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Comparison of the relative efficiencies of stereo-BRUVs and traps for sampling tropical continental shelf demersal fishes

Euan S. Harvey[a,*], Stephen J. Newman[b], Dianne L. McLean[a,c], Mike Cappo[d], Jessica J. Meeuwig[e], Craig L. Skepper[b]

[a] The UWA Oceans Institute and School of Plant Biology, Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley, 6009 Western Australia, Australia
[b] Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Government of Western Australia, P.O. Box 20, North Beach, WA 6920, Australia
[c] Mindabbie Marine Consulting, 37 Baal St, Palmyra, WA 6157, Australia
[d] Australian Institute of Marine Science, PMB 3, Townsville MC, QLD 4810, Australia
[e] The UWA Oceans Institute and Centre for Marine Futures, Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley, 6009 Western Australia, Australia

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ABSTRACT

The sampling efficiencies of commercial standard fish traps and baited remote underwater stereo-video systems (stereo-BRUVs) were compared by examining the diversity and relative abundance of tropical demersal fish that each method sampled on the north-western shelf (40–60 m) of Western Australia. Stereo-BRUVs recorded many more species (91 species from 32 families) than commercial fish traps (30 species and 15 families). Stereo-BRUVs also sampled many more individuals (mean 36.55 ± 5.91 SE) than fish traps (mean 12.30 ± 1.40 SE). This suggests stereo-BRUVs would be more capable of detecting changes in the relative abundance of species over time. Data from four commercially important species (*Epinephelus bilobatus, Epinephelus multinotatus, Lethrinus punctulatus* and *Lutjanus russelli*) revealed that stereo-BRUVs had much greater statistical power to detect change than an equivalent number of samples from fish traps. In contrast, fish traps had a greater statistical power to detect change for a fifth target species, *Lutjanus sebae*. For two commonly sampled species, *Abalistes stellatus*[1] and *Lethrinus punctulatus*, stereo-BRUVs sampled a smaller mean length than fish traps while for a third species, *Lutjanus sebae*, stereo-BRUVs recorded a larger mean length. The length frequencies for these species were not significantly different between methods, although stereo-BRUVs sampled a much larger range of lengths than was captured in traps. This study demonstrates that stereo-BRUVs are potentially a much more powerful technique than fish traps for assessing species richness, relative abundance and size structure in multi-species fisheries in north-western Australia.

1. Introduction

In many parts of the world, assessments for the sustainable management of tropical multi-species demersal finfish fisheries rely primarily on industry catch records (Hilborn and Walters, 1992). These assessments rely heavily on assumptions about the catchability of the individual species relative to the fishing gear used. In the limited entry Northern Demersal Scalefish Fishery (NDSF) in north-western Australia, a small number of boats use fish traps to capture a diverse suite of tropical demersal fish species (Newman et al., 2010). It is not known, however, whether the fish traps that are used in this fishery selectively catch certain species, or sizes of individuals over others. Fishery independent provision of such knowledge would enable assessment of the impact of this fishery on the structure of tropical demersal fish assemblages.

The introduction of Ecosystem-Based Fishery Management (EBFM) and Ecological Sustainable Development (ESD) approaches into Fishery Management Plans in Western Australia (Fletcher, 2006; Fletcher et al., 2005, 2010; Norse, 2010) has meant that fisheries managers need to be informed about the effects of fishing, not only on the target species, but also the non-target species and on biodiversity in general. In response, there has been interest in applying fishery-independent remote baited video systems to survey fish assemblage structure. This follows recent success in the application of this technique in assessing the effects of protection from fishing in Western Australia (e.g. Watson et al., 2007, 2009). Elsewhere, remote baited video systems have also proven useful in tackling sampling limitations imposed by depth, fish behaviour, seafloor rugosity and the selectivity inherent in hook, trap and trawl

[1] Usage follows CAABcodes (Rees, A.J.J., Yearsley, G.K., Gowlett-Holmes, K. and Pogonoski, J. Codes for Australian Aquatic Biota (on-line version). CSIRO Marine and Atmospheric Research, World Wide Web electronic publication, 1999 onwards. Available at: http://www.cmar.csiro.au/caab/.).

* Corresponding author. Tel.: +61 8 6488 2416.
E-mail address: euan.harvey@uwa.edu.au (E.S. Harvey).

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methods (e.g. Priede et al., 1994; Willis and Babcock, 2000; Cappo et al., 2007; Harvey et al., 2007; Murphy and Jenkins, 2010). The technique offers standardised, non-extractive methodologies for estimating the relative abundance of a range of marine fish (Cappo et al., 2003; Watson et al., 2005, 2010; Harvey et al., 2007; Langlois et al., 2010). When stereo-camera pairs are used, very precise and accurate length and biomass estimates are possible (Harvey and Shortis, 1996; Harvey et al., 2001a,b, 2002a,b, 2010; Watson et al., 2009). There have been few studies which compare traditional fisheries sampling techniques with these novel video based techniques in shelf waters (but see Willis et al., 2000; Cappo et al., 2004; Stoner et al., 2008; Wells et al., 2008). It is essential to understand how these new techniques perform in comparison to other sampling methods, such that any biases in sampling may be evaluated and used in assessing stock status and also how these new data may be incorporated into EBFM and ESD management and reporting arrangements.

Commercial fish traps are set to catch fish both diurnally and nocturnally. The use of fishery independent video techniques for nocturnal sampling necessitates the use of either artificial lighting to illuminate the field of view or very low light cameras that do not require lighting. The scant evidence that is available suggests that the eyes of many shallow water nocturnal fishes will be able to detect light between 487 and 575 nm (Lythgoe and Partridge, 1991; Lythgoe et al., 1994). Similar evidence exists from a comparative study in deep water (Raymond and Widder, 2007), which suggests that red light above 600 nm decreases the disturbance of lighting. In controlled laboratory experiments Ryer et al. (2009) demonstrated that white light had a variable influence on fish behaviour and detectability and that this varied with the intensity and proximity of the light. Azzuro et al. (2007) used a white light for surveying shallow nocturnal reef fishes via divers while Bassett and Montgomery (2011) used infra red light with a baited video because of behavioural concerns about white light. The selection of which lighting type to use must therefore carefully consider the potential responses of species and any bias this may cause. It must however, be balanced with logistical constraints and concerns. Both infrared, and red lighting are known to attenuate quickly in water (~1.2 m and 3 m respectively) with a greatly restricted field of view in comparison to white light.

The objectives of this study were to investigate the sampling efficiencies of fish traps and baited remote underwater stereo-video systems (stereo-BRUVs). In particular, we focused on comparing whether these two gear types sampled similar fish assemblages from a fishery perspective. We compared the species richness, the relative abundance, the mean length and length frequency of key target and non-target species between techniques. To quantify sampling efficiency, we calculated the statistical power of each technique to detect change at three different effect sizes for a number of target species. We have calculated the statistical power for target species only as they usually have lower relative abundances and greater variability than non-target species. For example, sampling programs on reefs have had lower power to detect change amongst predatory, target species than amongst more common, but unfished, herbivores (Langlois et al., 2010). In addition, this study aimed to obtain preliminary data about how red and white light illumination affected the nocturnal fish assemblages sampled in tropical north-western Australia.

2. Methods

2.1. Study area

Sampling was conducted off the Kimberley Coast, Western Australia (Fig. 1) aboard the *RV Naturaliste* from 29 June to 4 July 2006, in depths of 45–60 m in an epibenthic habitat characterised by sandy, rubble areas with a range of sponges and soft corals. Data were recorded from 69 stereo-BRUVs and 66 trap deployments. Forty-two stereo-BRUVs were deployed during the day and 27 at night. Of the night deployments, 13 used red light and 14 used white light illumination. Thirty-six traps were deployed during the day and 30 during the night. Of the night set traps, 9 used red light and 21 used white light illumination.

Traps and stereo-BRUVs were randomly deployed within the sampling area (see Fig. 1) with a minimum distance of 500 m between any trap and any stereo-BRUV system. Traps and stereo-BRUVs were equally distributed as was practicable across the different sub-habitat types. During night time only one set was completed due to statistical constraints.

2.2. Sampling techniques

2.2.1. Stereo BRUVS

Sampling was conducted using six stereo-BRUVs. Descriptions of the design of the stereo-video cameras, the stereo-BRUV system, measurement and calibration procedures are detailed in Harvey and Shortis (1996, 1998) and Watson et al. (2005). Each unit consisted of two Sony HC15 digital camcorders within waterproof housings. For nocturnal sampling the cameras were set to a night shot recording mode and fitted with either white or red lights. Bait arms, 1.5 m in length and made of 20 mm plastic conduit with a plastic coated wire bait canister fastened to one end, were attached to the stereo-video frame. For each deployment we used 1 kg of crushed pilchards (*Sardinops sagax*), placed in the bait bag. The stereo-BRUVs were retrieved after recording for 1 h at each station. One-hour deployments were selected as this was the maximum recording time for standard Mini Digital Video tapes at the time of this study.

2.2.2. Fish traps

The fish traps were the commercial standard used in the NDSF (see Newman et al., 2011). Traps were essentially rectangular with rounded corners measuring 600 mm in height, 1500 mm in length and 1200 mm in width, and were covered by 50 mm square steel mesh, apart from the side that contained the entrance of the trap. The width of the vertical entrance to the trap was 600 mm × 200 mm, tapering to 600 mm × 100 mm internally. The traps were baited using 1 kg of crushed pilchards (*S. sagax*) placed in a mesh box and left to soak for 3 h. The longer sampling time for fish traps (3 h vs. 1 h by stereo-BRUVs) was not considered an issue for the present study as we wished to compare the ability of each technique when used under 'typical' conditions.

2.2.3. Lights

Stereo-BRUVs and traps deployed at night were fitted with either white or red lights. For white lights we attached 2 Pelican SabreLite® dive torches fitted with diffusers to each trap or stereo-BRUV system. The red lights consisted of a waterproof housing containing a rechargeable battery unit and three red lights. Each red light contained a bank of twenty-five 630 nm LEDs. On the stereo-BRUVs the red lights were attached to the frame, one in the centre, and the other two to the far right and left sides of the top crossbar. Lights were set in a similar manner on the traps facing the entrance.

The white lights (550 nm) illuminated an area up to 5 m from the stereo-BRUVs while the red lights (620 nm) only 3 m. It should be noted that commercial fishers on the North West Shelf of Australia do not use lights on traps when they fish nocturnally, however it is probable that the use of white light may attract juvenile fish and crustaceans which in turn could increase the numbers of fish around both the stereo-BRUVs and traps.

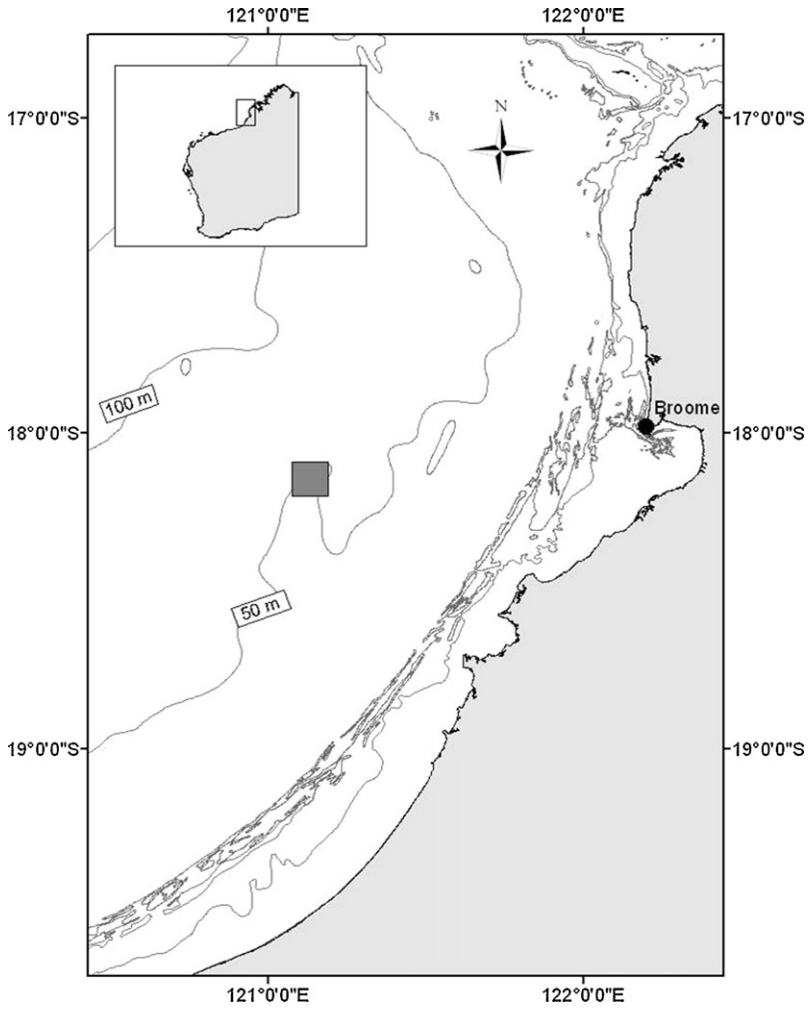

Fig. 1. Location of the study area where stereo-BRUVs and fish traps were set in the Northern Demersal Scalefish Fishery off the Kimberley coast of north-western Australia.

2.3. Data collection

Stereo-BRUVs: Interrogation of each tape was conducted using a custom interface (BRUVS1.5.mdb©, Australian Institute of Marine Science 2006) to manage data from field operations and tape reading, to capture the timing of events and to capture reference images of the seafloor and fish in the field of view. For each species we recorded the time of first sighting, time of first feeding at the bait, the maximum number seen together in any one time on the whole tape (*MaxN*), time at which *MaxN* occurred, and any intra-specific and inter-specific behaviour. *MaxN* is considered a conservative estimator of the relative abundance of a species (Willis et al., 2000) and its use has been reviewed in detail by Cappo et al. (2003, 2004). We used PhotoMeasure software (www.seagis.com.au) to measure the fork length of fish at the time of *MaxN*.

Traps: Fish caught in the traps were immediately identified, counted and the fork lengths of individuals measured to the nearest millimetre.

2.4. Statistical analyses

2.4.1. Fish abundance

We used a two-way non-parametric multivariate analysis of variance (PERMANOVA; Anderson, 2001; Anderson and Robinson, 2003; Anderson et al., 2008) to test for differences in the fish assemblages sampled by stereo-BRUVs and traps (Technique, fixed) and to compare diurnal and nocturnal samples (Diel, fixed). A Modified Gower Log base 10 dissimilarity measure (Anderson et al., 2006) was used. For Log base 10, an order of magnitude change in abundance is equal to a change in composition. For each term in the analysis we computed 4999 permutations of the raw data units to obtain *P*-values. Statistically significant terms in the model were explored using pairwise tests in PERMANOVA.

To visually compare the fish assemblages sampled by stereo-BRUVs and traps both during the day and at night under different lighting conditions, plots of the principal coordinates were constructed from a constrained Canonical Analysis of Principal Coordinates (CAP – Anderson and Robinson, 2003; Anderson and Willis, 2003). We used Spearman rank correlation *R* values greater than 0.3 or less than −0.3 to identify species influencing the pattern observed in the CAP plot (Anderson et al., 2008). We used the leave-one-out allocation test to provide a statistical estimate of mis-classification error and demonstrate how distinct groups of samples are in multivariate space (Anderson and Willis, 2003). We also tested for differences in the relative abundance of six important commercial species (*Epinephelus bilobatus*, *Epinephelus multinotatus*, *Lethrinus punctulatus*, *Lutjanus russelli, Lutjanus sebae* and *Plectropomus maculatus*), the numbers of individuals (calculated as the sum of $MaxN_i$ for stereo-BRUVs) and the total number of all fish species (*Nsp*) sampled by stereo-BRUVs and traps using permutational analysis of variance (Anderson and Millar, 2004). The data were analysed using the same two-factor model described above (4999 permutations) but used a Euclidean distance resemblance matrix (Anderson and Millar, 2004) on untransformed data.

For the initial analysis of differences between nocturnal and diurnal samples from stereo-BRUVs and traps we combined data from red and white light sources. We justify this as we believe any differences in the fish assemblages caused by lights would not be as great as the differences between sampling techniques or day vs. night. We also analysed for differences in samples collected by traps and stereo-BRUVs using red and white lights separately.

There were unequal sample sizes in the test for effects of lighting on species richness and abundance between techniques, and the responses showed strong over-dispersion with the variance proportional to the mean values. To allow robust estimation of fitted means and their 95% confidence intervals, we used general linear models and a Poisson family of error distributions, with log links and Type III sums of squares.

2.4.2. Power analysis

The statistical power of stereo-BRUVs and traps to detect changes in the abundance of six target species (*E. bilobatus*, *E. multinotatus*, *L. punctulatus*, *Lutjanus russelli, L. sebae* and *P. maculatus*) was calculated following Cohen (1988). For *L. russelli* we have calculated power on the nocturnal population. The power calculation requires estimates of means and variance along with a choice of α, and an effect size. Means and variance were calculated from the observed values for stereo-BRUVs and traps respectively. We have chosen to use a significance criterion of 0.05 and have calculated the numbers of samples required to detect effect sizes of 50%, 100% and 200% increase in the abundances of target species sampled by stereo-BRUVs or traps. A one-sided test was chosen, as mean values are typically so low as to make decreases undetectable.

2.4.3. Length comparisons

We tested for differences in the mean length and length frequency of the three most common species (*Abalistes stellatus*, *L. punctulatus* and *L. sebae*), which were caught by traps and also seen on stereo-BRUVs. We used only diurnal data for these comparisons to prevent any biases with diurnal variation and/or light source. To test for differences in the mean length we used a one-way Analysis of Variance using Minitab software. Differences in the length frequency data curves were assessed using a Kolmorgrov–Smirnoff (K–S) test with a significance criterion of 0.01 (Siegel, 1956).

3. Results

3.1. Fish assemblage description

The 69 stereo-BRUVs deployments sampled a total of 2522 fish (mean of 36.55 ± 5.91 SE) from 90 species (mean 8.96 ± 0.63 SE), compared to the 66 trap deployments that caught a total of 801 fish (mean of 12.30 ± 1.40 SE) from 30 species (mean 2.89 ± 0.20 SE). A large proportion of individuals observed on stereo-BRUVs were from the families Carangidae (25.6%), Lethrinidae (20.0%) and Nemipteridae (16.8%, Fig. 2a). The presence of a carangid (*Atule mate*) schooling in the hundreds on several occasions (200 individuals recorded on two occasions) increased the numbers of fish observed on the stereo-BRUVs by 16%. Exclusion of this species caused the proportion of individuals recorded in the family Carangidae by stereo-BRUVs to drop to 9% and numbers of fish to fall from 2522 to 2121. The remaining 27% of the fish observed belonged to 29 families (Fig. 2a).

The majority of all individuals caught in fish traps were from Lethrinidae (58.0%) or Lutjanidae (24.4%) (Fig. 2b). Five of the 30 species caught in traps (16%) were not observed on stereo-BRUVs, whilst 65 of the 90 species recorded by stereo-BRUVs (72%) were not caught in the traps (Table 1). Stereo-BRUVs sampled many more species than the traps. The most ubiquitous included *Gnathanodon speciosus, Scomberomorus* spp., *Pentapodus nagasakiensis, Pentapodus paradiseus, Lethrinus olivaceous* and *Carangoides gymnostethus* (Table 1). Species sampled by traps only were not common and were often only represented by a single individual or from a single site (e.g. *Lutjanus erythropterus, Leiognathus* sp., *Myripristis botche, Myripristis melanostictus, Rhynchostracion rhinorhynchus*, Table 1).

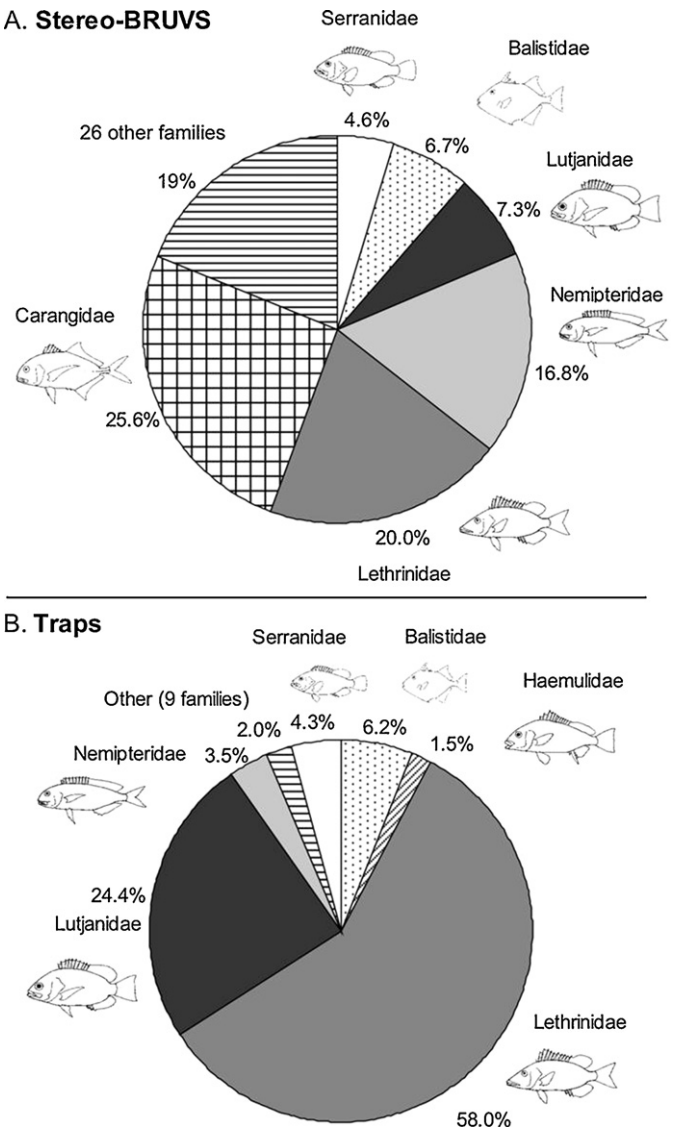

Fig. 2. Proportions of the total fish assemblage that different families of fish comprise according to sampling technique: (A) recorded by stereo-BRUVs and (B) caught in fish traps.

3.2. Fish assemblage comparisons

There were significant differences in the fish assemblages (relative abundance, *MaxN*, species richness) sampled by stereo-BRUVs and traps, and between those sampled nocturnally and diurnally. Additionally, a significant Technique × Diel interaction was recorded (Table 2). Pairwise comparisons of the interaction term show that there were significant differences between traps and stereo-BRUVs during the day ($t = 2.92$, P perm < 0.001), but not at night. There were also significant differences between stereo-BRUVs recorded at day and night ($t = 3.95$, P perm < 0.001), and between traps set at day and night ($t = 2.39$, P perm < 0.001).

These differences were demonstrated using a Canonical Analysis of Principal Coordinates (CAP, Fig. 3) with samples separated

Table 1
Relative abundances (mean ± 1 SE) of all fish species observed by stereo-BRUVs and captured in fish traps. Mean abundances are separated for day and night deployments and for each lighting technique ('–' indicates no individuals were observed/caught). Species responsible for driving the differences between nocturnal and diurnal assemblages recorded with traps and stereo-BRUVs (Spearman rank correlation *R* values greater than 0.3 or less than −0.3) are highlighted in bold.

Family	Genus species	Day		Night		Red light (night)		White light (night)	
		Stereo-BRUVs	Traps	Stereo-BRUVs	Traps	Stereo-BRUVs	Traps	Stereo-BRUVs	Traps
Acanthuridae	*Acanthurus auranticavus*	0.1 ± 0.06	–	–	–	–	–	–	–
	Acanthurus dussumieri	0.05 ± 0.03	–	–	–	–	–	–	–
	Acanthurus grammoptilus	0.19 ± 0.08	–	–	–	–	–	–	–
Apogonidae	*Apogon* sp.	2.14 ± 1.51	–	–	–	–	–	–	–
Balistidae	***Abalistes stellatus***	3.95 ± 0.38	1.36 ± 0.2	0.07 ± 0.05	–	0.08 ± 0.08	–	0.07 ± 0.07	–
	Sufflamen frenatus	0.05 ± 0.03	–	–	–	–	–	–	–
Caesionidae	*Pterocaesio chrysozona*	1.19 ± 1.19	–	–	–	–	–	–	–
Carangidae	*Atule mate*	9.55 ± 6.65	–	–	–	–	–	–	–
	Carangoides fulvoguttatus	2.64 ± 1.23	–	–	–	–	–	–	–
	Carangoides gymnostethus	1.1 ± 0.53	–	–	–	–	–	–	–
	Carangoides sp	0.05 ± 0.05	–	–	–	–	–	–	–
	Caranx sexfasciatus	0.17 ± 0.17	–	–	–	–	–	–	–
	Caranx sp.	0.02 ± 0.02	–	–	–	–	–	–	–
	Gnathanodon speciosus	1.79 ± 0.7	0.03 ± 0.03	–	–	–	–	–	–
	Seriolina nigrofasciata	0.07 ± 0.04	–	–	–	–	–	–	–
Carcharhinidae	*Carcharhinus albimarginatus*	0.02 ± 0.02	–	–	–	–	–	–	–
	Carcharhinus amblyrhynchos	0.02 ± 0.02	–	–	–	–	–	–	–
	Carcharhinus plumbeus	0.02 ± 0.02	–	–	–	–	–	–	–
	Carcharhinus sp	0.02 ± 0.02	–	–	0.07 ± 0.07	–	–	–	0.1 ± 0.1
	Galeocerdo cuvier	0.07 ± 0.04	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
Chaetodontidae	*Chaetodon* sp.	0.02 ± 0.02	–	–	–	–	–	–	–
	Chelmon marginalis	0.05 ± 0.05	–	–	–	–	–	–	–
	Coradion altivelis	0.02 ± 0.02	–	–	–	–	–	–	–
	Coradion chrysozonus	0.02 ± 0.02	–	–	–	–	–	–	–
	Heniochus acuminatus	0.17 ± 0.09	–	–	–	–	–	–	–
	Parachaetodon ocellatus	0.02 ± 0.02	–	–	–	–	–	–	–
Dasyatidae	*Taeniura meyeni*	0.02 ± 0.02	–	0.19 ± 0.09	–	0.08 ± 0.08	–	0.29 ± 0.16	–
Echeneidae	*Echeneis naucrates*	0.45 ± 0.17	0.17 ± 0.17	–	–	–	–	–	–
Ephippidae	*Platax batavianus*	0.02 ± 0.02	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
	Platax teira	–	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
Epinephelidae	***Epinephelus bilobatus***	1.19 ± 0.31	0.26 ± 0.13	0.07 ± 0.05	0.13 ± 0.08	0.08 ± 0.08	–	0.07 ± 0.07	0.19 ± 0.11
	Epinephelus coioides	0.07 ± 0.05	0.03 ± 0.03	0.07 ± 0.05	–	–	–	0.14 ± 0.1	–
	Epinephelus multinotatus	0.55 ± 0.17	0.29 ± 0.12	0.33 ± 0.16	0.22 ± 0.1	0.08 ± 0.08	–	0.57 ± 0.29	0.29 ± 0.14
	Epinephelus tukula	–	–	0.04 ± 0.04	–	0.08 ± 0.08	–	–	–
Gerreidae	*Gerres filamentosus*	–	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
Grammistidae	*Diploprion bifasciatum*	0.07 ± 0.05	–	–	–	–	–	–	–
Haemulidae	*Diagramma labiosum*	0.24 ± 0.08	0.08 ± 0.05	0.19 ± 0.08	0.23 ± 0.2	0.15 ± 0.1	0.78 ± 0.66	0.21 ± 0.11	–
	Plectorhinchus gibbosus	0.57 ± 0.13	–	–	–	–	–	–	–
	Plectorhinchus polytaenia	0.02 ± 0.02	0.03 ± 0.03	–	0.03 ± 0.03	–	–	–	0.05 ± 0.05
Holocentrtidae	*Myripristis botche*	–	0.03 ± 0.03	–	–	–	–	–	–
	Myripristis melanostictus	–	0.03 ± 0.03	–	–	–	–	–	–
Labridae	***Choerodon cauteroma***	0.86 ± 0.11	0.03 ± 0.03	–	–	–	–	–	–
	Choerodon schoenleinii	0.02 ± 0.02	–	–	–	–	–	–	–
	Choerodon venustus	0.02 ± 0.02	–	–	–	–	–	–	–
	Dotalabrus aurantiacus	0.02 ± 0.02	–	–	–	–	–	–	–
	Labroides dimidiatus	0.12 ± 0.06	0.03 ± 0.03	–	–	–	–	–	–
	Leptojulis cyanopleura	0.48 ± 0.29	–	–	–	–	–	–	–
	Suezichthys cyanolaemus	0.02 ± 0.02	–	–	–	–	–	–	–
Leiognathidae	*Leiognathus* sp.	–	0.19 ± 0.19	–	–	–	–	–	–

Table 1 (*Continued*)

Family	Genus species	Day		Night		Red light (night)		White light (night)	
		Stereo-BRUVs	Traps	Stereo-BRUVs	Traps	Stereo-BRUVs	Traps	Stereo-BRUVs	Traps
Lethrinidae	***Gymnocranius grandoculis***	0.31 ± 0.08	0.03 ± 0.03	0.07 ± 0.05	–	0.08 ± 0.08	–	0.07 ± 0.07	–
	Gymnocranius sp.	0.02 ± 0.02	–	0.04 ± 0.04	–	0.08 ± 0.08	–	–	–
	Lethrinus amboinensis	0.02 ± 0.02	–	–	–	–	–	–	–
	Lethrinus genivittatus	0.12 ± 0.1	–	–	–	–	–	–	–
	Lethrinus lentjan	0.02 ± 0.02	0.03 ± 0.03	–	–	–	–	–	–
	Lethrinus olivaceus	1.12 ± 0.5	–	–	–	–	–	–	–
	Lethrinus punctulatus	7.52 ± 0.91	9.25 ± 1.5	2.63 ± 0.4	3.1 ± 0.79	3.23 ± 0.65	1.33 ± 0.7	2.07 ± 0.45	3.85 ± 1.07
	Lethrinus ravus	1.07 ± 0.34	0.83 ± 0.41	0.07 ± 0.05	0.03 ± 0.03	–	–	0.14 ± 0.1	0.05 ± 0.05
	Lethrinus rubrioperculatus	0.02 ± 0.02	–	–	–	–	–	–	–
Lutjanidae	*Lutjanus carponotatus*	–	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
	Lutjanus erythropterus	–	0.17 ± 0.17	–	–	–	–	–	–
	Lutjanus russelli	–	0.03 ± 0.03	1.33 ± 0.32	0.07 ± 0.05	1.85 ± 0.61	–	0.86 ± 0.23	0.1 ± 0.07
	Lutjanus sebae	1 ± 0.37	3.0 ± 0.8	2.04 ± 0.48	1.13 ± 0.34	2.15 ± 0.67	1.3 ± 0.97	1.93 ± 0.71	1.05 ± 0.29
	Lutjanus sp.	–	–	0.07 ± 0.07	–	–	–	0.14 ± 0.14	–
	Lutjanus vitta	0.14 ± 0.06	0.28 ± 0.28	0.44 ± 0.15	1.06 ± 0.58	0.38 ± 0.18	–	0.5 ± 0.25	0.67 ± 0.27
	Pristipomoides multidens	0.19 ± 0.19	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
	Symphorus nematophorus	0.52 ± 0.12	–	–	–	–	–	–	–
Monacanthidae	*Aluterus scriptus*	0.02 ± 0.02	–	–	–	–	–	–	–
Mullidae	*Parupeneus chrysopleuron*	0.14 ± 0.14	–	–	–	–	–	–	–
	Parupeneus heptacanthus	0.14 ± 0.07	–	–	–	–	–	–	–
	Parupeneus indicus	0.05 ± 0.03	0.03 ± 0.03	–	–	–	–	–	–
Muraenidae	Gymnothorax sp.	0.19 ± 0.09	0.03 ± 0.03	0.22 ± 0.08	–	0.15 ± 0.1	–	0.29 ± 0.13	–
Nemipteridae	***Nemipterus furcosus***	2.69 ± 0.92	0.25 ± 0.08	0.37 ± 0.14	0.27 ± 0.15	0.54 ± 0.27	0.33 ± 0.24	0.21 ± 0.11	0.24 ± 0.19
	Pentapodus nagasakiensis	3.1 ± 0.92	0.17 ± 0.07	–	0.03 ± 0.03	–	0.11 ± 0.11	–	–
	Pentapodus paradiseus	1.02 ± 0.42	0.8 ± 0.06	–	–	–	–	–	–
	Pentapodus porosus	1.83 ± 0.95	–	–	0.03 ± 0.03	–	–	–	0.05 ± 0.05
	Scolopsis margaritifer	0.71 ± 0.71	–	–	–	–	–	–	–
	Scolopsis monogramma	0.45 ± 0.12	–	–	–	–	–	–	–
Odontaspididae	*Odontaspis ferox*	0.02 ± 0.02	–	–	–	–	–	–	–
Ostraciidae	*Rhynchostracion rhinorhynchus*	–	–	–	0.03 ± 0.03	–	–	–	0.05 ± 0.05
Pinguipedidae	*Parapercis nebulosa*	0.02 ± 0.02	–	–	–	–	–	–	–
Pomacanthidae	***Chaetodontoplus duboulayi***	0.33 ± 0.09	–	–	–	–	–	–	–
	Chaetodontoplus personifer	0.07 ± 0.05	–	–	–	–	–	–	–
	Pomacanthus imperator	0.02 ± 0.02	–	–	–	–	–	–	–
	Pomacanthus sexstriatus	0.14 ± 0.08	–	–	–	–	–	–	–
Pomacentridae	*Chromis westaustralis*	0.79 ± 0.51	1.5 ± 1.43	–	–	–	–	–	–
Ptereleotridae	*Ptereleotris* sp.	0.1 ± 0.1	–	–	–	–	–	–	–
Rachycentridae	*Rachycentron canadus*	0.1 ± 0.07	–	0.07 ± 0.05	–	0.08 ± 0.08	–	0.07 ± 0.07	–
Rhynchobatidae	*Rhynchobatus djiddensis*	0.02 ± 0.02	–	–	–	–	–	–	–
Scaridae	***Scarus ghobban***	0.29 ± 0.07	–	–	–	–	–	–	–
	Scarus schlegeli	0.05 ± 0.05	–	–	–	–	–	–	–
Scombridae	***Scomberomorus* spp.**	1.05 ± 0.29	–	–	–	–	–	–	–
Serranidae	***Plectropomus maculatus***	0.64 ± 0.2	0.08 ± 0.06	–	0.07 ± 0.03	–	–	–	0.1 ± 0.07
Tetraodontidae	*Lagocephalus lunaris*	0.05 ± 0.03	–	0.04 ± 0.04	–	–	–	0.07 ± 0.07	–
Triakidae	*Hemitriakis* sp.	0.02 ± 0.02	–	0.04 ± 0.04	–	0.08 ± 0.08	–	–	–
Zanclidae	*Zanclus cornutus*	0.05 ± 0.05	–	–	–	–	–	–	–

Table 2
PERMANOVA results for relative abundance, total number of individuals and species richness sampled by stereo-BRUVs and traps at night and during the day.

Source	d.f.	Abundance			# Individuals			Species richness		
		MS	Pseudo-*F*	*P* (perm)	MS	Pseudo-*F*	*P* (perm)	MS	Pseudo-*F*	*P* (perm)
Technique	1	1.53	2.82	0.002	12,975	12.47	<0.001	918.55	114.27	<0.001
Diel	1	7.75	14.23	<0.001	25,733	24.73	<0.001	635.89	79.11	<0.001
Technique × Diel	1	3.41	6.26	<0.001	10,462	10.06	<0.001	334.19	41.57	<0.001
Residual	131	0.54			1040.4			8.04		
Total	134									

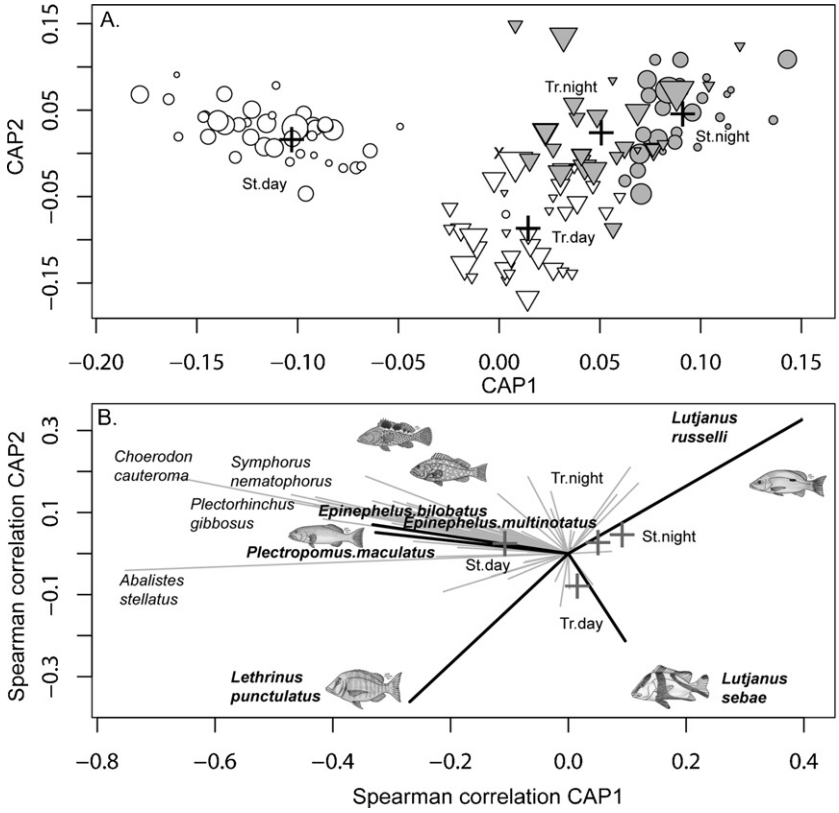

Fig. 3. Results of CAP analysis (using Modified Gower Log base 10 dissimilarity measure) showing site scores and centroids for stereo-BRUVs (St, circles) and traps (Tr, triangles) (A). Symbols are scaled to the species richness at each site, and filled for night deployments. Panel (B) shows the Spearman correlation coefficients between species vectors and site scores for each treatment. All species vectors are shown, but only those of economic importance (bold), and those with vector lengths (correlations) more than 0.5, are labelled with species names in panel (B). The treatment centroids are also shown for reference on the same scale.

into distinct clusters. These clusters were statistically significant (CAP permutation test, trace statistic (tr(Q_m'HQ_m)) $p < 0.001$) and had a high overall leave-one-out allocation success of 77.8% (with four groups an allocation success rate of 25% could be expected by chance).

Sixteen species had Spearman rank correlation *R* values greater than 0.3 or less than −0.3 (Table 1), indicating that they were the main species influencing the separation of samples in the CAP plot. The direction and relative influence of six commercially important species have been superimposed on the CAP plot (Fig. 3). *Lutjanus russelli* was highly associated with surveys conducted at night while *L. punctulatus* were associated with daytime surveys. *L. sebae* were more abundant in traps during the day, while *E. bilobatus, E. multinotatus* and *P. maculatus* were associated with daytime stereo-BRUVs surveys (Fig. 3).

3.3. Total number of individuals and species

Statistical differences in the fish assemblages sampled during the day were attributed to stereo-BRUVs (54.5 ± 8.65 SE) sampling significantly more individuals than traps (16.75 ± 2.11), as well as significantly more species. Stereo-BRUVs recorded 84 species (mean = 11.92 ± 0.70 SE) – more than twice as many as the 30 species caught by traps (3.44 ± 0.27) (Tables 1 and 2). Pairwise comparisons showed that nocturnal traps and stereo-BRUVs sampled approximately the same numbers of individuals (mean per stereo-BRUV system = 8.62 ± 0.85 SE, mean per Trap = 6.6 ± 1.14 SE, $t = 1.39$, *P* perm = 0.18) but stereo-BRUVs recorded more species than traps (Table 2, $t = 5.46$, *P* perm > 0.001, mean per stereo-BRUV system = 7.10 ± 1.11 SE, mean per Trap = 3.59 ± 0.96 SE).

3.4. Key commercial species

There were no significant differences in the abundances of *E. multinotatus* for time of day, or technique. There were significant diurnal differences in the abundances of *L. punctulatus*, with a 3-fold increase in abundances sampled during the day, regardless of technique. There were significant main effects and Technique × Diel interactions for *E. bilobatus, L. russelli, L. sebae* and *P. maculatus*, which were explored using pairwise tests. Stereo-BRUVs samples had higher abundances of *E. bilobatus* (mean = 1.19 ± 0.31 SE) than traps (0.26 ± 0.13) during the day, but no differences at night

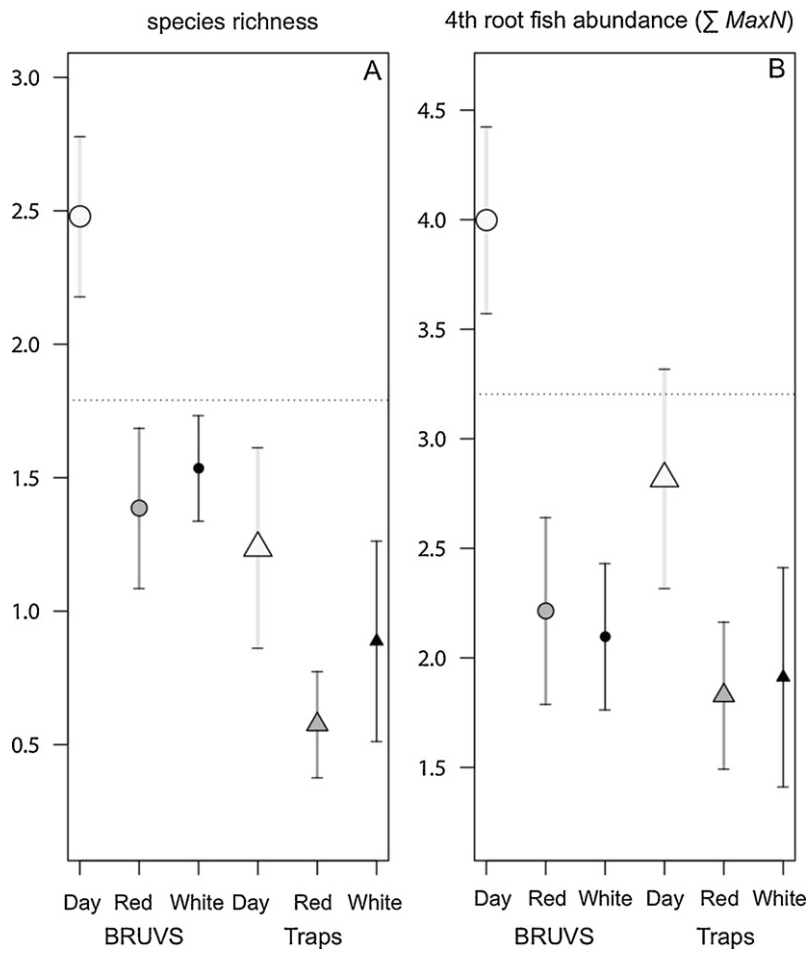

Fig. 4. Estimates of mean values, within 95% confidence intervals, on a log scale for species richness (A) and transformed abundance (4th root) (B) recorded by stereo-BRUVs and fish traps under conditions of daylight, and white and red lights at night. There was a significant interaction between technique and lighting for fish traps. Global means are shown by horizontal dotted lines.

(mean = 0.07 ± 0.05 SE vs. 0.13 ± 0.08). There was no significant difference in the numbers of *L. russelli* sampled by traps and stereo-BRUVs during the day, but significantly more fish were recorded in the stereo-BRUVs at night compared to traps (mean = 1.33 ± 0.32 SE vs. 0.07 ± 0.05, respectively). A greater abundance of *L. russelli* was recorded by stereo-BRUVs at night (mean = 1.33 ± 0.32 SE) than during the day (0), but there was no diurnal difference for traps. Traps sampled more *L. sebae* (mean = 3 ± 0.80 SE) during the day than stereo-BRUVs (1 ± 0.37), but the techniques did not differ at night. Whereas, trap counts for *L. sebae* did not differ from day to night and neither did stereo-BRUVs counts. The abundance of *P. maculatus* followed a similar pattern with stereo-BRUVs sampling more individuals (mean = 0.64 ± 0.19 SE) than traps (0.08 ± 0.06) during the day. While nocturnal and diurnal catches in traps were similar for *P. maculatus* (means = 0.07 ± 0.03 and 0.08 ± 0.06 SE), respectively), nocturnal stereo-BRUVs did not record any *P. maculatus*.

3.5. The effects of red and white light

For nocturnal trap and stereo-BRUVs samples collected under red and white illumination there were no main effects at the assemblages level, however a significant Technique × Lighting interaction was recorded (d.f. = 1,56, MS = 1.17, Pseudo-F = 2.33, P perm = 0.01). Pairwise comparisons of the interaction showed there were differences between traps and stereo-BRUVs illuminated by red light (t = 1.63, P perm = 0.01) but not by white. There were no differences between stereo-BRUVs illuminated by red and white light, however differences existed between traps illuminated by red and white light (t = 1.53, P perm = 0.04). A CAP analysis, while significant (P < 0.01), did not distinguish between groups well with a relatively low leave-one-out allocation success rate of 54%.

There were no significant differences in the total numbers of individuals recorded in traps or stereo-BRUVs under white (Traps mean = 6.76 ± 1.10 SE, stereo-BRUVs 8.14 ± 1.24) or red illumination (Traps mean = 6.22 ± 2.96 SE, stereo-BRUVs 9.15 ± 1.19) (Fig. 4). Only a significant main effect of Technique was detected for species richness (d.f. = 1,56, MS = 64.1, Pseudo-F = 30.91, P perm < 0.01). In general, stereo-BRUVs sampled more species of fish than traps at night regardless of the colour of the illumination (Fig. 4).

3.6. Statistical power

Four of the six commercially important species sampled with stereo-BRUVs had better statistical power for an equivalent number of replicates than sampling with traps (Table 3, Fig. 5). This was not the case for *L. sebae* where traps marginally out performed stereo-BRUVs and for *P. maculatus* where both traps and stereo-BRUVs had low statistical power (Table 3, Fig. 5).

Table 3
Actual change in mean abundances of six target species for a 50%, 100% and 200% increase in abundance.

	Stereo-BRUVS				Traps			
	Mean	50%	100%	200%	Mean	50%	100%	200%
Epinephelus bilobatus	1.19	1.78	2.38	3.57	0.19	0.29	0.39	0.58
Epinephelus multinotatus	0.55	0.82	1.1	1.64	0.3	0.46	0.61	0.92
Lethrinus punctulatus	7.52	11.28	15.05	22.57	9.25	13.87	18.5	27.75
Lutjanus russelli	1.33	2	2.66	4	0.06	0.1	0.13	0.2
Lutjanus sebae	1	1.5	2	3	3	4.5	6	9
Plectropomus maculatus	0.07	0.11	0.14	0.21	0.08	0.12	0.16	0.25

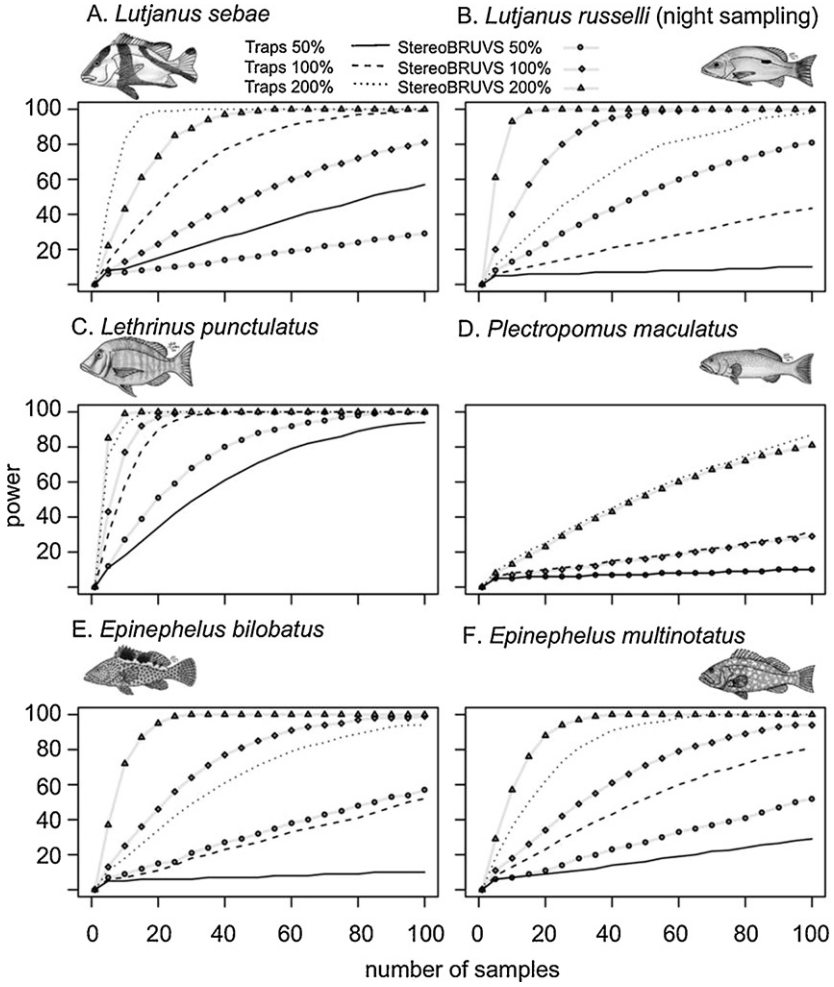

Fig. 5. (A–F) Power analysis for fish traps and stereo-BRUVs to detect 50%, 100% and 200% increases in the abundances of six commercial species based on a significance criterion of 0.05.

3.7. Fish length

Stereo-BRUVs and commercial fish traps sampled similar mean lengths (316.55 mm vs. 353.81 mm) but stereo-BRUVs sampled a much greater length range (35–2765 mm compared to 194–1014 mm). Three fish species (*A. stellatus, L. punctulatus* and *L. sebae*) were sufficiently common to facilitate statistical comparisons of length frequencies (Fig. 6). Stereo-BRUVs sampled smaller mean lengths of *A. stellatus* (d.f. = 1, 221, MS = 64274, $F = 21.76$, $p < 0.001$) and *L. punctulatus* (d.f. = 1, 645, MS = 9870, $F = 14.84$, $p < 0.001$), but larger *L. sebae* (d.f. = 1, 210, MS = 48436, $F = 11.51$, $p = 0.001$) than traps (Fig. 6). The K–S test showed there were no significant differences in the length frequency of *A. stellatus* or *L. sebae*, but there were significant differences for *L. punctulatus* with traps sampling a greater proportion of fish in the 280-299 and 300-319 size classes (Fig. 7).

4. Discussion

Building on the fundamental work of Priede et al. (1994), Ellis and DeMartini (1995) and Willis and Babcock (2000), baited remote underwater video systems are now being refined and promoted as a viable, fishery independent, non-destructive sampling tool to assess fish assemblages (Cappo et al., 2004, 2007; King et al., 2006; Harvey et al., 2007; Shortis et al., 2009; Murphy and Jenkins, 2010). Beyond the study of effects of fishing, there is increasing interest in using stereo-BRUVs for assessments of fish communities to help determine risks in an applied EBFM framework (Smale et al., 2011). However, there is a need to understand how the data collected from stereo-BRUVs compares with the relative abundance and length data presently collected by other techniques.

Two previous comparisons of baited cameras and traps have reached some similar conclusions about size-selectivity of different

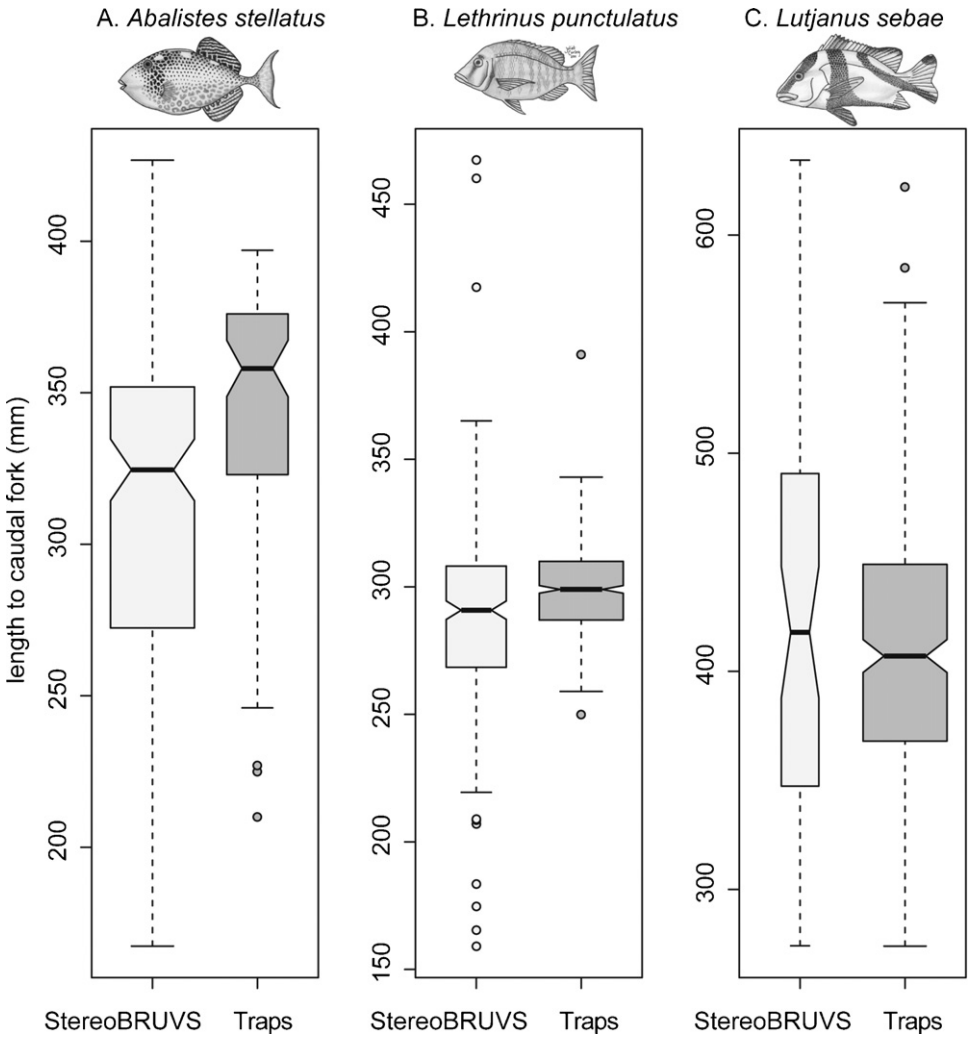

Fig. 6. Boxplots of the median lengths (length to caudal fork, mm) of *Abalistes stellatus* (A), *Lethrinus punctulatus* (B) and *Lutjanus sebae* (C) sampled by stereo-BRUVs and fish traps. The width of the boxes is proportional to the square root of the sample size n for each level of the plot. The notches on the box plots represent 1.5× (interquartile range of length/SQRT(n)). If the notches do not overlap this is 'strong evidence' that the two medians differ, independent of any assumptions about normality of data distributions or equivalence of variances (Chambers et al., 1983, p. 62).

gears. For red snapper *Lutjanus campechanus* in the Gulf of Mexico, Wells et al. (2008) found that an otter trawl sampled the most juveniles when compared to a small fish trap, a large chevron trap, and a baited video array on low-relief reefs. However, the relative effectiveness of a particular gear type was dependent on red snapper size, and chevron traps recorded the largest fish. The baited video array recorded both small and large red snapper, but not the extremes in those parameters, and the proportion of fish that could be measured with paired laser beams was not reported. That study concluded that a range of gears was necessary for understanding habitat preferences by different life stages, and there was no advantage reported for the use of the baited video array. Similarly, Priede et al. (1994) reported strong size-selectivity between sampling gears for some demersal scavengers on very deep (4000–5000 m) slope and rise seafloors of the Porcupine Seabight. There were poor catches (2 species) in a small fish trap compared with photographs of a bait station (18) and trawls (71). The lack of largest and smallest *Coryphaenoides (Nematonurus) armatus* (caught by trawls) in the photographs was attributed to sexual dimorphism in behaviours and swimming speed. The photographic technique used only a small (0.5 kg) amount of bait but did record a representative sample of the dominant species in the sampling area.

In our field comparison we have shown that stereo-BRUVs and commercial fish traps sampled different components of the demersal fish assemblage, driven by the higher species richness and greater number of individuals recorded by the lower selectivity of stereo-BRUVs. Commercial traps sampled only 31.7% of the total number of fish and 32.9% of the species sampled by stereo-BRUVs. Both techniques approached a species asymptote quickly with 93% and 73% of the species recorded in the first 20 samples for stereo-BRUVs and traps, respectively.

When comparing techniques it is important to consider their cost effectiveness. While stereo-BRUVs recorded more species from their 1-h deployment than the 3-h deployments of the traps each 1-h video recording took between 1.5 and 2.5 h to post process in the laboratory. The time taken to record the species captured and their lengths varied depending on the number of fish in a trap, but generally took between 10 and 20 min.

Soak times of the stereo-BRUVs (1 h) was limited to one-third of that for fish traps by the use of mini-DV tapes. It is highly probable that the number of species and individuals recorded on the stereo-BRUVs would have increased for soak times equivalent to traps – resulting in an increased statistical power, especially for rarer species. Longer soak times are now possible with the

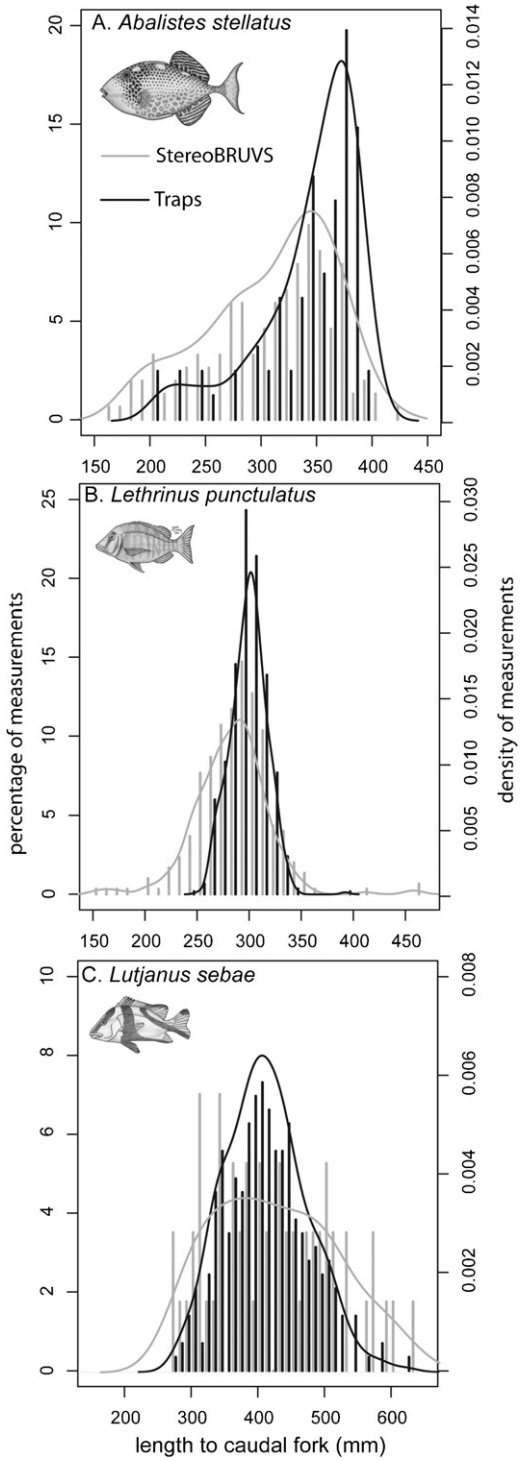

Fig. 7. Length frequency histograms and density plots for *Abalistes stellatus* (A), *Lethrinus punctulatus* (B) and *Lutjanus sebae* (C) sampled by stereo-BRUVs and fish traps during daylight deployments.

new generation of handicams that record to memory stick or hard drive.

Stereo-BRUVs sampled a much greater range of lengths than did commercial fish traps, due to the limit on the physical size of fish able to enter the traps and an inability of traps to retain smaller fish less than 200 mm fork length. The other significant factor affecting trap catches is behavioural responses. For example, small individuals may have avoided entering fish traps with larger, predatory fish inside or nearby. Differences in habit, morphology, behaviour and diel activity were discussed by Cappo et al. (2004) to explain how BRUVs recorded more larger, mobile species from a much wider size range of families than otter trawls. Trawls caught mainly small (≤300 mm), sedentary or cryptic, demersal species – such as flatfishes, apogonids, synodontids, triglids and callionymids.

The use of *MaxN* implies that only the maximum number of fish of any one species seen in a single video frame over the whole recording are counted (and hence measured) to avoid duplicate counts on any one deployment. This may pose a limitation in the current protocols where the lengths of fish are only measured at the time of *MaxN* to avoid repeated measurements of the same individual (e.g. Watson et al., 2009; McLean et al., 2010). This decreases the number of fish that can be measured, relative to the numbers seen at various times on the tapes, and the size-specific effects of bait, or intra- or inter-species behaviour are unknown. It could be argued that many small fish arrive first to be displaced later by fewer, larger fish. If this was the case, stereo-BRUVs measurements would underestimate the true mean length and length frequency as the larger fish would not be included in the counts or measurements. This is one important area of research that we recommend is investigated in the future.

Clear diel effects were exhibited for *L. punctulatus, L. laticaudis* and *L. nebulosus* each tending to be more abundant in trap catches during the day than at night. This is consistent with the results of previous trapping studies (Newman and Williams, 1995, 2001; Travers et al., 2006). Carpenter and Allen (1989) reported that most species of lethrinids feed at night, but recognize that many species 'forage coincidentally or purposefully during the day'. For the present study is it difficult to infer feeding behaviour with the introduction of bait, however it is interesting to note that bait did elicit daytime feeding behaviour. The fact that the balistid *A. stellatus* also made relatively greater contributions during the day follows the results of Newman and Williams (1995) on the Great Barrier Reef. Furthermore, the relatively greater contributions of lutjanids to nighttime catches is consistent with other studies that have found nocturnal feeding behaviour (Randall and Brock, 1960; Hobson, 1965, 1968, 1974; Parrish, 1987).

Our results show that some species of fish, and in particular *L. russelli*, were caught in traps and sampled by stereo-BRUVs in greater abundances at night than during day. Similar results have been found for other Western Australian fish (e.g. *Glaucosoma herbraicum*, Fitzpatrick, unpublished data). We found significant differences in the diurnal and nocturnal fish assemblages regardless of technique and illumination. There were not any great differences in the demersal fish assemblages, numbers of species or in the total numbers of fish sampled under white or red light. However, there may be species specific reactions to lighting (dependant on species spectral sensitivity) and this is an area which needs further research, particularly if baited cameras are to be used as a fishery independent sampling technique in low light conditions, i.e. in deepwater or nocturnal sampling.

In summary, this comparison of the data collected by stereo-BRUVs and commercial fish traps has revealed that stereo-BRUVs and fish traps sampled different components of the fish assemblage. This is due to the stereo-BRUVs sampling more species than is retained in commercial fish traps. Stereo-BRUVs also tended to sample many more individuals than fish traps. This has important implications for detecting changes in fish assemblage structure over time. Four commercially important species, *E. bilobatus, E. multinotatus, L. punctulatus* and *L. russelli* sampled by stereo-BRUVs had much greater statistical power for detecting change than an equivalent number of samples derived from fish traps. For *L. sebae*, fish traps marginally outperformed stereo BRUVS, while for *P. maculatus* both sampling techniques performed poorly due to the low number of fish sampled. Length frequencies for these species did not differ significantly, however it was notable that stereo-BRUVs

sampled a much larger range of lengths than was captured in the fish traps. This may be due to traps tending to selectively capture large individuals of these species. The extra information collected by stereo-BRUVs makes them a more versatile sampling tool than traps alone.

Stereo-BRUVs show great promise as a tool for collecting fishery independent data across a range of habitats and depths in a cost effective and statistically rigorous manner (Watson et al., 2010; Langlois et al., 2010). The efficacy of the results from this study in north-western Australia need to be further examined over larger spatial and temporal scales. In this study, stereo-BRUVs clearly sample more species and have more power to detect change than fish traps. Therefore, in any monitoring program stereo-BRUVs would be more effective than fish traps individually as sampling tools, particularly where detecting change is an important criterion. As such, from this study stereo-BRUVs show great promise in contributing significant fisheries independent data with the added benefit of direct views of the seafloor habitats that are a critical requirement for assessing changes to fish populations.

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