes (e.g. diversity, richness). These relationships can inform the design of spatially-explicit management approaches that may include closures to fishing or other activities to ensure critical and/or representative habitats are protected [45]. Similarly, extensive depth and spatial information from BRUVs may also be used to forecast shifts in the distributions of species under changing climate regimes to help inform long-term planning for ecosystem-based fisheries management and spatial planning designed to protect biodiversity.

By housing annotation data in a central repository (GlobalArchive), BRUVs data are securely stored and readily accessible. Permanent BRUVs records can then be repeatedly scrutinised to verify original findings, used for comparisons to new data, or to collect additional information. This is important to test reproducibility and to promote further interrogation, while also being a valuable source of educational material on the marine environment and the relevance of management actions. Due to the annotation and database management associated with image scoring, these data also provide a valuable training data library for the applications of machine learning approaches for species classification with the potential to reduce manual scoring typically associated with BRUVs in the future.

The workshop described herein has provided a foundation to examine data, forge collaborations and develop research projects to improve our understanding of finfish, shark and ray assemblages around Australia. The workshop generated discussion and idea creation that evolved through subsequent meetings and will ultimately form the basis of many future publications. These include, but are not limited to the following areas of interest and endeavour: (1) an Australia-wide assessment of no-take marine reserves; (2) examination of the influence of proximity to human populations on the body-size distribution of Australian fishes; (3) evaluation of Australian elasmobranchs: species richness, abundance and the influential environmental and spatial drivers; (4) biogeography of Australian fish; (5) the effects of marine parks and region in influencing abundance and size of snapper *Chrysophrys auratus*; and (6) a national BRUVs data network for long-term

State of the Environment reporting that assesses fish assemblages based on common indicator metrics.

Importantly, the workshop provided a template for studies to form a baseline to scale up to global level studies. The collective insight of colleagues working together with input from resource managers during and after the workshop has been extremely beneficial. This has facilitated the generation of questions and hypotheses that can only be answered with large datasets (sensu GlobalArchive) that sensibly link to each of the proposed studies (see above). This has allowed the development of a prioritised list of projects to be completed. These provide a definitive strategic direction for the use of these data. Much of this proposed research has the potential to benefit policy development and management arrangements and will ultimately lead to further alternative or serendipitous outcomes.

CRediT authorship contribution statement

All authors are equally credited with the conceptualization of this manuscript, contributing data and meta data to the workshop and writing. EH, JG, MM and SN were responsible for funding acquisition.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104430.

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