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Combining underwater video methods improves effectiveness of demersal fish assemblage surveys across habitats

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ABSTRACT: Knowledge of the biases and advantages of various methods can inform and create more efficient sampling of either whole fish assemblages or targeted species. Comparisons of stereo baited remote underwater video (stereo-BRUV) and stereo-towed video, a new and relatively uncommon methodology of assessing fish assemblages, were made for assessing fish assemblages beyond diveable depths (>30 m). Stereo-BRUV and towed video footage were analysed for species composition and functional feeding groups in structure-forming macroalgae and sponge-dominated benthic habitats in temperate waters off Warrnambool, Victoria, Australia. Multibeam echosounder (MBES) data, light attenuation and temperature recordings were gathered for each deployment in order to characterise the seafloor structure and oceanographic parameters at each stereo-BRUV location and towed transect. A more abundant and diverse fish assemblage was observed in stereo-BRUV compared to towed video. The fish assemblage observed using the 2 methods was relatively similar in canopy forming algae habitat, but clearly distinct in sponge habitats. Power analysis also showed stereo-BRUV to have greater statistical power when observing total individuals, species richness and functional group richness across both habitats, with the exception of functional group richness in the sponge habitat. Stereo-BRUVs observed higher abundances of elasmobranches, *Meuschenia* spp., snapper *Chrysophrys auratus*, demersal invertivores and pelagic planktivores, whilst towed video observed more cryptic and territorial species such as *Olisthops cyanomelas* and *Pempheris multiradiata*. Using a combination of stereo baited and towed video sampling techniques records a more detailed description of the fish assemblage on temperate reefs than using either method alone.

KEY WORDS: Methodological comparison · Stereo-BRUV · Stereo-towed video · Multibeam sonar

INTRODUCTION

Fish assemblage data are often used to help understand how human activities influence marine ecosystems (Hewitt et al. 2005, Caselle et al. 2015) or as a measure of ecosystem health (Jennings & Polunin 1995) and help form the basis for managerial decisions (Andrew & Mapstone 1987). Multiple techniques are available to survey fish assemblages, including trawling (Unsworth et al. 2014), baited remote underwater video (Harvey et al. 2007), towed video (Monk et al. 2010), remotely operated vehicles (Laidig et al. 2013), fish traps and long-lining (Morrison & Carbines 2006). However, all sampling techniques have inherent bi-

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ases that influence how they represent the fish assemblage observed. Understanding these biases and potential implications across habitat types and target species is essential when choosing an appropriate sampling design (Williams et al. 2015).

Traditionally, fisheries have used extractive methods such as trawling for assessing the fish stocks of commercially important species (Kokkalis et al. 2015). However, these methods impact fish diversity and abundance (Mangano et al. 2014), are impractical to use in complex reefs due to the potential for gear loss (Uzmann et al. 1977) and are undesirable or illegal in ecosystems of high biological significance that have key ecological features or no-take areas, such as marine reserves (Willis & Babcock 2000). This leaves non-destructive sampling techniques as a more desirable choice for fish surveys, as they have minimal impact on targeted assemblages and their supporting environment (Westera et al. 2003). Underwater visual census (UVC) is a diver-based, non-destructive fish survey technique that has been commonly used since the 1950s (Brock 1954, Stobart et al. 2007). However, diver-based methodologies are inherently limited to shallow waters, leaving deeper fish communities unsurveyed. Remotely deployed underwater video systems provide opportunities to collect data on fish assemblages beyond diveable depths (>30 m). They have the additional advantages of extended bottom times and provide permanent records that allow the standardisation of data collection and analysis in long-term monitoring programs (Mallet & Pelletier 2014).

Stereo baited remote underwater video (stereo-BRUV) is a popular technique that has been used as an effective tool for surveying fish assemblages over the last 2 decades (Stobart et al. 2007, Watson et al. 2010, Bernard & Götz 2012). This system remains stationary on the seafloor and attracts the surrounding fishes into the cameras' field-of-view using bait. Stereo-BRUVs are effective for surveying deep habitats beyond diveable depths (Malcolm et al. 2011, Zintzen et al. 2012), but like other underwater visual techniques, rely on good visibility (Priede & Merrett 1996). Due to their stationary nature and use of bait, stereo-BRUVs provide a measure of relative abundance (MaxN) rather than an absolute measure. MaxN is known to be a conservative measure of relative abundance and may underestimate the abundance of a population of fish (Cappo et al. 2003). The use of bait has been shown to increase the number of carnivorous species sampled while still sampling fishes from lower trophic groups (Harvey et al. 2007, Watson et al. 2010). The attraction distance of fishes depends on the bait plume dispersal, which is influenced by local oceanographic factors and topographic complexity. Consequently, data collected from stereo-BRUVs cannot be expressed as densities (Cappo et al. 2003, 2007, Harvey et al. 2007).

Towed (Bailey et al. 2006, Monk et al. 2010, McIntyre et al. 2013) or drifted (Warnock et al. 2016) underwater video are also tools that have been used to sample fish assemblages. In particular, towed underwater video has become increasingly popular in recent years due to the miniaturisation of videography and positioning equipment, making it a standard tool for marine ecological studies such as benthic habitat mapping (Ierodiaconou et al. 2011, Calvert et al. 2015). Towed video has the additional advantage of providing spatially distinct records of species along each transect and, in theory, will provide a greater ability to model species–habitat relationships, in comparison to stereo-BRUV deployment which only provides data at single locations. The main limitation of these systems is that fishes tend to react to the presence of the operating vessel and towed unit by displaying avoidance behaviour (Morrison & Carbines 2006, Stoner et al. 2008), making it difficult to observe and identify species accurately.

Since each sampling method has a specific bias, research is required to compare and contrast these methods' results to understand how their biases influence measurements of a fish community. A number of studies have compared the results of various underwater video methods to standard UVC (e.g. Harvey et al. 2001, Watson et al. 2010, Lowry et al. 2012, Holmes et al. 2013, Mallet & Pelletier 2014), but few have looked at a comparison between stereo-BRUV and stereo-towed video surveys. Morrison & Carbines (2006) compared towed video against common fish survey techniques (e.g. Danish seine, trawls, pots, jigs, gillnets, long-lines, diver operated video and BRUV) and found towed video provided better abundance estimates of snapper *Chrysophrys auratus* and overall species diversity than BRUVs within an estuary habitat.

Studies comparing the methodologies of these techniques often fail to take into account variations over time, biological habitat and physical seafloor structure, all of which have been shown to influence fish assemblages (Willis & Babcock 2000, Pita et al. 2014). Previous comparison studies also lack analyses of power to detect differences associated with sampling methods. Power analyses provide context for statistical findings and a measurement of how well the sampling procedure can detect differences, whether or not they exist (Hewitt et al. 2016).

This study addresses the need to better understand potential biases associated with video techniques to characterise fish assemblages beyond diveable depths, where there has been a paucity of comparative studies to date. We sampled fish communities using stereo-BRUVs and towed video in macroalgae and sponge habitats over 2 surveys. In order to account for variation in physical parameters characterising the seafloor and water column, we used multibeam echosounder bathymetry data and collected temperature and light measurements. These data were used to address the following objectives: (1) to compare fish assemblages observed from baited and towed video using species composition and functional feeding groups; (2) to determine the influence of benthic habitat on fish assemblages; and (3) to determine the influence of physical parameters on fish assemblages observed.

MATERIALS AND METHODS

Study site

This study was conducted offshore from the town of Warrnambool (38° 22′ S, 142° 29′ E), in Victoria, Australia at depths ranging from 11 to 47 m (Fig. 1). Multibeam echosounder (MBES) data had previously been acquired in this area as part of the Victorian Habitat Mapping Project's benthic biota assessment (Ierodiaconou et al. 2007), allowing us to target specific habitats. We chose 2 habitats to represent the infralittoral and circalittoral zones that dominate the Victorian coastline for the comparison of fish census approaches using stereo-towed and BRUV techniques. Shallow (<30 m) canopy-forming macroalgae *Ecklonia radiata* dominates the infralittoral zone and is a major habitat in Victorian coastal waters and marine parks. This habitat is associated with an increased presence of cryptic and herbivorous species (Taylor & Schiel 2010). Invertebrate-dominated habitat (including sponges, ascidians, bryozoans, hydroids and gorgonians) have extensive coverage in the circalittoral zone (>30 m) along the Victorian coastline. Its greater depth allowed us to compare methods in areas considered beyond diveable depths.

Experimental design

To determine the influence of habitat biota on fish observations from the underwater video methodologies, we used geolocated underwater imagery and predicted habitat maps from Ierodiaconou et al. (2007), which allowed targeting and replication of sample sites in *E. radiata* and sponge habitat types across the study site. We targeted four 600 × 600 m sites in each of *E. radiata* and invertebrate-dominated reefs (hereafter referred to as sponge habitat) where ≥75% cover was observed. Within each site, 3 samples were collected for each of the fish census methods. Sampling was undertaken over 2 surveys to account for short-term temporal variation. For each survey we targeted optimal weather conditions for sampling gear deployment. The first survey occurred between 14 and 30 April 2015 and the second survey between 15 June and 9 August 2015 (Fig. 1). For both surveys, data were collected between 09:00 and 16:00 h to avoid the effects of diurnal changes in the fish community (Willis et al. 2006, Mallet et al. 2016, Myers et al. 2016).

Fish survey methods

Stereo-BRUV

We used 2 high-definition digital cameras (Sony Legria HF G10 or M300) fitted on each of the 6 stereo-BRUV systems deployed in this study. The cameras on the stereo-BRUVs were mounted 0.7 m apart on a base bar and inwardly converged at 8° to maximise the image overlap in the field-of-view of both cameras.

Each deployment was baited with 800 g of pilchards *Sardinops sagax* in a mesh bag suspended 1.2 m in front of the 2 cameras. A strobing LED diode was also placed in the field-of-view to enable synchronisation of imagery from the left and right cameras for stereo-video measurement.

Each system was deployed off the side of the boat and lowered to the seafloor. The 3 sampling locations were a minimum of 250 m apart to reduce the likelihood of fish swimming between deployed frames. The cameras were left to record for 60 min on the seafloor to characterise the fish assemblages for each sampling location (Watson et al. 2007, Taylor et al. 2013, Harasti et al. 2015). Six frames were deployed sequentially, but only one frame was deployed at any given time within each site to eliminate the risk of combined bait plumes compromising the spatial independence of each sample. Three samples were acquired within each of the 4 sites per habitat type, resulting in 24 stereo-BRUV deployments for each survey.

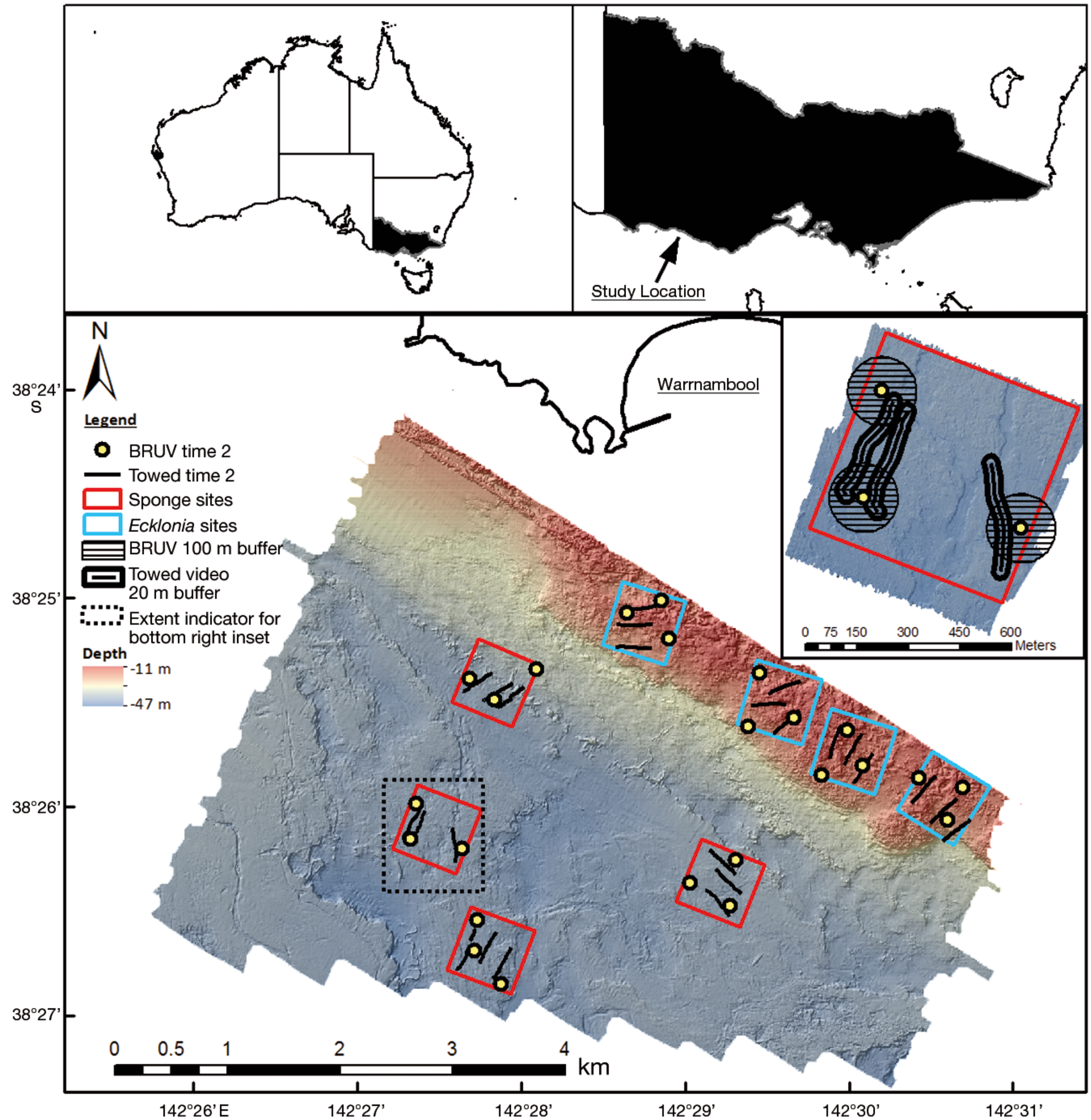

Fig. 1. Study site off Warrnambool, Victoria, Australia, showing *Ecklonia radiata* and sponge sites with stereo baited remote underwater video (stereo-BRUV) locations and towed video transects from the second survey. The underwater video deployment locations are overlayed on the bathymetry provided from the earlier Victorian Habitat Mapping Project. The extent indicator provides an example of the buffers applied to stereo-BRUV and towed video sampling locations (100 and 20 m, respectively) within a sponge site overlayed on bathymetry sampled from our multibeam echosounder (MBES) survey

Towed underwater video

A VideoRay remotely operated vehicle (ROV) was modified to function as a drift camera by inserting it into a stainless steel frame and adding a microwing attachment to assist in drifting across the seafloor. The reviewed footage was taken from 2 HD GoPro Hero 3+ cameras that were fastened to the top of the frame in a custom built stereo housing with a 40 cm base bar. To reduce the distorting effect of the fisheye lens in the cameras, the footage was recorded in a medium field-of-view, at a resolution of 1920 × 1080 pixels and 60 frames per second (FPS). The position of the unit in the water column was tracked at 1 s intervals using a Tracklink 1500MA ultra short baseline (USBL) acoustic tracking system. The operator was able to keep the unit 1 m above the seafloor by manipulating the winch controls while observing a live-feed obtained via an umbilical cable from the ROV unit. The time synchronisation between the live towed video, stereo GoPro HD data and USBL system enabled measuring the geographical location of fish observations along transects. The start location for each transect was randomly allocated with a towed/drift configuration with speeds between 0.5 and 1.0 knots (0.26 to 0.5 m s^{-1}). For all transects, the cameras were at an angle of 45° towards the seabed, allowing the capture of the seabed as well as the water column in the camera's field-of-view. Similar angles have been used in other studies assessing fish communities (Spencer et al. 2005). All transects for the drift video were limited to 320 m in length in an attempt to create a balanced design for comparison of fish assemblages across continuous benthic habitat types within each defined site. Three sampling transects were collected within each of the 4 sites for each of the 2 habitat types, resulting in the acquisition of 24 stereo-towed video transects for each survey.

Physical and oceanographic data collection

Multibeam echosounder

High-resolution MBES data were collected to characterise the seafloor at each site location to assess the influence of seafloor structure on the fish assemblage observed. The survey was completed between 22 and 29 April 2015. MBES data were collected using a Kongsberg Maritime EM2040C mounted on Deakin University's 9.2 m RV 'Yolla' (see Schimel et al. 2015 for methods). The MBES data provided 1 m gridded bathymetry, which was imported into ArcMap10.1 (ESRI). A total of 9 bathymetry derivatives representing seafloor complexity were produced using the Benthic Terrain Modeler tool (Wright et al. 2012): northness, eastness, slope, curvature, rugosity, vector ruggedness measure (VRM), mean depth, standard deviation depth, and variation depth (Table 1).

In ArcMap, the mean values for the bathymetry derivatives listed above were calculated within a buffer of 100 m around the location of each stereo-BRUV location and a buffer of 20 m around the towed video transect (see buffer example on the bottom-right insert on Fig. 1). These distances were chosen so that data for each sample were spatially independent from each other, while retaining as much area as possible. We made the assumption that the potential

Table 1. Description of bathymetry statistics

Derivatives	Description	Example
Aspect statistics	The direction that a topographic slope faces. The circular nature of aspect cannot be directly used because 359° and 0° are only 1° apart. To overcome this, 2 trigonometric transformations were applied which are proxies for exposure	
Sine	Northness: a value ranging from −1 to 1	Monk et al. (2010)
Cosine	Eastness: a value ranging from −1 to 1	Monk et al. (2010), Moore et al. (2010), Cameron et al. (2014)
Slope	Identifies the gradient (or highest rate of change) for each cell in the raster surface. Output in degree units	Iampietro et al. (2008)
Curvature	Shape of the slope	Young & Carr (2015)
Rugosity	Computes a ratio of surface area to planar area and operates using a 3 × 3 neighbourhood grid to measure structural complexity	Monk et al. (2010), Iampietro et al. (2008)
VRM	Vector ruggedness measure; a measurement of terrain ruggedness as the variation in 3-dimensional orientation of grid cells within a neighbourhood. This method effectively captures variability in slope of aspect within a single measure. Values of 0 represent no terrain variation, while values of 1 represent complete terrain variation.	Young et al. (2010), Young et al. (2011)
Depth statistics (mean, SD and variation)	Depth summary statistics averaged over the neighbourhood	Monk et al. (2010), Moore et al. (2010), Iampietro et al. (2008)

influence of the physical environment on fish presence was only to be measured within a short distance from the transect location since the towed video system had no bait and therefore would not likely attract fish further away.

Oceanographic data

To assess whether oceanographic conditions influence fish assemblages observed by the underwater video techniques, luminescence and temperature were recorded with each stereo-towed video transect and stereo-BRUV deployment. HOBO Pendant temperature/light data loggers (UA-002-08) recorded mean light (lum ft^{-2}) and temperature (°C) at 10 s intervals for the duration of each deployment.

Data analyses

Fish assemblage data

Observed fish species were classified into 10 functional feeding groups based on their dietary information and similar ecological roles within the ecosystem (Bulman et al. 2001). Benthic and demersal categories were defined for herbivores, invertivores and omnivores, whilst higher carnivores and planktivores were grouped into demersal and pelagic categories. Fish species abundance and functional feeding group abundance were used as the response variables in the comparative analysis between baited and towed video.

Stereo-BRUV

By default, footage from the right-hand camera in each stereo-pair was chosen to be reviewed to characterise fish assemblages for each deployment. However, the cameras were prone to occasional smothering from macroalgae at the *E. radiata* sites, in which case footage from the left-hand view was used instead. For each deployment, the maximum number of one particular species in the camera's field-of-view at one time (MaxN) was recorded, following common practice (Ellis & DeMartini 1995, Priede & Merrett 1996, Cappo et al. 2003, 2004). Fish were identified to the lowest taxonomic level possible. A single observer reviewed all of the footage from the survey to eliminate inter-observer bias. Recording of fish abundance, feeding behaviour, stage (juvenile or adult) and sex (where possible) was done using the program EventMeasure (SeaGIS) to efficiently log fish assemblage data for each 60 min deployment starting from the moment the frame came in contact with the seafloor.

Towed underwater video

Fish observations in towed video footage were logged using EventMeasure. Records started from the moment the seafloor came into view and ended after the towed system reached a distance along the transect of 320 m. The abundance and size of each species was measured as the cumulative number of fish observed within a particular transect. An accuracy of 10 mm (as opposed to the 5 mm used for stereo-BRUV) was used for stereo measurements in response to fish often being viewed in the edges of video and shorter space bar. A synchronising diode was placed in front of the towed video before and after transects to sync both cameras and to assess if frames were dropped during the deployment. As the towed video system is in motion, we made the assumption that any fish that swam into the field-of-view was doing so for the first time and thus constitutes observation of a new individual.

Statistical analyses

We used non-parametric analysis of variance (PERMANOVA; Anderson 2001) to test the differences in the composition of the fish assemblage observed between baited and towed video. The design consisted of 4 factors: method (2 levels: baited and towed, fixed), habitat (2 levels: sponge and *E. radiata*, fixed), survey (2 levels: time 1 and time 2, fixed), site nested within habitat (8 levels: random). Because of the large range in abundance between species in the data, a square-root transformation was applied to the count data to down-weigh the influence of the most abundant taxa (Anderson et al. 2008). The Bray-Curtis dissimilarity measure was chosen as it is better for assessing joint absences in community structures than using Euclidean Distance (Anderson 2001). Interactions and main effects were subject to pairwise analysis.

We used a canonical analysis of principal coordinates (CAP; Anderson & Willis 2003) to visualise and determine relationships between species/functional groups observed for each method, habitat and time. To determine which species and functional groups were driving the differences observed between method and habitat, a Pearson correlation of $r \geq 0.4$ and $r \geq 0.35$ was used to select the highly-correlated individuals/groups in a vector overlay. The choice of correlation values used to plot species and groups vector overlays was chosen to highlight major drivers of variation while maintaining interpretable figures, as done by Warnock et al. (2016).We used PERMANOVA on a Euclidean distance dissimilarity matrix to test for differences in each of these species/functional groups (Anderson & Millar 2004). When the number of unique permutations was below 100, Monte Carlo p-values were used to assess the significance (Anderson et al. 2008). Since both methods captured data in stereo, allowing for length measurements, we compared length measurements of species observed using both methods. This was restricted to the second survey due to incorrect settings (recorded at extra wide angle field-of-view) recorded on the stereo-towed GoPros for the first survey, causing accurate size measures to be unavailable due to calibration issues. For comparison, we selected the most abundant species observed across the 2 methods for comparison using *t*-tests. Before conducting 2-sample *t*-tests we checked that the length data had equal variances and a normal distribution.

A distance-based linear model multivariate analysis (DISTLM) (Anderson et al. 2008, Moore et al. 2010) was used to measure the relationship between the fish community and the physical and oceanographic variables measured. Draftsman's plots were used to assess correlation between the environmental variables. Any variables that exceeded a correlation of 0.7 were excluded from the model (Moore et al. 2010). The BEST solutions procedure was used to determine the optimal model fit with Bayesian information criterion (BIC) as the selection criteria. To visualise the results of the DISTLM, distance-based redundancy analyses (dbRDA) with an $r \geq 0.4$ vector overlay assisted in determining which variables were influencing species abundance. All analyses were done using PRIMER v.7.0.9 (Plymouth Routines In Multivariate Ecological Research), with 9999 permutations for each PERMANOVA and CAP analysis.

Power analyses

The statistical power of stereo-BRUV and towed video to detect change in 3 univariate variables (species richness, functional groups, total abundance) was investigated using a simple 1-way ANOVA model with 2 levels (before and after). The power of both methods to detect a change of 20 and 50% using a significance criterion of 0.05 was estimated using mean and variance for each univariate variable in both habitats (Langlois et al. 2010, Harvey et al. 2012, Warnock et al. 2016). Non-central *F* probabilities were calculated for each analysis using the G*Power programme (Faul et al. 2007).

RESULTS

A total of 2490 fish observations across 46 taxa belonging to 29 families were observed from 46 stereo-BRUV deployments (2 deployments failed during the first survey) and 48 towed video transects. Forty taxa were observed in stereo-BRUV footage and 33 taxa in towed video footage, with 13 and 6 species observed exclusively in each technique, respectively (Table 2). Similar numbers of species were detected in both habitats (n = 32 in sponge habitat and n = 30 in *Ecklonia radiata* habitat; Table 3).

Species and habitat diversity

Stereo-BRUVs recorded a significantly higher Shannon's diversity index than towed video (ANOVA; df = 92, MS = 0.211, $F = 22.3$, $p \leq 0.001$). Additionally, stereo-BRUV viewed significantly more individuals of fish than towed video ($p \leq 0.05$; Table 4). An ANOVA conducted on Shannon's index determined that sponge habitat had a more diverse fish assemblage than *E. radiata* habitat. Pairwise comparisons revealed that fish species observed within stereo-BRUV and towed video differed significantly between habitats (stereo-BRUV: $t = 6.94$, p = 0.027; towed video: $t = 4.09$, p = 0.025). Visual examination of the proportion of families showed similar

Table 2. Stereo baited remote underwater video (stereo-BRUV) and towed video observations and survey time in field

	Stereo-BRUV	Towed video	Total
Total no. of individuals	1508	982	2490
Total no. of taxa	40	33	46
Total no. of taxa exclusive to method	13	6	–
Survey time (hours)	46	12	58
Processing time (hours)	92	12	104
Total no. of individuals in sponge	1160	576	1736
Total no. of individuals in *Ecklonia radiata*	348	406	754

Table 3. Relative abundances (mean ± SE) of all fish species observed by stereo-BRUV and towed video for each habitat type (*Ecklonia radiata* or sponge dominated)

Family	Species	Functional group	Common name	*E. radiata*		Sponge	
				Stereo-BRUV	Towed video	Stereo-BRUV	Towed video
Apolodactylidae	*Aplodactylus arctidens*	Demersal herbivore	Marblefish			0.08 ± 0.06	0.04 ± 0.04
Arripdae	*Arripis truttaceus*	Pelagic higher carnivore	Western Australian salmon			0.17 ± 0.17	
Berycidae	*Centroberyx gerrardi*	Demersal invertivore	Bight redfish			0.04 ± 0.04	0.13 ± 0.09
Carangidae	*Trachurus* sp.	Pelagic planktivore	Mackerel	1.82 ± 1.05	0.21 ± 0.21	4.63 ± 2.95	0.88 ± 0.83
Cheilodactylidae	*Cheilodactylus nigripes*	Benthic invertivore	Magpie perch	0.05 ± 0.05		0.13 ± 0.07	0.71 ± 0.24
	Dactylophora nigricans	Benthic invertivore	Dusky morwong		0.04 ± 0.04		
	Nemadactylus douglasii	Benthic invertivore	Grey morwong				0.04 ± 0.04
	Nemadactylus valenciennesi	Demersal invertivore	Queen snapper			0.71 ± 0.14	0.5 ± 0.21
Dasyatididae	*Dasyatis brevicaudata*	Benthic invertivore	Smooth stingray	0.09 ± 0.06		0.04 ± 0.04	
Diodontidae	*Diodon nicthemerus*	Demersal invertivore	Globefish	0.05 ± 0.05	2.38 ± 2.29		
Dinolestidae	*Dinolestes lewini*	Pelagic higher carnivore	Long-finned pike	1.73 ± 0.54	1.96 ± 0.85	0.04 ± 0.04	0.83 ± 0.57
Enoplosidae	*Enoplosus armatus*	Demersal invertivore	Old wife		0.08 ± 0.08		
Gempylidae	*Thyrsites atun*	Pelagic higher carnivore	Barracouta		0.04 ± 0.04	0.21 ± 0.17	0. 04 ± 0.04
Gerreidae	*Parequula melbournensis*	Benthic invertivore	Silverbelly	0.05 ± 0.05		1.21 ± 0.40	0.38 ± 0.24
Heterodontidae	*Heterodontus portusjacksoni*	Benthic invertivore	Port Jackson shark	0.14 ± 0.07			
Labridae	*Eupetrichthys angustipes*	Benthic invertivore	Snakeskin wrasse				0.21 ± 0.08
	Notolabrus fucicola	Benthic invertivore	Purple wrasse	0.32 ± 0.10	0.04 ± 0.04		
	Notolabrus tetricus	Benthic invertivore	Bluethroat wrasse	3.23 ± 0.32	6.00 ± 1.02	0.67 ± 0.20	0.54 ± 0.18
	Pictilabrus laticlavius	Benthic invertivore	Senator wrasse	1.77 ± 0.30	0.21 ± 0.08		0.13 ± 0.07
	Pseudolabrus rubicundus	Benthic invertivore	Rosey wrasse			1.88 ± 0.33	1.17 ± 0.32
Monacanthidae	*Acanthaluteres vittiger*	Benthic omnivore	Toothbrush leatherjacket	3.55 ± 1.93	0.17 ± 0.10	0.08 ± 0.06	
	Eubalichthys gunnii	Benthic invertivore	Gunn's leatherjacket			0.04 ± 0.04	0.04 ± 0.04
	Eubalichthys mosaicus	Benthic invertivore	Mosaic leatherjacket			0.08 ± 0.06	
	Meuschenia australis	Benthic invertivore	Brownstriped leatherjacket	0.05 ± 0.05		0.04 ± 0.04	
	Meuschenia flavolineata	Benthic invertivore	Yellowstriped leatherjacket	0.05 ± 0.05		0.04 ± 0.04	
	Meuschenia freycineti	Benthic invertivore	Sixspine leatherjacket	0.45 ± 0.13	0.08 ± 0.06	0.08 ± 0.06	
	Meuschenia hippocrepis	Demersal omnivore	Horseshoe leatherjacket	0.05 ± 0.05			
	Meuschenia scaber	Benthic invertivore	Velvet leatherjacket		0.04 ± 0.04	2.88 ± 0.45	0.38 ± 0.16
	Thamnaconus degeni	Benthic invertivore	Degen's leatherjacket		2.46 ± 2.29	0.88 ± 0.23	
Moridae	*Pseudophycis bachus*	Demersal higher carnivore	Red cod			0.08 ± 0.06	
Mullidae	*Upeneichthys vlamingii*	Benthic invertivore	Southern goatfish	0.59 ± 0.55	0.13 ± 0.07	1.25 ± 0.26	1.46 ± 0.51
Myliobatidae	*Myliobatis australis*	Benthic invertivore	Southern eagle ray	0.09 ± 0.06	0.04 ± 0.04		
Neosebastidae	*Neosebastes scorpaenoides*	Benthic invertivore	Common gurnard perch			0.25 ± 0.09	0.04 ± 0.04
Odacidae	*Odax acroptilus*	Benthic herbivore	Rainbow cale	0.05 ± 0.05			
	Olisthops cyanomelas	Benthic herbivore	Herring cale	0.91 ± 0.15	2.58 ± 0.38		
	Siphonognathus beddomei	Benthic invertivore	Pencil weed whiting		0.04 ± 0.04		
Parascyllidae	*Parascyllium variolatum*	Benthic invertivore	Varied carpetshark		0.13 ± 0.07		
Pempherididae	*Pempheris multiradiata*	Benthic invertivore	Common bullseye			0.04 ± 0.04	1.63 ± 1.11
Pinguipedidae	*Parapercis allporti*	Benthic invertivore	Eastern barred grubfish			0.04 ± 0.04	
Pomacentridae	*Parma victoriae*	Benthic herbivore	Victorian scalyfin	0.18 ± 0.08	0.21 ± 0.08		
Pristiophoridae	*Pristiophorus cirratus*	Demersal invertivore	Common sawshark			0.04 ± 0.04	
Scyliorhinidae	*Cephaloscyllium laticeps*	Benthic invertivore	Swell shark			0.17 ± 0.10	
Serranidae	*Caesioperca* sp.	Demersal planktivore	Butterfly perch & Barber perch	0.36 ± 0.36	0.04 ± 0.04	24.29 ± 7.60	14.50 ± 2.62
Sparidae	*Chrysophrys auratus*	Demersal invertivore	Snapper			8.25 ± 2.92	0.38 ± 0.23
Sphyraenidae	*Sphyraena novaehollandiae*	Pelagic higher carnivore	Shortfin pike	0.23 ± 0.09			
Syngnathidae	*Phyllopteryx taeniolatus*	Demersal planktivore	Weedy seadragon	0.05 ± 0.05	0.04 ± 0.04		

Table 4. PERMANOVA of square-root transformed fish species abundance and fish functional groups abundance data observed by stereo-BRUV and towed video over 4 sites each within sponge and *Ecklonia radiata*-dominated habitats. Results are based on Bray-Curtis dissimilarity measure. Method (M): stereo-BRUV or towed video; habitat (H): sponge or *E. radiata*; survey time (T): 1 or 2; and fixed factors. Si(H): Site (habitat) is a random factor with 8 levels. The p-values were obtained using 9999 permutations given the permutable units for each unit. p < 0.05 in **bold**

Groups	df	Functional group abundance			Assemblage composition		
Source		MS	Pseudo-*F*	P(PERM)	MS	Pseudo-*F*	P(PERM)
Method	1	4805.1	3.8602	0.054	10711	5.0126	**0.02**
Habitat	1	62985	36.66	**<0.001**	118 000	39.968	**<0.001**
Survey	1	3158.4	3.9406	0.061	3694.8	2.838	0.104
Site (habitat)	6	1719.8	1.9594	**0.008**	2954.8	2.1293	**0.003**
M × H	1	5114.7	4.1089	**0.048**	13758	6.4386	**0.014**
M × T	1	1242.7	1.0596	0.363	2346.3	1.2266	0.290
Ha × T	1	1569.6	1.9583	0.169	2655.9	2.0401	0.159
M × Si(H)	6	1245.5	1.419	0.106	2138.3	1.5409	0.050
T × Si(H)	6	801.34	0.91297	0.566	1301.7	0.93804	0.534
M × H × T	1	1538.7	1.312	0.272	1919.8	1.0036	0.376
M × T × Si(H)	6	1173.4	1.3368	0.146	1913.9	1.3792	0.100
Residual	62	877.73			1387.7		
Total	93						

patterns between the 2 habitats for both methods (Fig. 2).

Assemblage composition

Species composition

A significant interaction between method and habitat was observed for fish assemblages observed across both methods ($p \leq 0.05$; Table 4). Pairwise comparisons between these factors showed significant differences in fish assemblage between methods in sponge (t = 2.42, p = 0.005) and *E. radiata* (t = 2.37, p = 0.006) habitats. CAP analysis of species abundance showed that stereo-

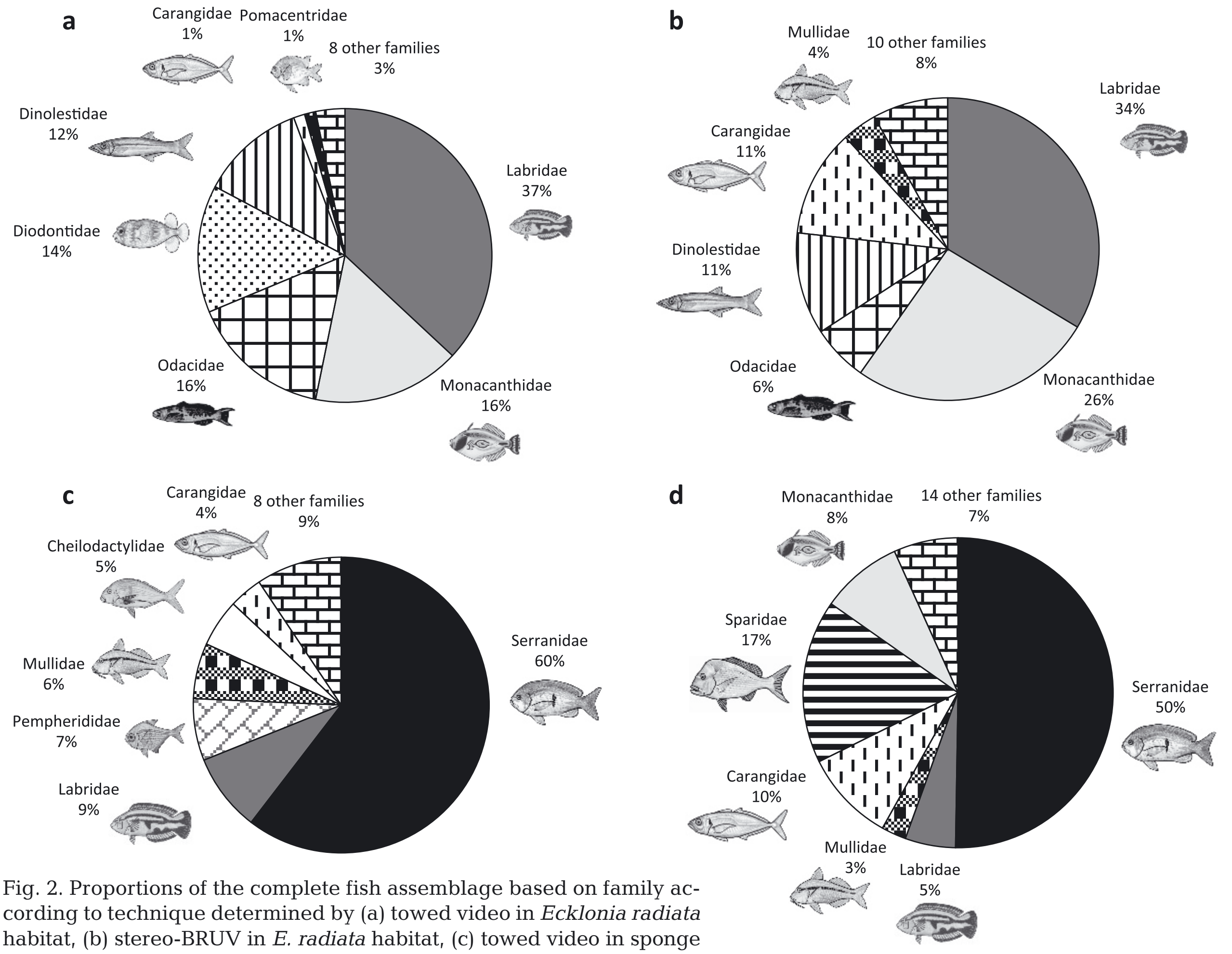

Fig. 2. Proportions of the complete fish assemblage based on family according to technique determined by (a) towed video in *Ecklonia radiata* habitat, (b) stereo-BRUV in *E. radiata* habitat, (c) towed video in sponge habitat, and (d) stereo-BRUV in sponge habitat

BRUV and towed video formed 2 distinct groups within sponge habitat, suggesting that the methods detected separate components of the fish assemblage (Fig. 3). In contrast, stereo-BRUV and towed video displayed less separation within *E. radiata* habitat (Fig. 3). There was no clear pattern of species detectability over both methods in *E. radiata* habitat. Univariate and pairwise analysis of highly correlated species showed most displayed a higher relative abundance within stereo-BRUV samples when compared to towed video (Table 5, Fig. 4). Only 1 species (*Olisthops cyanomelas*) was observed in greater abundances on towed video in comparison to stereo-BRUVs ($t = 3.27$, $p = 0.037$; Fig. 4c).

Species length comparison

Stereo-BRUV was able to measure 87.1% of fish that swam into its field-of-view compared to towed video, where measurements of only 52.2% of fish observed was possible (Table 6). Additionally, stereo-BRUV measured 97% of the fish it observed in sponge habitat, while towed video measured 62.4% of fish it observed. Overall, both methods achieved fewer measurements within *E. radiata*, but towed video (44.9%) recorded slightly more measurements of fish than stereo-BRUV (40.6%) within this habitat (Table 6). Only 2 fish species (*Caesioperca* sp. and *Notolabrus tetricus*) were common enough in both underwater video methods to enable statistical comparisons for length frequency data to be conducted. There was no significant difference between stereo-BRUVs and stereo-towed video for *Caesioperca* sp. ($t = 0.99$, df = 471, 2-tailed $p = 0.32$). Stereo-BRUVs viewed a larger size range than towed video (30–270 vs. 91–250 mm, respectively; Fig. 5a). There was no significant difference between stereo-BRUV and stereo-towed video measurements for *N. tetricus* ($t = -0.09$, df = 84, 2-tailed $p = 0.93$) but both methods found a similar size range for the species (150 to 430 mm; Fig. 5b). Additionally, towed video was able to measure more males than stereo-BRUV (23 and 15, respectively). Females were also measured more in stereo-towed video than stereo-BRUV (32 and 26, respectively).

Functional group analysis

The demersal omnivore group was exclusively observed in stereo-BRUV footage. No significant main effect of method between stereo-BRUV and towed video was observed for fish functional groups. However, pairwise comparisons of the method × habitat interaction (Table 4) indicated there was a significant difference between stereo-BRUV and towed video within sponge sites ($t = 2.15$, $p = 0.018$). An overlay of the Pearson correlation vectors ($|r| \geq 0.4$) was placed on the CAP displaying functional groups to visualise their influence (Fig. 6). Demersal planktivores and demersal invertivores were correlated with stereo-BRUV observations rather than towed video in the sponge habitat, whilst benthic herbivores were correlated with *E. radiata* habitat.

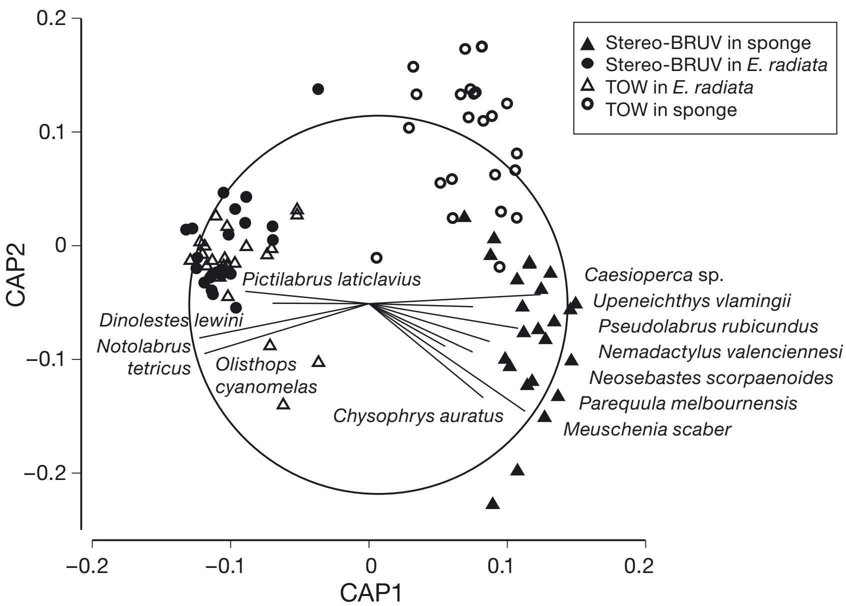

Fig. 3. Canonical analysis of principal coordinates (CAP) ordination based on Bray-Curtis dissimilarity for fish species abundance, displaying the interaction between method (stereo-BRUV or towed video [TOW]) and habitat (canopy-forming macroalgae *Ecklonia radiata* or sponge dominated). Highly correlated (Pearson r > 0.4) species are represented as vectors in an overlay. The direction and length of the vectors on the overlay represent the strength and direction of the relationship

Influence of environmental variables on fish community

A DISTLM for all species observed in stereo-BRUV explained 53.1% of the total variation in assemblage composition with only the mean depth being significant (Fig. 7a). Mean depth explained the highest percentage of variance (51%) while the remaining vari-

Table 5. Univariate PERMANOVA of fish species abundance data observed by stereo-BRUV and towed video over 4 sites each within sponge and *Ecklonia radiata*-dominated habitats. Results are based on Euclidean distance dissimilarity measure. These species were selected due to their high correlations observed in the canonical analysis of principal coordinates. Data for *Chrysophrys auratus* and *Dinolestes lewini* were square-root transformed; p-values were obtained using 9999 permutations given the permutable units for each unit; p < 0.05 in **bold**. Three species (*Meuschenia freycineti*, *M. scaber* and *Olisthops cyanomelas*) use Monte Carlo p values to determine significance, due to the analysis using less than 100 permutations

Source	df	*Meuschenia freycineti*				*Chrysophrys auratus*		
		MS	Pseudo-*F*	p(PERM)	p(MC)	MS	Pseudo-*F*	p(PERM)
Method	1	1.1136	5.7334	**0.035**	0.055	22.408	192.48	**<0.001**
Habitat	1	1.1136	7.5228	0.043	**0.0324**	32.933	19.01	**0.029**
Survey	1	0.12374	46.962	**<0.001**	0.001	0.46474	1.0228	0.357
Site(Habitat)	6	0.14806	1.0799	0.376	0.385	1.7338	1.62	0.148
M × H	1	0.42677	2.1971	0.186	0.188	22.408	192.48	**<0.001**
M × T	1	0.002525	0.037513	0.832	0.855	1.6506	1.1893	0.325
H × T	1	0.12374	46.962	**<0.001**	0.001	0.46474	1.0228	0.358
M × Si(H)	6	0.19435	1.4176	0.222	0.217	0.11447	0.10696	0.996
T × Si(H)	6	0.00236	0.017216	1	0.999	0.45313	0.42338	0.877
M × H × T	1	0.002525	0.037513	0.829	0.857	1.6506	1.1893	0.330
M × T × Si(H)	6	0.067175	0.48998	0.820	0.813	1.3885	1.2973	0.271
Res	62	0.1371			1.0703			
Total	93							
Source	**df**	*Meuschenia scaber*				*Dinolestes lewini*		
		MS	Pseudo-*F*	P(PERM)	P(MC)	MS	Pseudo-*F*	P(PERM)
Method	1	35.162	29.187	**0.002**	0.001	0.077137	0.0585	0.787
Habitat	1	59.889	103.08	0.018	**<0.001**	12.773	6.9236	0.059
Survey	1	0.49495	0.8519	0.397	0.399	1.8999	2.2549	0.186
Site(Habitat)	6	0.57889	0.35891	0.914	0.904	1.8475	3.3503	**0.006**
M × H	1	37.586	31.199	**0.002**	0.002	0.99236	0.7526	0.429
M × T	1	0.81818	0.45089	0.537	0.537	1.2318	1.8565	0.227
H × T	1	0.25253	0.43464	0.521	0.543	0.010911	0.012949	0.908
M × Si(H)	6	1.2039	0.74641	0.612	0.614	1.3201	2.3939	**0.039**
T × Si(H)	6	0.57889	0.35891	0.913	0.901	0.84316	1.529	0.183
M × H × T	1	0.49495	0.27276	0.622	0.624	0.32044	0.48298	0.516
M × T × Si(H)	6	1.815	1.1253	0.362	0.356	0.6637	1.2035	0.309
Res	62	1.6129			0.55146			
Total	93							
Source	**df**	*Olisthops cyanomelas*				Demersal invertivores		
		MS	Pseudo-*F*	p(PERM)	p(MC)	MS	Pseudo-*F*	p(PERM)
Method	1	16.162	11.042	**0.013**	0.015	13.643	20.151	**0.002**
Habitat	1	71.273	86.603	0.0001	**<0.001**	23.482	8.995	**<0.001**
Survey	1	0.040404	0.055608	0.84	0.828	0.18674	0.12903	0.734
Site(Habitat)	6	0.82249	0.77264	0.603	0.593	2.6126	1.6231	0.145
M × H	1	16.162	11.042	**0.011**	0.016	32.144	47.479	**<0.001**
M × T	1	0.040404	0.18767	0.681	0.686	3.5851	2.0349	0.203
H × T	1	0.040404	0.055608	0.846	0.820	2.0666	1.4279	0.277
M × Si(H)	6	1.4645	1.3757	0.235	0.241	0.67511	0.41942	0.867
T × Si(H)	6	0.7259	0.6819	0.679	0.663	1.4469	0.89892	0.517
M × H × T	1	0.040404	0.18767	0.680	0.676	0.23619	0.13406	0.738
M × T × Si(H)	6	0.21355	0.20061	0.975	0.972	1.7622	1.0948	0.375
Res	62	1.0645			1.6096			
Total	93							

ables temperature (2.2%), rugosity (2.2%), northness (1.9%), curvature (1.4%) and eastness (0.9%) made minor contributions to the variation explained.

The results of the DISTLM routine were represented in a dbRDA with an overlay displaying correlated variables with a Pearson correlation value (|r| ≥ 0.4; Fig. 7a). Raw Pearson correlations were used to determine which environmental variables were represented by the dbRDA axis (Table 7). Mean depth was negatively correlated with the first axis (r = –0.99), while temperature was positively correlated with the second axis (r = 0.92). In the first axis, mean

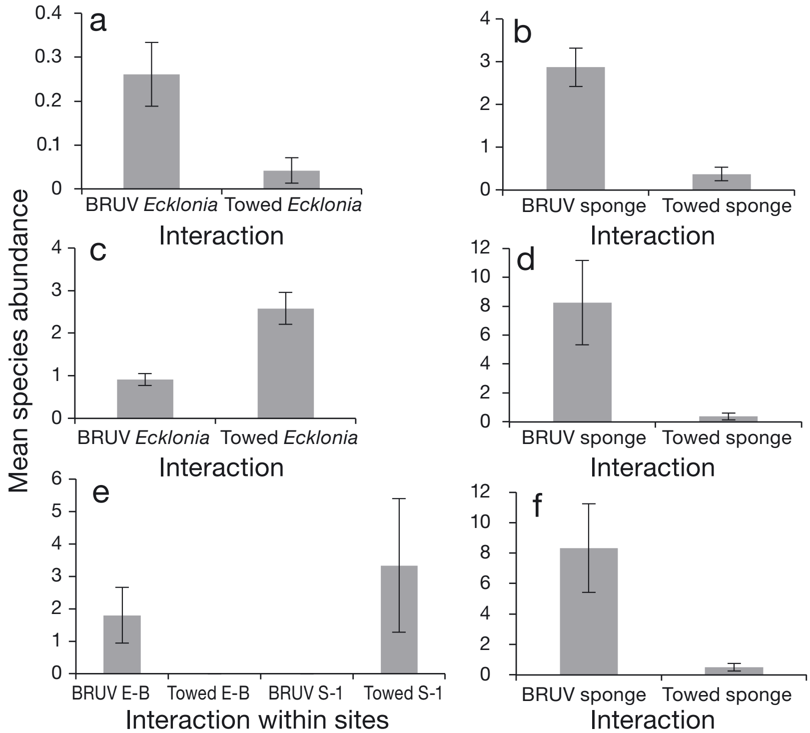

Fig. 4. Mean (±SE) relative abundances of species detected by each method (BRUV or towed video) in each habitat type (*Ecklonia radiata* or sponge dominated) showing (a) *Meuschenia freycineti* displaying significant difference in method, (b) *Meuschenia scaber* displaying significant method by habitat interaction, (c) *Olisthops cyanomelas* displaying significant method by habitat interaction, (d) *Chrysophrys auratus* displaying significant method by habitat interaction, (e) *Dinolestes lewini* displaying significant method by site (habitat) interaction, and (f) demersal invertivores displaying a significant method by habitat interaction

Table 6. Total fish and percentage of successful measurements for stereo-BRUV and towed video for the second survey in both habitats

Method	Habitat	Total measurements	Total fish observed	Percentage measured (%)
Stereo-BRUV	Sponge	700	721	97.1
	Ecklonia radiata	63	155	40.6
	Total	763	876	87.1
Towed video	Sponge	83	133	62.4
	Ecklonia radiata	84	187	44.9
	Total	167	320	52.2

depth created a separation of species abundance between habitats. In the second axis, temperature had differentiated deployments by time of survey.

Separate DISTLM analyses were conducted for deployments in sponge and *E. radiata* habitats. The variables used in the analysis explained a total of 11.7 and 14.7% of total variation, respectively (Fig. 7b,c). Stereo-BRUV observations in sponge habitat revealed that no environmental variable was significant in explaining variation in the fish assemblage. However, the dbRDA figure revealed a separation of samples displayed by temperature, which was positively correlated with the second axis (r = 0.62; Table 7). Northness was statistically significant for stereo-BRUV in *E. radiata* and negatively correlated (r = –0.52; Table 7) with the second axis of the dbRDA (Fig. 7c).

A DISTLM for all species observed in towed video explained 44.5% of the total variation in the assemblage composition and is attributed to mean depth (44.3%) and rugosity (38.3%), both of which were significant (Fig. 8a). While remaining variables temperature (4.0%), eastness (3.0%), northness (1.8%) and curvature (1.4%) only explained a small portion of variability in the presence of fish observed.

DISTLM results were represented in a dbRDA with an overlay displaying correlated variables with a Pearson correlation value (|r| ≥ 0.4; Fig. 8a). However, as with stereo-BRUV deployments within habitats, mean depth was not significant for towed video deployments. Sponge habitat environmental variables explained a total of 17.5% of variation. Temperature was significant, explaining 10.9% of variation; this influence is reflected in the dbRDA analysis by separating survey times (Fig. 8b, Table 7). The variables northness and mean depth only explained very small portions of variation (8 and 7%, respectively). Within the *E. radiata* habitat, the same variables explained a total of 11.3% of variation. No environmental variables were found to significantly influence fish presence (Fig. 8c, Table 7).

Statistical power

The power to detect changes in species richness was found to be higher in stereo-BRUV than towed video for both sponge-dominated and *E. radiata*-dominated habitats (Fig. 9a,b). Within the *E. radiata*-dominated habitat, stereo-BRUV had better statistical power for functional group richness than towed

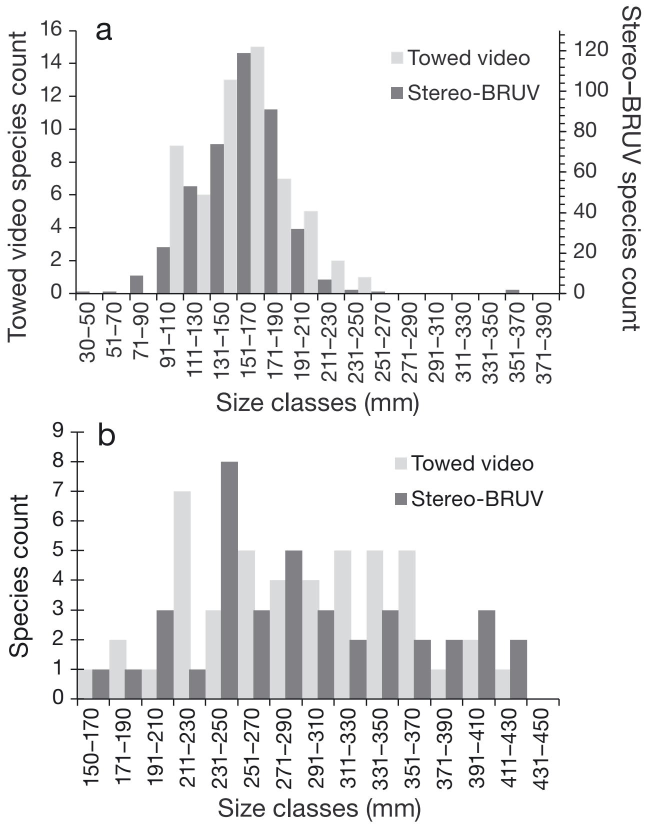

Fig. 5. Length frequency histograms comparing towed video and stereo-BRUV measurement data. (a) Size frequencies for *Caesioperca* sp. observed by towed video and stereo-BRUV. (b) Size frequencies for *Notolabrus tetricus* observed by towed video and stereo-BRUV

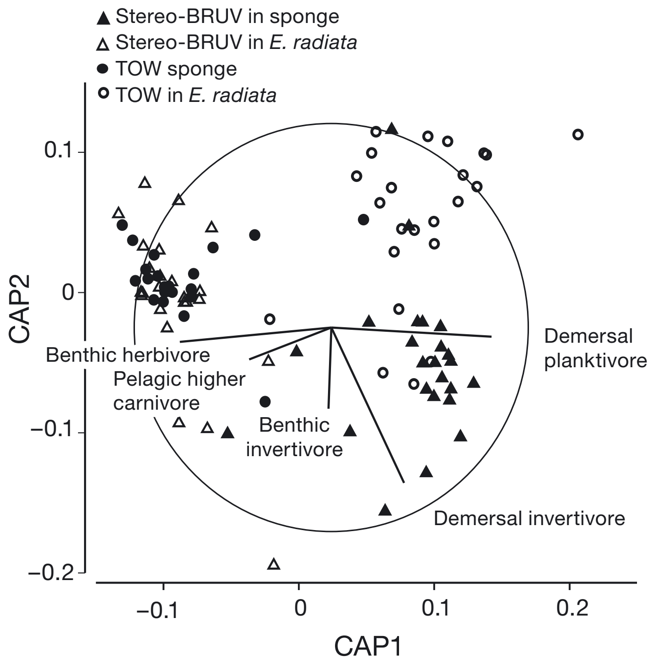

Fig. 6. Canonical analysis of principal coordinates (CAP) ordination based on Bray-Curtis dissimilarity for fish functional groups abundance, displaying the interaction between method (stereo-BRUV or towed video [TOW]) and habitat (*Ecklonia radiata* or sponge dominated). Highly correlated (Pearson's r > 0.4) species are represented as vectors in an overlay. The direction and length of the vectors on the overlay represent the strength and direction of the relationship

Table 7. Stereo-BRUV and towed video with combined habitats and for separate habitats (*Ecklonia radiata* or sponge dominated). Pearson correlations of how environmental variables influence fish species with 2 distance-based redundancy analyses (dbRDA) axes

Variable	Temperature	Northness	Curvature	Mean depth	Eastness	Rugosity
Stereo-BRUV in across both habitats						
dbRDA1	0.054	−0.009	0.085	−0.994	−0.018	−0.031
dbRDA2	0.918	−0.261	0.168	0.058	0.076	0.23
Stereo-BRUV in sponge habitat						
dbRDA1	0.42	−0.553	−0.381	−0.324	0.025	−0.516
dbRDA2	0.616	0.707	0.004	−0.297	0.169	−0.065
Stereo-BRUV in *E. radiata* habitat						
dbRDA1	0.568	−0.517	0.229	−0.589	−0.069	0.073
dbRDA2	−0.268	0.112	0.752	−0.151	0.156	−0.55
Towed video across both habitats						
dbRDA1	−0.019	−0.026	−0.053	0.997	0.032	0.024
dbRDA2	0.85	−0.248	0.016	0.02	−0.431	0.174
Towed video in sponge						
dbRDA1	−0.757	0.333	−0.275	0.082	0.298	−0.38
dbRDA2	−0.085	−0.411	0.031	0.879	0.185	0.122
Towed video in *E. radiata*						
dbRDA1	0.435	0.137	0.063	−0.721	−0.502	−0.13
dbRDA2	0.205	−0.934	−0.211	−0.038	0.002	−0.198

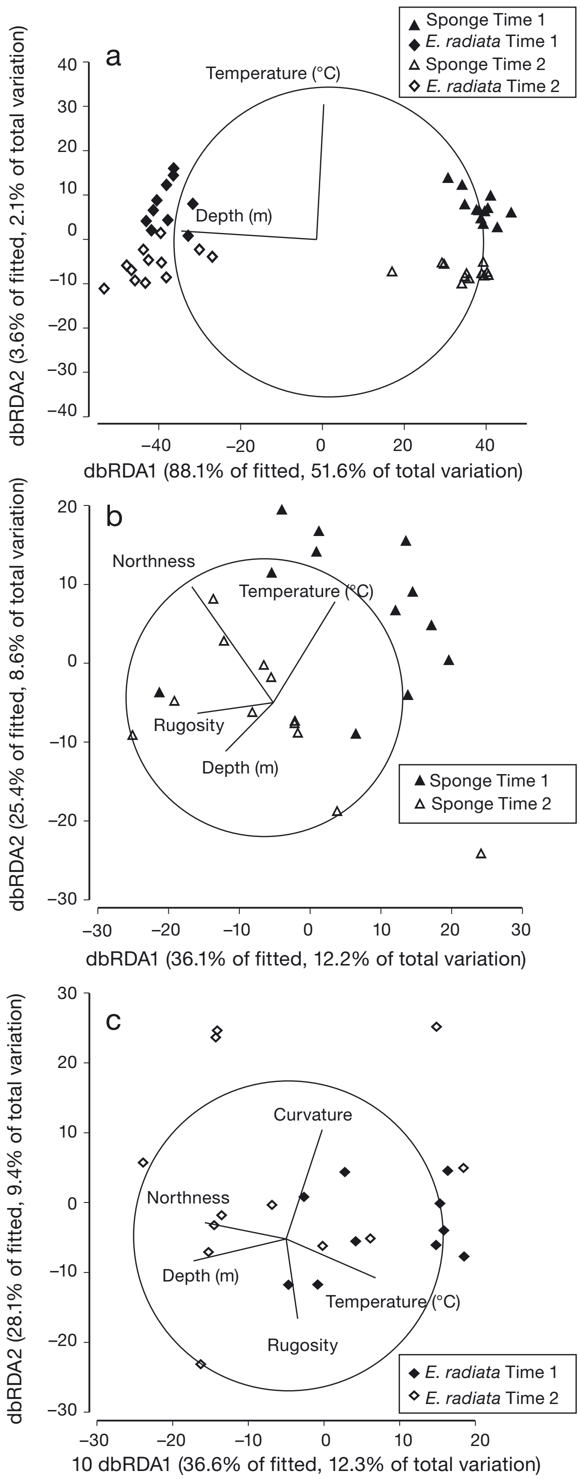

Fig. 7. Distance-based redundancy analysis (dbRDA) displaying results of the stereo-BRUV species abundance distance-based linear model multivariate analysis (DISTLM), with symbols displaying habitat (*Ecklonia radiata* or sponge dominated) by time. The direction and length of the vectors on the overlay represent the strength and direction of the relationship. (a) Combined BRUV across both habitats; (b) stereo-BRUV in sponge; (c) stereo-BRUV in *E. radiata*

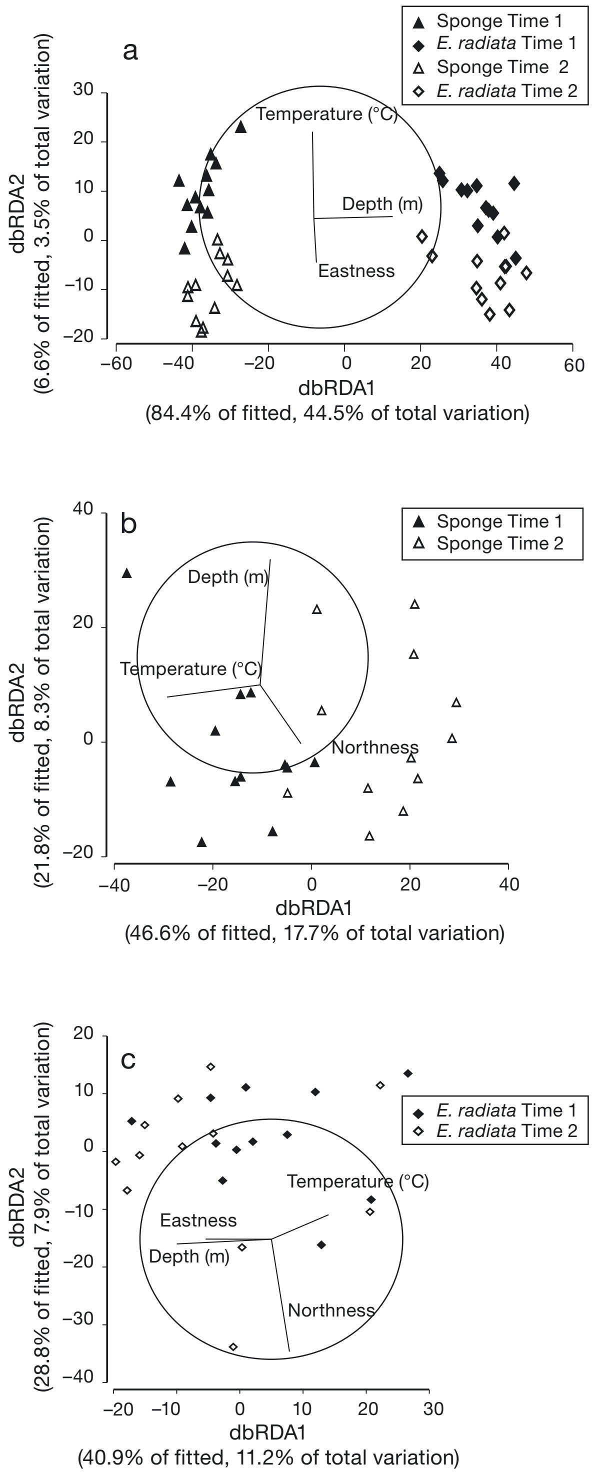

Fig. 8. Distance-based redundancy analysis (dbRDA) displaying results of the towed video species abundance distance-based linear model multivariate analysis (DISTLM), with symbols displaying habitat (*Ecklonia radiata* or sponge dominated) by time. The direction and length of the vectors on the overlay represent the strength and direction of the relationship. (a) Combined towed video data for both habitats; (b) towed video in sponge; (c) towed video in *E. radiata*

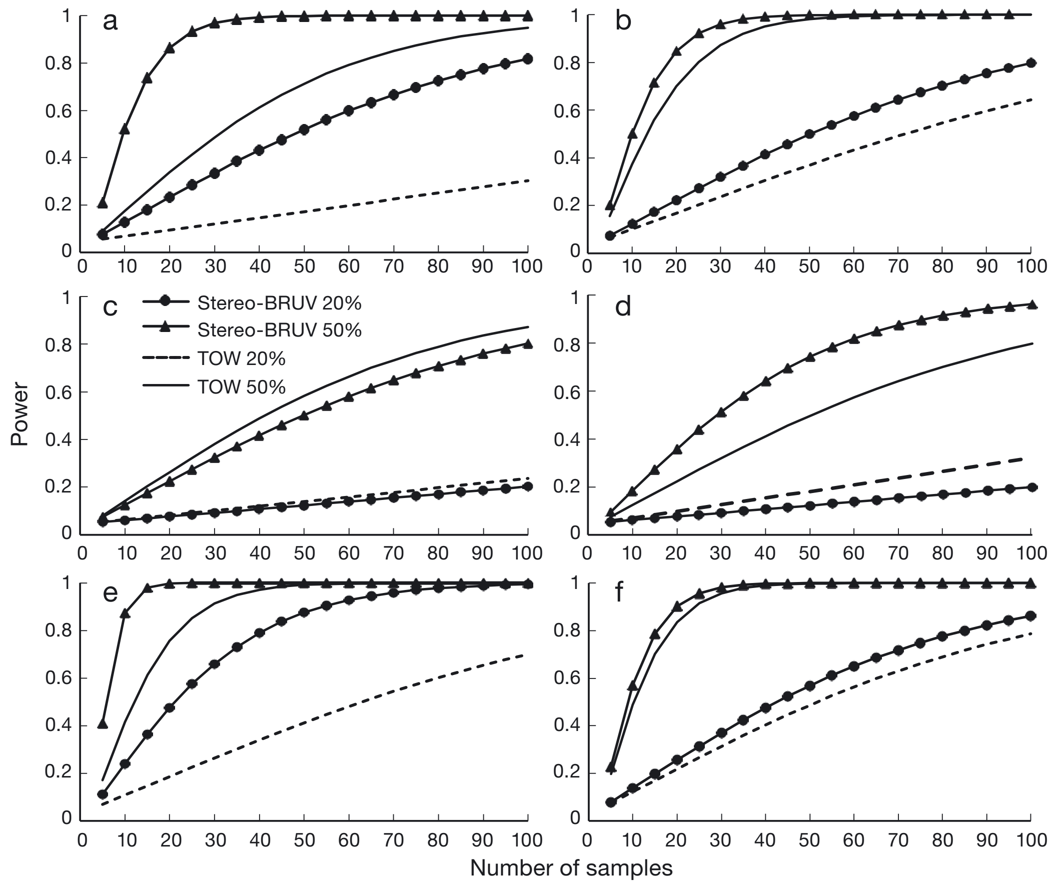

Fig. 9. Power analysis for stereo-BRUV and towed video to detect 20 and 50% increases for species richness in (a) sponge and (b) *E. radiata* habitats, functional group richness in (c) sponge and (d) *E. radiata*, and total individuals in (e) sponge and (f) *E. radiata* based on significance criterion of 0.05

video (Fig. 9d). However, towed video had higher statistical power than stereo-BRUV in sponge-dominated habitat (Fig. 9c). Power analyses determined that stereo-BRUV had greater statistical power than towed video across both habitats when detecting the total number of individuals, with the difference in power being significantly greater in the sponge-dominated habitat (Fig. 9e,f).

DISCUSSION

Comparing MaxN to count abundance used for methods such as towed video, UVC and diver operated video (DOV) involves numerous complexities (due to associated biases), and multiple assumptions are made when comparing these abundance measures (Watson et al. 2005). However, it is important for new methods such as stereo towed video to be compared against more common techniques as it is the best available way to gauge or calibrate the performance of the method (Cappo et al. 2003, Stobart et al. 2007, Lowry et al. 2012). There have been multiple studies that have compared both of these abundance measures against each other. Watson et al. (2005) compared total number of individuals between stereo-BRUV, DOV, and remote underwater video (RUV) and found that the remote video techniques observed greater abundance of the common labridae species, but DOV recorded greater abundances of cryptic species. Lowry et al. (2012) compared abundance measures between BRUV and UVC and found that UVC recorded a greater number of individuals than BRUV.

The significant difference in fish assemblages observed between stereo-BRUV and towed video in this study illustrates the importance of sampling technique choice and understanding their biases. It is possible to alter the interpretation of fish assemblage data due to differences in detectability and biases between approaches (Williams et al. 2015). Since shelf temperate marine ecosystems exhibit a high degree of heterogeneity in benthic habitats (Anderson 1994), it is also important to understand how differing habitat types influence fish survey methods. While numerous studies exist that quantify the differences between fish survey methods (Willis & Babcock 2000, Cappo et al. 2004, Harvey et al. 2004, Morrison & Carbines 2006, Watson et al. 2010), this study represents the first to explicitly assess how 2 video methods differ in the detection of temperate marine fishes in relation to variation in seafloor habitat. Whilst accounting for seabed structure, light and temperature, we found that a combination of stereo-BRUV and towed video provided a more comprehensive view of fish assemblages in both *Ecklonia radiata* and sponge habitats than either method alone.

Differences in fish assemblage observed between the 2 methods are due to a number of operational differences, including the presence or absence of bait, variations in survey time, and the stationary or mobile nature of the survey technique. Higher species abundance and diversity were observed in stereo-BRUV compared to towed video due to bait, in agreement with previous studies (Willis & Babcock 2000). For example, elasmobranches were observed in higher abundances in stereo-BRUV deployments, suggesting that bait is causing their higher abundances compared to other visual census techniques (Harvey et al. 2007). Additionally, *Meuschenia* spp. and snapper *Chrysophrys auratus* were also observed in higher abundances in stereo-BRUV footage in comparison to towed video, again most likely due to their attraction to bait plumes, as they were observed actively feeding on bait bags during stereo-BRUV deployment. *Chrysophrys auratus* displayed avoidance behaviour to vessel noise and/or the towed system, which has previously been observed (Sarà et al. 2007, Stoner et al. 2008, Popper & Hastings 2009). We note that our results contrast with those of Morrison & Carbines (2006), who found that towed video was more effective at measuring abundances of *C. auratus* than BRUV; however, their study was conducted at night where they observed *C. auratus* sleeping inert on the seafloor, and thus avoidance was not observed. This nocturnal behaviour of *C. auratus* was also observed by Hartill et al. (2003) in a harbour environment.

This research is the first to compare the lengths of fish in observations between stereo-BRUV and stereo towed video. Fish length measurements for *Caesioperca* sp. and *N. tetricus* are comparable between methods. However, the ability of each method to obtain measurements within each habitat varied. In the sponge habitat we found the static nature of stereo-BRUV allowed more successful measurements to be made as fish swam into the field-of-view. The lower percentage of fish measurements for towed video is possibly due to its mobility, which limits the time fish are in the field-of-view and the aversion behaviour observed (Sarà et al. 2007, Stoner et al. 2008, Popper & Hastings 2009). Additionally, fish were often observed in the edges of the towed video field-of-view, in which measurements with acceptable precision were rarely achieved. However, the spatially explicit size measurements provided from towed video can offer the opportunity to understand ontogenic and sex-based preferences across habitats. The decrease of measurement success within *E. radiata* habitat across both methods is likely due to the obscuring of fish caused by the dense canopy-forming macroalgae (Langlois et al. 2017). Further research is required to understand how biases influence measurements from both of the methods across a broader range of species.

In our study, stereo-BRUV and towed video techniques were shown to display higher abundances of particular functional groups. Demersal invertivores and pelagic planktivores were represented in higher abundance in stereo-BRUV than towed video. It is likely that stereo-BRUV observed more species belonging to these functional groupings due to its use of bait (Harvey et al. 2007, Watson et al. 2010). Therefore, as expected, benthic herbivores were represented in higher abundances in towed video observations compared to stereo-BRUV. These fish species are likely to have little to no attraction to the stereo-BRUV deployments, and remain in other parts of the habitat. It is expected that towed video will observe more of fish of this functional group as it can easily observe larger sections of the habitat due to its mobility.

Towed video recorded higher abundances of species that displayed territorial and cryptic behaviour. The footage from the mobile towed video system covers a larger geographical area than the stationary stereo-BRUVs, which increases the chances of towed video passing through multiple territories and observing higher abundances of these species. This could explain why towed video is more statistically powerful for total number of species in the invertebrate-dominated habitat, as it is able to observe areas of refuge. Therefore, it is possible that towed video in *E. radiata*-dominated habitats was unable to view more species that exhibit these characteristics due to obstruction from the macroalgae canopy in the field-of-view. However, towed video detected slightly more individuals within this habitat than stereo-BRUV, whilst stereo-BRUVs observed significantly more species in sponge habitat. The ability of stereo-BRUVs to observe species in *E. radiata* habitat may have been reduced due to infrequent occurrences of its field-of-view being partially smothered by the dominant macroalgae *E. radiata* for a whole deployment. Langlois et al. (2017) found similar issues when conducting stereo-BRUVs in *E. radiata*, with deployments omitted if over 90% of the field-of-view was smothered. The ability of a towed video system to remain above the thick macroalgae canopy showed advantages in fish detection compared to BRUVs in this study and applicability in other localities across different canopy structures should be explored.

The importance of depth in structuring fish assemblages has been noted previously (Anderson & Millar 2004, Yeh & Drazen 2009, Moore et al. 2010, Zintzen et al. 2012, Parsons et al. 2016). Depth is correlated with many other environmental variables that could affect the distribution of fish assemblages, including characteristics such as light attenuation and reductions in wave exposure (Smale et al. 2011 and references therein). Rugosity also contributed a significant explanation of fish assemblage variability when using towed video. This particular physical variable, at various scales, has previously been deemed important for explaining and modelling a variety of fish species (Friedlander & Parrish 1998, Monk et al. 2011, Cameron et al. 2014). However, the significant influence of rugosity was lost when analysing methods in each habitat, potentially due to too few samples.

The large portion of unexplained variation is potentially due to high natural variability in visual fish counts (Edgar et al. 2004) or to variables that were not measured in this study. The benthic biological community can also influence resident fish assemblages. Herbivorous species were far more abundant in *E. radiata* in our study. Fish assemblage composition is often correlated with the type of macroalgae present (Harman et al. 2003).

Stereo-BRUV is a powerful tool often used for assessing changes in targeted fish or whole assemblages on temporal and broad-spatial scales (Cappo et al. 2000). Watson et al. (2010) recommended BRUVs to be deployed at least 250 m apart to ensure spatially independent areas of attraction. However, there is uncertainty regarding the extent of the bait plume, and the area of attraction may differ between deployments due to localised hydrodynamics. Despite restricting observations to relative abundance, inclusion of bait could explain why the BRUV had greater statistical power for detecting species richness, total individuals and functional groups across both habitats (with the exception of total individuals), by actively attracting species. In comparison, towed video does allow the estimation of fish density, with the additional advantage that individual fish observations can be geolocated along the video track using acoustic positioning employed (Rattray et al. 2014). Towed video also allows the characterisation of patterns across transitional zones. An additional advantage is that geo-referenced fish locations and detailed habitat information can be combined to develop species distribution models (Guisan & Zimmermann 2000, Hirzel & Guisan 2002) and contribute to spatial and ecosystem-based management approaches.

When choosing which video technique to use to survey fish assemblages, it is important to consider the costs, time and efforts required to obtain and analyse the footage. In our study, stereo-BRUVs and towed video considerably differed in field survey time and video analysis effort. The major operational advantage of stereo-BRUVs was the ability to deploy multiple frames simultaneously, greatly increasing survey efficiency. However, towed video presented the advantage of allowing operators to adjust sampling procedures based on the footage received in 'real time' from a live-feed, while the quality (or lack thereof) of the footage in stereo-BRUV could only be discovered after the deployment ended. In this study, the towed video surveying required 3.5 d to collect 12 h of footage, while stereo-BRUV deployments required 3 d to collect 46 h of footage. However, processing the video for stereo-BRUV took considerably longer (92 h) than towed video (12 h), with the rate of video data analysis for stereo-BRUV footage twice as long as towed video data analysis processing. These results are particularly important for researchers to consider while deciding which video survey technique to use to collect and analyse data; however, analysis time is likely to differ based on habitat characteristics and fish density observed.

Our study demonstrated that stereo-BRUV and towed video have distinct advantages and biases. Stereo-BRUV allowed us to observe a more diverse and abundant fish assemblage, particularly in sponge habitat, using a highly efficient survey deployment procedure. However, bait alters fish behaviour and condenses their abundances, making density estimates difficult due to the challenges associated with quantifying the dispersal of bait plumes. Towed video was a useful technique for examining both benthic herbivores and territorial species due to the larger geographical area it was able to observe. However, field surveys using this method typically take much longer than stereo-BRUV due to only a single unit being deployed.

Surveys targeting a single species should determine the most effective sampling method based on the biases discussed in this paper and other comparative studies. However, the biases associated with each technique and the variations in habitat indicate that there is no optimal method for assessing the whole fish assemblage. Instead, a combination of techniques should be used for fish assemblage studies where possible.

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