

# Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park

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## Abstract

A field comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls was made to assess the sampling options for describing patterns of fish biodiversity in the lagoonal waters of the Great Barrier Reef Marine Park. Replicated comparisons were made during the day and night on trawl grounds with different biophysical characteristics. Each trawl was made close and parallel to a long-shore set of five BRUVS set at regular intervals along one nautical mile. For each species, the sum of the maximum number of fish sighted on BRUVS at any one time ( $\Sigma \text{Max}N_1, \dots, s$ ) was compared with the number of fish caught in trawls ( $N$ ).

The two techniques recorded significantly different components of the fish fauna on the trawl grounds. Trawls caught mainly small ( $\leq 300$  mm), sedentary or cryptic, demersal species—such as flatfishes, apogonids, synodontids, triglids and callionymids. The BRUVS recorded more larger, mobile species from a much wider size range of families, including large elasmobranchs, more fusiform pelagic species (such as carangids and scombrids), and numerous eels. Species accumulation curves were parallel and very similar in shape for both techniques, but were separated by about 11 extra species in trawls. Fifty-two species in 17 families were caught only in trawls and 38 species in 15 families were recorded only by BRUVS. The occurrence of 38 small mobile species in 21 families was common to both techniques, but most of these showed marked differences in relative abundance. Trawls recorded higher species richness at all sites, and at night, but the average number of species and individuals recorded per transect were only about 26% and 19% lower for the BRUVS. The BRUVS consistently recorded more species during the day than trawls, and are limited most by water clarity. Multivariate analyses showed that both techniques indicated the presence of six fish assemblages based on day and night in three locations, despite sampling quite different

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components of the fauna. The six assemblages accounted for 78.9% of the variation in the BRUVS data compared to 68.9% of the variation in the trawl data, and there was a lower error rate in discriminating the six assemblages in the BRUVS data.

BRUVS are non-extractive and can be used on complex topographies and in sensitive habitats in most or all zones of the Marine Park, but models of bait plumes are needed to convert fish sightings to density estimates. They may have a particular role in studies of larger, rarer elasmobranchs and teleosts of special conservation interest. Trawls can be used in any level of water clarity and provide direct estimates of fish density, particularly those smaller teleosts most vulnerable to the effects of trawling. The complementary use of prawn trawls and BRUVS would enable a more comprehensive assessment of teleost and elasmobranch diversity in the variety of inter-reef seabed topographies and management zones comprising the Marine Park.

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## 1. Introduction

Commercial trawling gear has been used to describe patterns of distribution and abundance of fish species in the inter-reef waters of the Great Barrier Reef Marine Park (GBRMP) (Jones and Derbyshire, 1988; Watson and Goeden, 1989; Wassenberg et al., 1997). Demersal research trawling is an extractive activity (Van Dolah et al., 1987), restricted to certain zones of the GBRMP, and cannot be used on very rough seabeds, palaeo-reef edges or other outcrops of “hard ground”. Such seabed topographies are known to provide the substrata for attachment of sponges, gorgonians, alcyonarians and macroalgae (e.g. Miller et al., 2001), but much softer sediments also provide the basis for enucleation of patches of such “megabenthos” at much larger spatial scales (Pitcher et al., 1999, 2000). The mosaics of soft and hard, biotic and biotic habitats on low-latitude shelves provide food resources, shelter and spawning aggregation sites for a significant and varied fish fauna—most notably a “bycatch fauna” in prawn trawl fisheries (e.g. Stobutzki et al., 2001a; Ramm et al., 1990) on soft sediments, and the snapper–grouper complex on more complex topographies (Koenig et al., 2000). These shelf habitats are very extensive but largely unexplored because they occur in depths below the limits of scientific SCUBA diving (McManus, 1997).

Underwater visual surveys (UVS) using submersibles have been used to estimate fish densities in these deeper habitats (Ralston et al., 1986; Matlock et al., 1991; Gibbons et al., 2002), but are expensive and not readily available in most equatorial countries. Towed still cameras mounted on trawl head-ropes, or towed video cameras, have also been used to determine fish-habitat associations (Adams et al., 1995; Sainsbury et al., 1997). Hydro-acoustic measurements validated by video or submersible offer potential to enumerate low-diversity fish communities (Barans and Holliday, 1983; Stanley and Wilson, 2000; Nasby-Lucas et al., 2002). Most commonly, however, selective trapping, hook and line fishing or trawling has been undertaken to survey fish communities (Cappo and Brown, 1996; Newman et al., 1997; Mahon and Hunte, 2001).

More recently, baited “video-fishing” techniques have been used to count juvenile fishes (Ellis and DeMartini, 1995), to identify the scavengers of prawn (shrimp) trawl discards (Hill and Wassenberg, 2000), to measure the performance of marine protected areas (Willis and Babcock, 2000; Willis et al., 2000), and to measure abundance of abyssal scavengers (Priede and Merrett, 1996) and other deep-water species (Gledhill et al., 1996; Yau et al., 2001). Such video techniques might offer a “hybrid” of the sampling advantages offered by UVS and extractive fishing techniques, whilst avoiding some of the selectivity associated with these methods.

Our goal was to develop a fleet of baited remote underwater video stations (BRUVS) for use in future biodiversity surveys of all management zones of the GBRMP, including those inaccessible to diver-based surveys and extractive techniques. Here we report on a direct field comparison of BRUVS with prawn trawls to evaluate the relative performance, inherent biases and selectivity of this video technique. The main factors we set up in the field comparison were contrasts in three locations during the day and night, based on knowledge that the largest catches of fish might be expected in night trawls (Wassenberg et al., 1997), that distinct cross-shelf changes occur in habitats and fish communities of the GBRMP lagoon (Jones and Derbyshire, 1988; Watson and Goeden, 1989; Newman et al., 1997), and that distinct regional and biophysical patterns exist long-shore (e.g. Fabricius and De’ath, 2001; Stobutzki et al., 2001a).

Specifically, we aimed to compare the two techniques in terms of species richness, the ability to discern spatial patterns, the ability to discriminate amongst groups in those patterns, the estimates of relative abundance of species common to both, and general logistics of data acquisition.

## 2. Materials and methods

### 2.1. Study sites and materials

The basic design was to set five baited remote underwater video stations (BRUVS) about 450 m apart along an 1800 m (1 nautical mile) track in prawn trawl grounds, then trawl alongside (about 150–200 m away) and parallel to that same 1800 m track with a prawn trawl. Each trawl and each set of five BRUVS is hereafter referred to as a “transect”. The transect dimensions and trawl configuration were designed to standardise with previous studies in the region (Wassenberg et al., 1997). The number and separation of the BRUVS was chosen on the basis of prevailing currents and previous studies (Ellis and DeMartini, 1995) in an attempt to achieve independence of each unit and to sample approximately the same area of seabed as that swept by the trawl.

Distinct biophysical regions exist north and south of Cape Grafton in the Cairns region of the GBRMP (R. Pitcher, personal communication, CSIRO Division of Marine Research, Cleveland). To maximize the contrast in habitat types for the comparison we selected two locations north of Cape Grafton (“Double Island” (DI); inshore, 18–23 m depth, “Double Island Wide” (DIW); offshore, 31–33 m) and one location south of the cape (“Scott Reef” (SR); offshore, 29–38 m). The inshore DI location had terrigenous sediments, and the other two offshore locations had mixed terrigenous and carbonate

sediments. Each comparison was made along a new path on the trawl grounds, parallel to the prevailing wind (along current) prior to and during the full moon in January 23–28, 2002 (Fig. 1). Three (DI, DIW) or four (SR) replicate pairs of trawls and BRUVS transects were made at each location during the day and during the night, giving a total of 19 BRUVS and trawls transects.

The BRUVS consisted of a galvanized roll-bar frame enclosing a simple camera housing made from PVC pipe with acrylic front (dome) and rear ports. Stabilizing arms and bait arms (20 mm plastic conduit) were attached and detached during and after deployment. The bait arm had two 50-mm square scale grids either end of a 350-mm plastic mesh bait canister containing one kilogram of crushed pilchards *Sardinops neopilchardus* (Fig. 2). BRUVS were deployed with ropes and surface floats bearing a flag (day) and strobe light and cyalume stick (night), and were retrieved with an hydraulic pot-hauler wheel.

Sony™ Hi-8 Handicams (model TR516E) with wide-angle lenses (Hama™ 0.5×) were used in the housings. Exposure was set to “Auto”, focus was set to “Infinity/manual”,

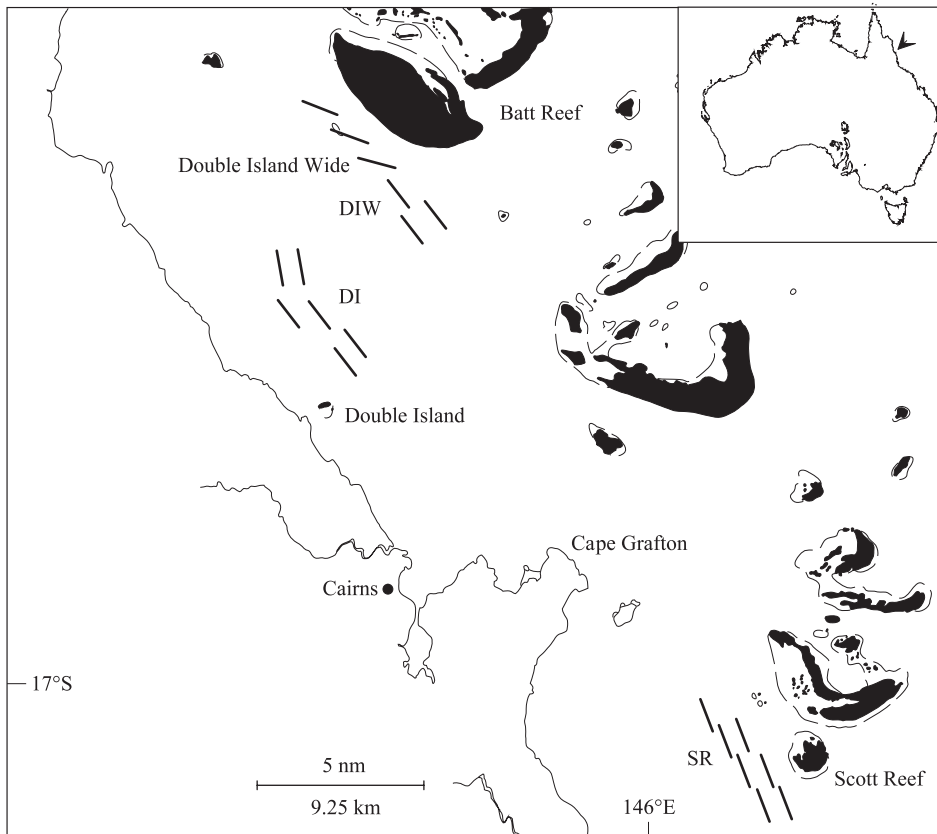


Fig. 1. Schematic bars (to scale) representing the location of the 19 pairs of parallel BRUVS/trawl transects, along 1800 m (one nautical mile) paths, named “Double Island” (DI), “Double Island Wide” (DIW) and “Scott Reef” (SR).

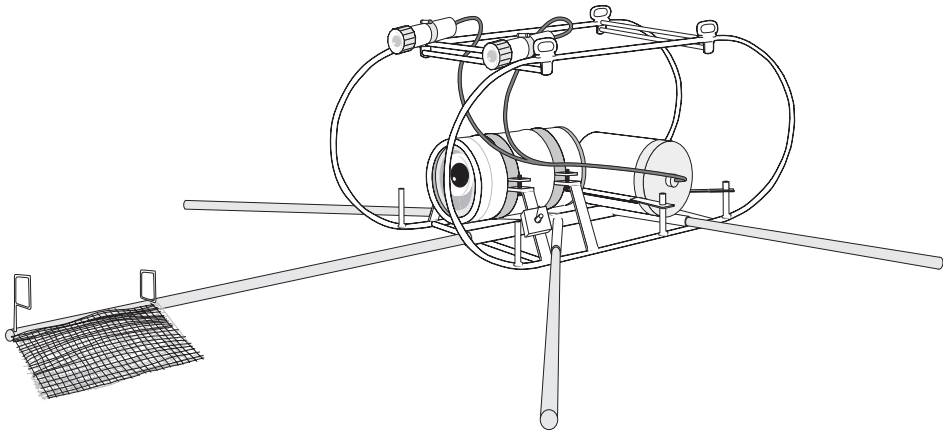


Fig. 2. The BRUVS frame and housing with lights and battery pack fitted, showing the removable stabilising legs and bait arm, with bait canister and 50 mm scale grids fitted.

“Standard Play” mode was selected, and date/time codes were overlaid on footage. For night sets with lights, “Night-Shot” function was selected. Lighting for night sets was provided by two 35 W–12 V dichroic lamps in separate housings covered by Lee™ “Bright Red 026” filters to transmit red light in the wavelengths above the sensitivity of many marine fish at night (J. Shand, personal communication, University of Western Australia). Power-packs for lights were made of 12 V rechargeable gel-cell batteries in waterproof housings. The BRUVS were deployed to provide 60 min of film recorded at the seabed.

Interrogation of each tape provided the time the BRUVS settled on the seabed and, for each species, the time of first sighting (*TFAP*), 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 the intraspecific and interspecific behaviour (in eight categories). Coarse measurements of the total length of the largest individuals of some species were made by comparing them with the scale grids on the bait arm. These measurements could be made only when the fish were perpendicular to the camera and immediately next to, or between, the scale grids. At such opportunities the tape play-back was paused to provide a still image, and the outlines of the fish and scale grids were compared using a plastic graduated ruler to provide a visual estimate of length. Harvey et al. (2002a) showed that accuracy of such a procedure is degraded by the rotation of the subject beyond 20° relative to the camera, reduced when the subject is more than one metre to the left or right of the calibration bar, and severely compromised when the fish silhouette was behind or in front of the calibration bar.

The trawl gear deployed by FRV “Gwendoline May” was identical to that described by Wassenberg et al. (1997), with the exception that each net in the current study was fitted with the bycatch reduction devices (BRD) and turtle exclusion device (TED) required under the current legislation covering the East Coast Trawl fishery. The trawl gear consisted of two, 8 m (footrope length) “Florida Flyer” nets (50 mm mesh) deployed over the stern of the vessel. The BRD was a “square mesh panel” (100 mm mesh), and the

TED was an aluminium grid of deflector bars, angled backwards and spaced about 120 mm apart (see Eayrs et al., 1997 for full description).

The time, depth, position, duration and track was recorded for each set of BRUVS and trawls using MaxSea™ navigation software linked to a Garmin™ GPS receiver. The trawls were about 20 min duration (on bottom), during which a path approximately one nautical mile long (1.8 km) and no more than 16 m wide was trawled. The catch from both nets was weighed to the nearest 0.1 kg on a Salter spring balance. The “fish” component of the catch was boxed and frozen for further analysis to record the number of each species in each catch ( $N$ ), and the range in total length measurements (*MinLength* and *MaxLength*) of each species. All fish identifications were made using Gloerfelt-Tarp and Kailola (1984), Sainsbury et al. (1985), Allen and Swainston (1988) and Russell (1990).

Five main working approximations were made to allow definition of abundance measures. It was assumed that: fish were not counted on more than one BRUVS in a transect; the BRUVS and trawl transects were independent and did not influence each other; the total area sampled by each BRUVS was the same; and, the total area sampled by five BRUVS was similar to the area swept by the trawl. These untested approximations provided the statistic used to compare the BRUVS transect with the associated trawl transect  $N$  as the sum of  $MaxN$  pooled across the five BRUVS for each fish species.

## 2.2. Statistical analysis

The patterns of presence and absence of the fish species were highly variable, with only one species (on BRUVS) present on all transects. The data for all species were therefore transformed by fourth root before multivariate analysis. This down-weighted highly abundant species and reduced skewness in the distributions of values for each species.

All multivariate analyses were based on species dissimilarity. For data characterised by moderate to high alpha diversity, relationships between species dissimilarity and ecological distance can be enhanced by the choice of an appropriate similarity measure (Faith et al., 1987) and use of extended dissimilarity (De'ath, 1999). The extended version of site-standardised Manhattan dissimilarity was selected for the basis of all multivariate analyses, other than exploratory clustering. This measure is equivalent to extended, site-standardised Bray–Curtis. Clustering of the Bray–Curtis dissimilarity measure using a flexible UPGMA fusion strategy, and principal coordinates analysis (PCoA), were used to illustrate the basic structure and groupings in the transformed abundance data. Principal coordinates analysis and distance-based redundancy analysis (db-RDA) (Legendre and Anderson, 1999; McArdle and Anderson, 2001) were used to assess species variation between the six treatments (defined by the three locations, day and night) and the interactions between them. Permutation tests were used to assess the significance of the variation (McArdle and Anderson, 2001). Linear discriminant analysis (LDA) was used to assess how accurately information from BRUVS and trawls could predict the species assemblages. Analyses were carried out using S-Plus™ software (Statistical Sciences, 1999).

Species indicators that characterised each of the treatment groups for BRUVS and trawls were identified using an indicator species index based on relative abundance (untransformed data) and relative frequency of occurrence (Dufrêne and Legendre, 1997). The index was defined as the product of relative abundance and relative

frequency of occurrence of the species within a group. The index had a value of 100 if the species occurred at all replicates within the group, and did not occur in any other group. The index distinguished between ubiquitous species that dominated many groups in absolute abundance, and species that occurred consistently within single groups but had low abundance.

The functional morphology and habits of the numerous genera and families mentioned below in the text and tables are summarised in Table 10 to provide ecological context for the differences reported between sampling methods.

3. Results

3.1. Species richness

Overall, there were 6247 individuals of 128 teleost and elasmobranch species recorded in the study from 53 families (Table 1). The trawl catch rates were low, between 2.25 and 33.63 kg h<sup>-1</sup> with an average of 16.55 kg h<sup>-1</sup>. Trawls recorded higher species richness overall, at all sites, and at night, but the average number of species and individuals recorded per transect were only about 26% and 19% lower for the BRUVS (Table 2). Catch rates in night trawls (22.62 kg h<sup>-1</sup>) were higher than those in the day (11.09 kg h<sup>-1</sup>). BRUVS recorded consistently higher diversity in the day (Table 2). Of the total species list, 52 (17 families) were caught only by trawls and 38 (15 families) were recorded only by BRUVS. There were 38 species (21 families) recorded by both sampling techniques.

Species accumulation curves record the rate at which new species (*y*) are added with continued sampling effort (*x*) (Thompson et al., 2003). Accumulation of new species by both techniques showed BRUVS consistently about 11 species below trawls for any extra transect in simulations (Fig. 3, Table 2). These curves were fitted best by logarithmic functions (BRUVS  $y = 22.308 \ln(x) + 12.199$   $r^2 = 0.9928$ ; Trawls  $y = 23.358 \ln(x) + 20.808$   $r^2 = 0.9973$ ). The most notable features of these curves are their similarity, with low inflection points on the ordinate axis, a long upward slope to the asymptote, and evidence that there was insufficient sampling to estimate the asymptote and total species richness.

The BRUVS recorded fish families from a greater range of body sizes and functional groups than trawls. Large sharks and shovelnose rays (Carcharhinidae, Sphyrnidae, Rhynchobatidae) and pelagic scombrids and echeneids most likely evaded, or escaped from, the trawls and were recorded only by BRUVS. Eels were recorded on all transects by

Table 1  
Total number of families, species, and individuals (*n* fish) recorded by 19 trawls and 95 BRUVS sets along 19 transects.

	<i>n</i> families (species)	Avg. <i>n</i> species ± SE (range)	<i>n</i> fish	Avg. <i>n</i> fish ± SE (range)
BRUVS	36 (76)	16.7 ± 1.4 (6–27)	2790	146.8 ± 15.9 (43–288)
Trawls	38 (90)	22.6 ± 2.2 (9–38)	3457	181.9 ± 34.5 (48–588)

Average number of species and *n* fish for these transects are shown with standard errors and ranges.



Table 2

Number of species and families (brackets) recorded by day and night and in total by 19 trawls and 95 BRUVS sets along 19 transects.

	BRUVS			Trawls		
	Day	Night	Total	Day	Night	Total
Double Island (DI)	29 (16)	20 (15)	39 (24)	23 (16)	41 (24)	48 (26)
Double Island Wide (DIW)	34 (16)	20 (15)	40 (20)	27 (20)	45 (25)	50 (28)
Scott Reef (SR)	43 (23)	18 (14)	51 (29)	36 (19)	54 (27)	62 (29)
Total	67 (30)	34 (21)	76 (36)	58 (30)	77 (35)	90 (38)

BRUVS, but were absent from trawls (Table 3). In terms of both prevalence and abundance along transects, the BRUVS recorded more demersal scavengers and predators in the families Teraponidae, Tetraodontidae and Carangidae, fewer herbivorous siganids and fewer labrids. The mobile black-banded kingfish (*Seriolina nigrofasciata*) and school mackerel (*Scomberomorus queenslandicus*) were almost ubiquitous on BRUVS sets in the two deeper locations but only two specimens of *S. nigrofasciata* were caught by trawl (Table 4).

In contrast, trawls caught mainly small, sedentary or cryptic, demersal species found lower in the water column or on the seabed. Many of these species had small dorso-ventrally compressed bodies, heavy head and fin spination, venoms or toxins, armoured scales and specialised mouth parts adapted to a sedentary, demersal life history over soft sediments (see Table 10). The BRUVS did not record a single flatfish or flathead (bothids, psettodids, platycephalids), and apogonids were sighted only once, yet these families were major components of the trawl catch in terms of diversity, prevalence and abundance along transects. The flatfishes and flatheads, gurnard-like species (callionymids, dactylopterids,

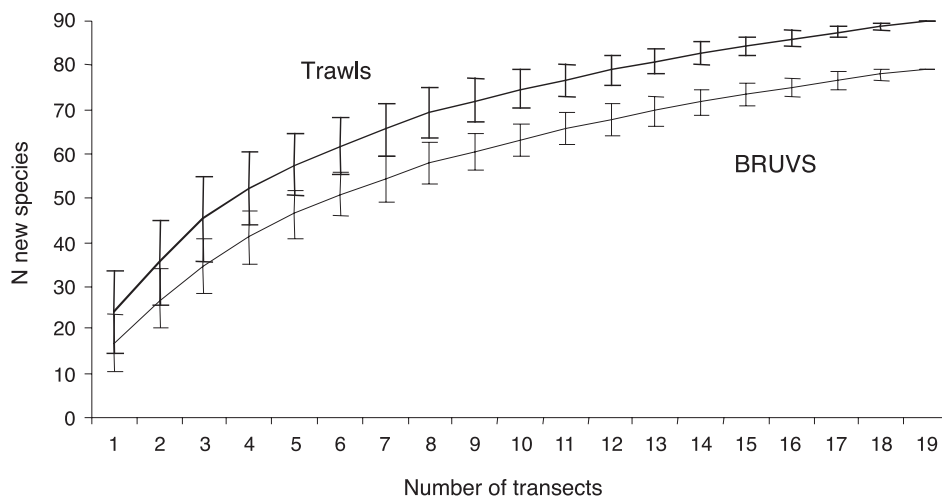


Fig. 3. Accumulation of new species with successive transects by each sampling method, based on 50 repeated, random selections of ordering of sampling transects.



Table 3

Families recorded by only BRUVS or by only trawls in descending order of abundance.

BRUVS			Trawl		
Family ( <i>n</i> spp.)	<i>n</i> fish ( <i>n</i> transects)	Avg. <i>n</i> fish $\pm$ SE	Family ( <i>n</i> spp.)	<i>n</i> fish ( <i>n</i> transects)	Avg. <i>n</i> fish $\pm$ SE
Muraenidae (2)	131 (19)	6.9 $\pm$ 0.70	Platycephalidae (4)	189 (14)	13.5 $\pm$ 3.81
Scombridae (2)	71 (10)	7.1 $\pm$ 2.00	Bothidae (9)	135 (17)	13.2 $\pm$ 9.48
Echeneidae (1)	24 (10)	2.4 $\pm$ 0.50	Callionymidae (3)	132 (10)	7.9 $\pm$ 1.67
Ophichthidae (1)	8 (6)	1.3 $\pm$ 0.21	Priacanthidae (1)	43 (10)	4.3 $\pm$ 1.29
Carcharhinidae (2)	6 (4)	1.5 $\pm$ 0.50	Triglidae (1)	20 (4)	5.0 $\pm$ 1.00
Rhynchobatidae (2)	3 (2)		Scorpaenidae (3)	17 (7)	2.4 $\pm$ 0.37
Sciaenidae (1)	3 (2)	1.5 $\pm$ 0.50	Caesionidae (1)	12 (1)	
Rachycentridae (1)	2 (1)		Plotosidae (1)	8 (4)	2.0 $\pm$ 0.58
Blenniidae (1)	2 (1)		Gobiidae (1)	8 (3)	2.7 $\pm$ 0.33
Sphymidae (2)	5 (4)	1.2 $\pm$ 0.25	Triacanthidae (1)	7 (3)	2.3 $\pm$ 0.33
Congridae (1)	2 (2)		Ostracidae (2)	6 (3)	2.0 $\pm$ 1.00
Dasyatididae (1)	1 (1)		Antennariidae (3)	4 (4)	
Balistidae (1)	1 (1)		Psettodidae (1)	4 (2)	2.0 $\pm$ 1.00
Stegastomatidae (1)	1 (1)		Gerreidae (1)	3 (1)	
Muraenesocidae (1)	1 (1)		Dactylopteridae (1)	1 (1)	
			Pseudochromidae (1)	1 (1)	
			Centriscidae (1)	1 (1)	

The number of species (*n* spp.) is shown for each family in brackets, with total number of fish (*n* fish), the number of transects along which the family was recorded (*n* transects) and the average number of that family recorded on those transects, with standard errors.

triglids, scorpaenids), catfishes (plotosids) and nocturnal planktivores (priacanthids) were exclusively caught by trawls, as were a variety of other sedentary or slow-moving species (Table 3). Small schooling pomacentrids (*Pristotis jerdoni*), gregarious labrids and mullids were more prevalent and abundant in trawls, but BRUVS recorded more schooling pelagic *Selaroides leptolepis* and other carangids (Table 4). The lutjanids, sparids, serranids and some nemipterid and monacanthid species were recorded in similar numbers by both techniques. Within the Nemipteridae and Monacanthidae there were notable differences in prevalence and abundance of *Scolopsis taeniopterus*, *Nemipterus furcosus*, *Pentapodus paradiseus*, *Paramonacanthus lowei* and *P. japonicus* (Table 4). These may relate to the nature of their small-scale distribution, aggregative behaviour, vulnerability to the trawls and differential attraction to the BRUVS.

The average of the difference between *MinLength* and *MaxLength* measured for all species caught by trawls was used as an estimate of total length for the same species recorded by BRUVS. The lengths of other species recorded only by BRUVS were estimated coarsely by comparison with the scale grids on bait arms where possible, or estimated from lengths reported in Gloerfelt-Tarp and Kailola (1984). Most of the trawl catch had an average length less than 300 mm total length, yet nearly half the BRUVS species were at or beyond this length up to direct estimates of 1.6–2.0 m for sightings of large hammerhead sharks and shovelnose rays (Fig. 4).

The identity of 10 of the 38 taxa recorded uniquely by BRUVS was uncertain. These taxa were sometimes seen at such a distance, or aspect, that important diagnostic features

Table 4

Abundance ( $n$  fish) and occurrence ( $n$  transects) of species common to both techniques, ranked in descending order of abundance in the BRUVS records for the 19 transects.

Family	Species	BRUVS		Trawl	
		$n$ fish ( $n$ transects)	Avg. ( $n$ fish) $\pm$ SE	$n$ fish ( $n$ transects)	Avg. ( $n$ fish) $\pm$ SE
Teraponidae	<i>Terapon theraps</i>	537 (9)	59.7 $\pm$ 11.58	27 (7)	3.9 $\pm$ 1.28
Carangidae	<i>Selaroides leptolepis</i>	529 (10)	52.9 $\pm$ 17.56	124 (6)	20.7 $\pm$ 16.93
Tetraodontidae	<i>Lagocephalus sceleratus</i>	237 (19)	12.5 $\pm$ 3.15	99 (10)	9.9 $\pm$ 5.76
Nemipteridae	<i>Nemipterus furcosus</i>	149 (11)	13.5 $\pm$ 3.57	17 (5)	3.4 $\pm$ 1.91
Nemipteridae	<i>N. nematopus</i>	128 (7)	18.3 $\pm$ 4.56	99 (6)	16.5 $\pm$ 1.93
Nemipteridae	<i>N. peronii</i>	75 (10)	7.5 $\pm$ 2.18	47 (11)	4.3 $\pm$ 0.84
Lethrinidae	<i>Lethrinus genivittatus</i>	76 (12)	6.3 $\pm$ 2.33	39 (9)	4.3 $\pm$ 1.79
Nemipteridae	<i>Pentapodus paradiseus</i>	71 (8)	8.9 $\pm$ 5.24	10 (4)	2.5 $\pm$ 0.65
Carangidae	<i>Seriolina nigrofasciata</i>	55 (10)	5.5 $\pm$ 0.82	2 (2)	
Nemipteridae	<i>N. theodorei</i>	51 (6)	8.5 $\pm$ 2.45	7 (3)	2.3 $\pm$ 1.33
Nemipteridae	<i>Scolopsis taeniopterus</i>	46 (5)	9.2 $\pm$ 4.80	189 (15)	12.6 $\pm$ 3.30
Nemipteridae	<i>N. hexodon</i>	39 (7)	5.6 $\pm$ 1.74	31 (3)	10.3 $\pm$ 4.06
Labridae	<i>Choerodon</i> sp2	33 (4)	8.3 $\pm$ 1.75	268 (12)	22.3 $\pm$ 6.59
Pomacentridae	<i>Pristotis jerdoni</i>	27 (4)	6.8 $\pm$ 2.50	606 (14)	43.3 $\pm$ 19.61
Monacanthidae	<i>Paramonacanthus japonicus</i>	22 (6)	3.7 $\pm$ 0.67	86 (9)	9.6 $\pm$ 4.49
Haemulidae	<i>Pomadasyus maculatus</i>	16 (2)	8.0 $\pm$ 6.00	2 (2)	
Carangidae	<i>C. fulvoguttatus</i>	17 (5)	3.4 $\pm$ 0.81	1 (1)	
Carangidae	<i>C. talamparoides</i>	13 (1)		8 (2)	4.0 $\pm$ 3.00
Monacanthidae	<i>P. otisensis</i>	14 (5)	2.8 $\pm$ 0.58	31 (2)	15.5 $\pm$ 13.50
Sphyrnidae	<i>Sphyrna putnamiae</i>	13 (4)	3.3 $\pm$ 1.31	4 (1)	
Mullidae	<i>U. tragula</i>	13 (5)	2.6 $\pm$ 1.36	100 (7)	14.3 $\pm$ 6.52
Sparidae	<i>Argyrops spinifer</i>	10 (3)	3.3 $\pm$ 1.20	3 (3)	
Lutjanidae	<i>Lutjanus malabaricus</i>	9 (3)	3.0 $\pm$ 1.53	2 (2)	
Siganidae	<i>Siganus canaliculatus</i>	9 (2)	4.5 $\pm$ 0.50	12 (8)	1.5 $\pm$ 0.38
Apogonidae	<i>Apogon quadrifasciatus</i>	9 (1)		158 (16)	9.9 $\pm$ 3.31
Tetraodontidae	<i>Torquigener pallimaculatus</i>	8 (6)	1.3 $\pm$ 0.21	10 (5)	2.0 $\pm$ 1.00
Mullidae	<i>U. moluccensis</i>	8 (1)		3 (1)	
Carangidae	<i>Carangoides chrysophrys</i>	7 (4)	1.8 $\pm$ 0.25	1 (1)	
Mullidae	<i>Upeneus luzonius</i>	6 (3)	2.0 $\pm$ 0.58	3 (2)	1.5 $\pm$ 0.50
Monacanthidae	<i>P. lowei</i>	5 (3)	1.7 $\pm$ 0.33	38 (6)	6.3 $\pm$ 2.75
Serranidae	<i>Epinephelus sexfasciatus</i>	5 (2)	2.5 $\pm$ 1.50	3 (3)	
Mullidae	<i>U. sundaicus</i>	4 (2)	2.0 $\pm$ 1.00	34 (11)	3.1 $\pm$ 0.58
Fistulariidae	<i>Fistularia petimba</i>	4 (1)		18 (10)	1.8 $\pm$ 0.39
Synodontidae	<i>Saurida undosquamis</i>	3 (2)	1.5 $\pm$ 0.50	114 (18)	6.3 $\pm$ 1.10
Lutjanidae	<i>L. vitta</i>	2 (2)		1 (1)	
Labridae	<i>Xiphocheilus typus</i>	2 (1)		65 (9)	7.2 $\pm$ 1.84
Pinguipedidae	<i>Parapercis nebulosa</i>	2 (1)		6 (3)	2.0 $\pm$ 0.58
Chaetodontidae	<i>Coradion chrysozonus</i>	1 (1)		1 (1)	

Average abundance and standard errors are shown for each species for those transects on which they were recorded.

were not visible. This may have caused under-estimation of the true commonality of records of some *Saurida* and *Carangoides* species for the two techniques in Table 4. The records for *C. talamparoides*, *C. uii*, *Saurida undosquamis* and *S. micropectoralis* were grouped to the common level of their genus where species lists from trawls and BRUVS

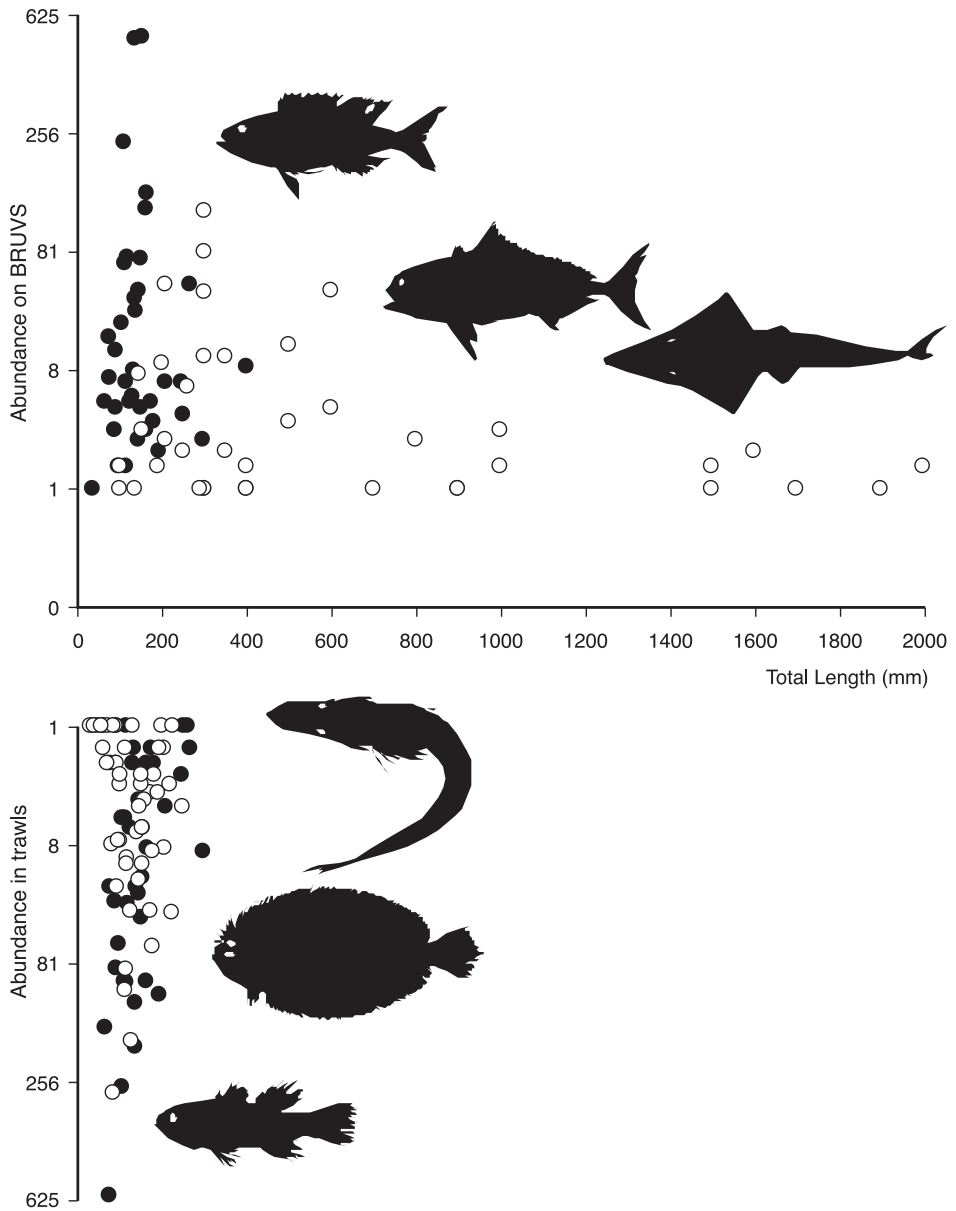


Fig. 4. Scatter plots of the average total length of each species, measured or estimated, from trawl catches and BRUVS sightings. Abundance has been scaled using the fourth root transformation. Each point represents the number of individuals of a species. Filled symbols represent species recorded by both techniques and open symbols represent species unique to each technique.

were directly compared in Fig. 6. A large proportion (42%) of the 76 species sighted by BRUVS were classified as passing through the field of view without ever feeding on the bait canister. Forty-four species (57.9%) fed on, or touched, the bait canister at least once during their appearance on BRUVS tapes.

### 3.2. Description of patterns in fish assemblages

Both techniques recorded the same general trends in ranking of transects by diversity of fish species, with the difference amongst techniques greatest at night, when trawls performed best (Fig. 5, Table 2). The Bray–Curtis dissimilarity measure and flexible UPGMA fusion strategy were used in exploratory clustering of the transformed data (Fig. 6) to investigate the associations among the fish communities. This indicated the presence of strong groupings based on splits between trawl and BRUVS, day and night, and location. The primary split in the clustering was by technique. At the higher levels of dissimilarity the day transects were clustered in two groups for both techniques with Double Island and Double Island Wide separate from Scott Reef. The night transects showed a different grouping, with distinct Double Island (trawls) and Scott Reef (BRUVS) clusters.

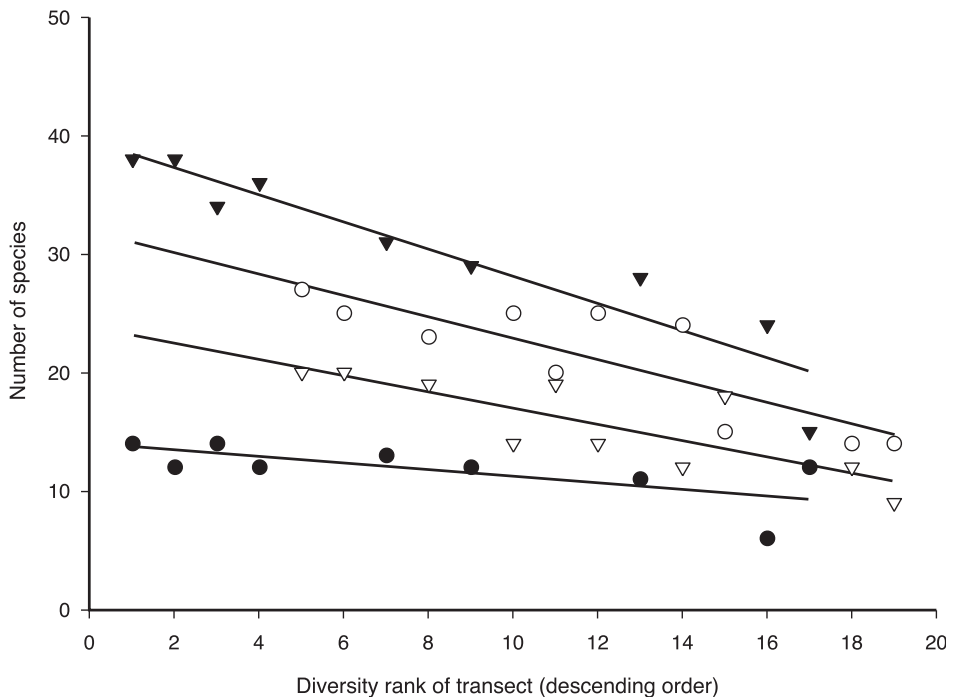


Fig. 5. Number of species recorded by BRUVS (circles) and trawls (triangles) during day and night along transects ranked in descending order of their total species diversity. Filled symbols indicate night samples, and open symbols are day sets. Lines are best fits through each combination of technique and time of day.

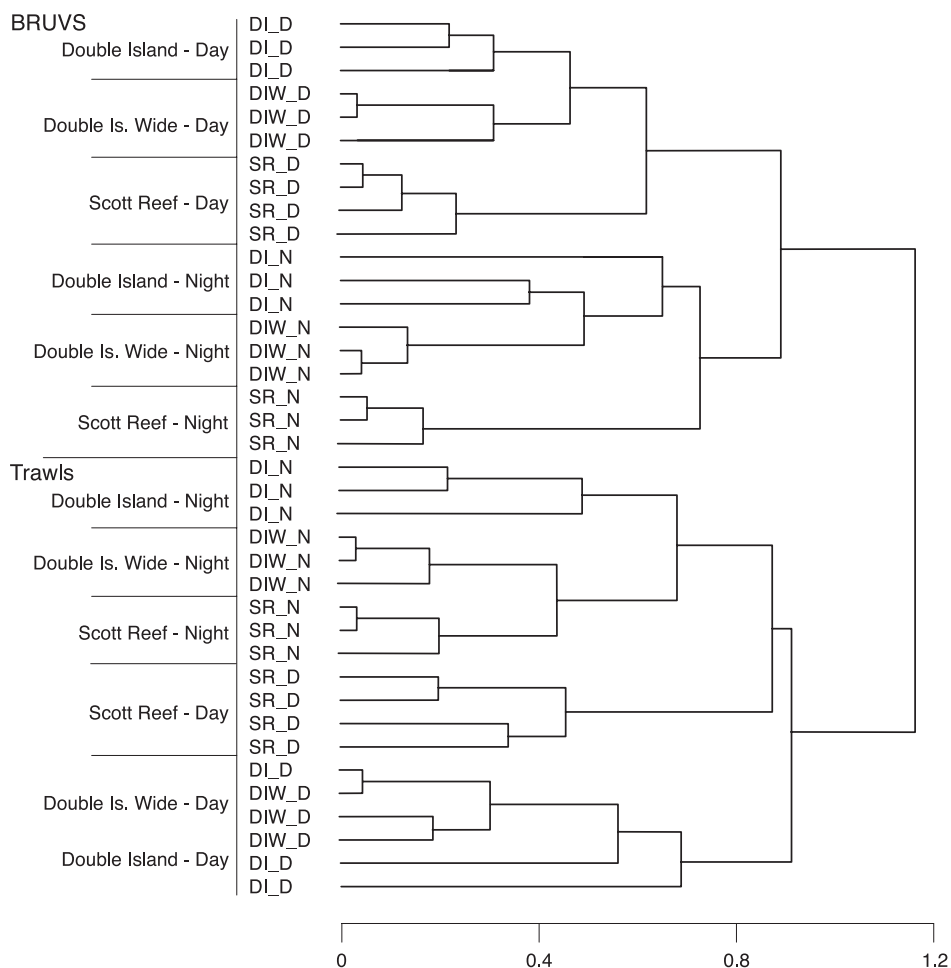


Fig. 6. Clustering of transformed abundance data using the Bray–Curtis dissimilarity measure and flexible UPGMA fusion strategy for 74 taxa recorded by BRUVS (upper) and 88 taxa caught by trawls (lower). The locations are Double Island (DI), Double Island Wide (DIW) and Scott Reef (SR). The suffixes \_N and \_D represent night and day transects.

The transformed data from transects within each of the six treatment groups are outlined by polygons in the principal coordinates analysis (Fig. 7). Both data sets showed strong group differences with the main effects of locations (DI, DIW and SR) and day–night forming the primary two dimensions in multivariate space. For the BRUVS, the first dimension showed strong day–night differences and Scott Reef separated strongly from the two Double Island locations on the second dimension. The patterns of separation for the trawls between the treatments were very similar to the BRUVS, but for trawls the variation within groups was somewhat larger. The six groups, or species assemblages, accounted for 78.9% of the distance variation for the BRUVS data and 68.9% for the trawl

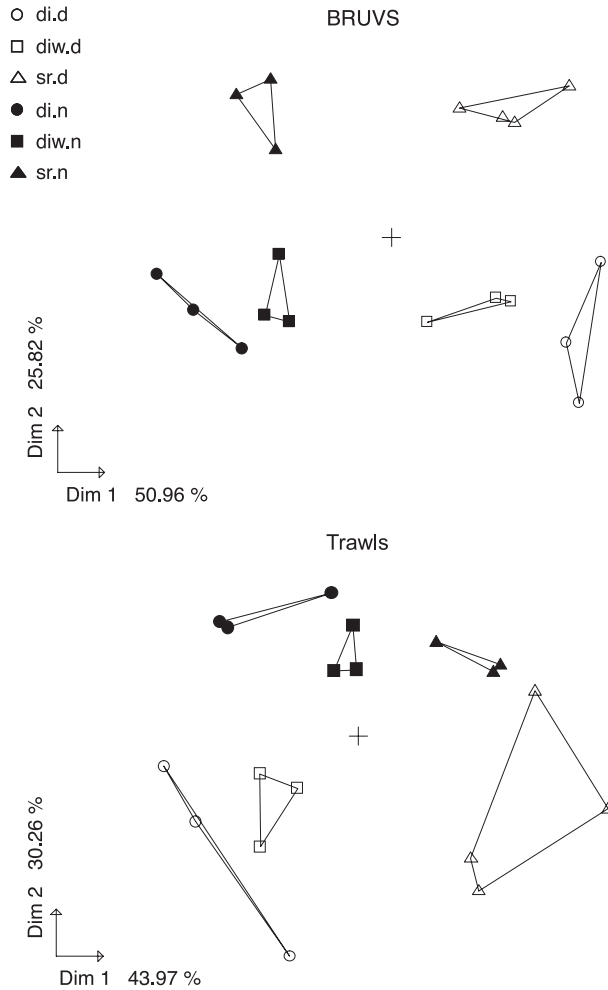


Fig. 7. Principal Coordinates Analysis (PCoA) for species recorded by BRUVS (upper) and trawls (lower). The PCoA was based on extended dissimilarities calculated from species abundances which were transformed and row standardised. The 19 transects within each of the six treatment groups (three locations by day–night) are outlined by polygons. The locations are Double Island (di), Double Island Wide (diw) and Scott Reef (sr), the filled and open symbols are night and day sets.

data (Table 5), and 83.3% for the BRUVS data and 67.8% for the trawl data when analyses were restricted to only those species recorded by both techniques (Table 6).

### 3.3. Predicting group membership

A more useful assessment of the relative effectiveness of the two techniques was their capacity to discriminate and to predict the fish assemblages represented by the six

Table 5

Distance-based redundancy analysis of full dissimilarity matrices for transformed BRUVS and trawl data.

Effect	df	BRUVS			Trawls		
		SS	Pseudo- <i>F</i>	<i>P</i>	SS	Pseudo- <i>F</i>	<i>P</i>
Locations (L)	2	2.73	8.74	<0.001	3.38	8.05	<0.001
Day–Night (DN)	1	4.40	28.2	<0.001	2.09	9.95	<0.001
L*DN	2	0.48	1.54	0.251	0.58	1.38	0.286
(L*DN)/Transect	13	2.03			2.73		

treatment groups. This was assessed using linear discriminant analysis of the principal coordinates from the extended dissimilarities. The linear discriminant analysis showed that 96.4% of the variation between the six assemblages discriminated by BRUVS was accounted for by the first two discriminant axes (Fig. 8). In the case of trawls, these two axes accounted for 94% of the variation between assemblages (Fig. 8).

Drop-out analyses were performed by repeatedly and randomly excluding one transect and predicting its group membership from the other transects. The best level predictions occurred when only the first two principal coordinates were analysed. The BRUVS data provided more accurate predictions. The error rate using the BRUVS data was 5.3% (one transect in 19), and using the trawl data the error rate was 21% (four transects in 19). Mis-classification rates also increased with the number of coordinates used (Table 7). Given the small sample size these mis-classification rates were likely to be fairly imprecise. All classification errors were within day or night groupings—that is, a “day” fish assemblage was not predicted as a “night” assemblage, and vice versa.

### 3.4. Indicator species for the six fish assemblages

Large elasmobranchs, sphyraenids and several families of eels were important in characterising BRUVS samples at night (Table 8). The Carangidae and Nemipteridae were recorded ubiquitously by BRUVS, but different members of those families characterised assemblages. The nemipterids (*Nemipterus*, *Pentapodus* and *Scolopsis*) that were major indicator species for all “day” assemblages are small mobile predators of benthic organisms and scavengers (Table 10). The four *Saurida* and *Carangoides* taxa specified

Table 6

Distance-based redundancy analysis of full dissimilarity matrices for transformed BRUVS and trawl data restricted to species recorded by both techniques

Effect	Df	BRUVS			Trawls		
		SS	Pseudo- <i>F</i>	<i>P</i>	SS	Pseudo- <i>F</i>	<i>P</i>
Locations (L)	2	2.89	12.2	<0.001	2.30	8.69	<0.001
Day–Night (DN)	1	4.01	33.9	<0.001	1.05	7.50	<0.001
L*DN	2	0.78	3.29	<0.001	0.48	1.65	0.315
(L*DN)/Transect	13	1.54			1.82		



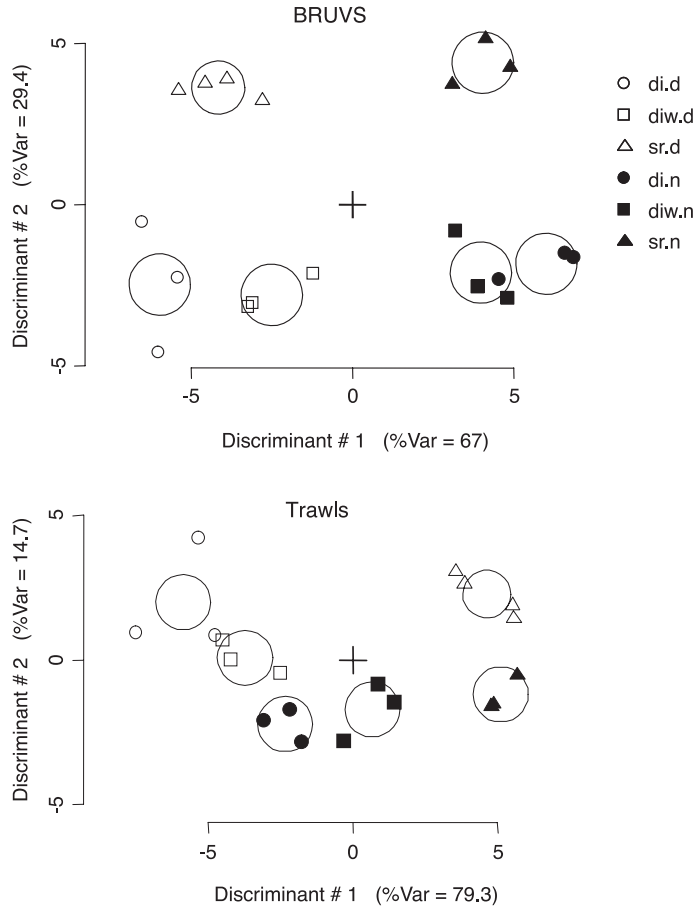


Fig. 8. Linear discriminant analysis plots based on the first 2 principal coordinates and six fish assemblages, defined by location and day–night, for the transformed BRUVS data (upper) and trawls (lower). The circles denote one Standard Error about the group means, and the symbols denote the transect means and assemblage membership. All conventions are the same as those for Fig. 7.

as higher-order indicator species for Day and Night BRUVS assemblages at Double Island Wide were considered to be separate taxa from a reference collection of images, but it is possible they were mis-identified. This would not prevent the grouping, but would change

Table 7  
Prediction of treatment groups using single drop-out linear discriminant analysis for varying numbers of variables from principal coordinates analysis (PCoA).

PCoA variables	BRUVS error rate (%)	Trawls error rate (%)
1,2	5.3	21.0
1,2,3	10.5	42.1
All	42.1	47.4

Table 8

The top six “indicator species” and their indices in brackets, defined as the product of relative abundance and relative frequency of occurrence of the species, within the six assemblages identified by BRUVS.

Double island-day	Double island-night	Double island wide-day	Double island wide-night	Scott reef-day	Scott reef-night
<i>Scolopsis taeniopterus</i> (87.4)	<i>Sphyrna putnamiae</i> (51.3)	<i>Alepes</i> sp (81.2)	<i>Saurida</i> sp (40.8)	<i>Choerodon</i> sp2 (100)	<i>Decapterus russelli</i> (95)
<i>Nemipterus hexodon</i> (69.2)	<i>Terapon theraps</i> (48)	<i>Saurida undosquamis</i> (66.7)	<i>Rhina ancylostoma</i> (33.3)	<i>Ophichthidae</i> sp (100)	<i>Muraenidae</i> sp (51.6)
<i>Upeneus sundaicus</i> (66.7)	<i>Sphyrna mokarran</i> (44.4)	<i>Sphyrna lewini</i> (66.7)	<i>Carangoides</i> sp (29.6)	<i>Pentapodus paradiseus</i> (90.8)	<i>Leiognathus</i> sp (33.3)
<i>Nemipterus peronii</i> (57.3)	<i>Stegastoma fasciatum</i> (33.3)	<i>Nemipterus nematopus</i> (60.9)	<i>Carcharhinus</i> sp (20)	<i>Paramonacanthus otisensis</i> (81.8)	<i>Muraenesox cinereus</i> (33.3)
<i>Selaroides leptolepis</i> (54.2)	<i>Pomadasys maculatus</i> (29.2)	<i>Argyrops spinifer</i> (60)	<i>Rhynchobatus djiddensis</i> (19.1)	<i>Paramonacanthus lowei</i> (75)	<i>Sphyrna jello</i> (33.3)
<i>Lagocephalus sceleratus</i> (46.4)	<i>Terapon jarbua</i> (26.7)	<i>Carangoides talamparoides/iii</i> (50.2)	<i>Conger cinereus</i> (16.7)	<i>Upeneus luzonius</i> (75)	<i>Gymnothorax minor</i> (27.6)

See Table 10 for descriptions of functional morphology and habits of these genera and families.

the ranking of these taxa amongst the indicator indices for the 32 (DIW-D) and 16 (DIW-N) other species in the groups.

A wider variety of small, sedentary species, flatfish (e.g. bothids), mobile demersal carnivores (e.g. nemipterids), cryptic demersal ambush predators (e.g. synodontids) and some small pelagic carangids, were indicator species for the assemblages identified by trawls (Table 9). The sedentary, demersal, platycephalids (*Elates* and *Suggrundus* spp.) caught by trawls and the pelagic piscivorous *S. queenslandicus* and *S. nigrofasciata* recorded by BRUVS did not appear in the top six indicator species because of the prevalence of their occurrence on many transects. In Tables 8 and 9 there were only five species common to four of the assemblages identified by both techniques: *Upeneus sundaicus* (Double Island-Day); *Terapon theraps* (Double Island-Night); *Argyrops spinifer* and *S. undosquamis* (Double Island Wide-Day); and *Choerodon* sp2 (Scott Reef-Day). These were relatively small (mainly 150–300 mm TL), mobile, demersal predators of benthic invertebrates and fish, with the exception of the ambush predator *S. undosquamis* (see Table 10).

### 3.5. Logistical considerations

The performance of BRUVS was governed by the prevailing levels of light and water clarity, and even moderate levels of turbidity can drastically alter the ability to identify and count fish in the field of view in deeper water. Trawls provided the highest possible level of taxonomic classification when specimens were retained, and can be used in any levels of turbidity or time of day. The need to freeze part or all of the trawl catch for later identification imposed strict limits on the type and size of vessel to be used in trawl surveys, but a fleet of BRUVS can be used from smaller, less specialised platforms. Each BRUVS along a transect was set and retrieved rapidly (every 3–5 min), but the vessel had to retrace its path to retrieve them, consuming 90 min in the completion of a 60-min BRUVS transect. The trawls consumed only 20 min fishing on the seabed for each transect, because the extra 10–15 min needed for setting and hauling the net was done whilst continually steaming toward new stations. The catch was partially processed during this time. The greatest time penalty in accumulating biodiversity data from the BRUVS was the need for a single skilled observer to scan 5 h of videotape for each transect. This was shortened markedly, depending on the number and abundance of fish in the field of view, with the aid of fast-forward playback. Trawl samples were rapidly sorted and processed once a reference collection was assembled and identified, and this reference collection aided in the identification of the BRUVS reference images. The overall ratio of staff time in the field and laboratory to obtain the final BRUVS and trawl data was 3:2.

Linear discriminant analysis of the transformed *MaxN* abundance data showed the number of BRUVS set per transect might have been reduced from five (a 5.3% error rate) to three (a 14.9% error rate) without compromising sensitivity to patterns in fish assemblages (Table 11). The average time elapsed before first sighting (*TFAP*) of all species over all BRUVS during the one hour sets was  $16 \pm 14$  min, and the average time elapsed before *MaxN* occurred was  $23 \pm 16$  min. Re-analysis of tapes to ascertain the species accumulation and abundance curves by soak time and number of replicates

Table 9

The top six “indicator species” and their indices in brackets, defined as the product of relative abundance and relative frequency of occurrence of the species, within the six assemblages identified by trawls.

Double island-day	Double island-night	Double island wide-day	Double island wide-night	Scott reef-day	Scott reef-night
<i>Apogon quadrifasciatus</i> (55.5)	<i>Pseudotriacanthus strigilifer</i> (100)	<i>Saurida micropectoralis</i> (45.4)	<i>Dactylopus dactylopus</i> (92.4)	<i>Choerodon</i> sp2 (66.3)	<i>Engyprosope</i> sp (100)
<i>Xiphocheilus typus</i> (46.1)	<i>Terapon theraps</i> (74)	<i>Argyrops spinifer</i> (44.4)	<i>Euristhmus nudiceps</i> (87.5)	<i>Grammatobothus pennatus</i> (50)	<i>Parapercis nebulosus</i> (100)
<i>Upeneus sundaicus</i> (41.2)	<i>Carangoides talamparoides</i> (66.7)	<i>Carangoides chrysophrys</i> (33.3)	<i>Priacanthus tayenus</i> (69.8)	<i>Anacanthus barbatus</i> (25)	<i>Yongeichthys nebulosus</i> (100)
<i>Leiognathus moretoniensis</i> (33.3)	<i>Leiognathus</i> sp1 (66.7)	<i>Pseudochromis quinquedentata</i> (33.3)	<i>Nemipterus nematopus</i> (61.6)	<i>Antennarius</i> sp (25)	<i>Upeneus tragula</i> (93.9)
<i>Lutjanus vitta</i> (33.3)	<i>Upeneus sulphureus</i> (63.6)	<i>Saurida undosquamis</i> (24)	<i>Pseudorhombus elevatus</i> (49.1)	<i>Centriscus scutatus</i> (25)	<i>Trachinocephalus myops</i> (91.7)
<i>Pentaprion longimanus</i> (33.3)	<i>Nemipterus hexodon</i> (60.2)	<i>Pseudotriacanthus strigilifer</i> (100)	<i>Apistus carinatus</i> (46.7)	<i>Pseudorhombus duplicicellatus</i> (25)	<i>Lepidotrigla japonicus</i> (90)

See Table 10 for descriptions of functional morphology and habits of these genera.

Table 10

The functional morphology, habits and approximate, reported size range of adults or juveniles\* (after Gloerfelt-Tarp and Kailola, 1984; Sainsbury et al., 1985) of the genera and families mentioned in the text and tables.

Genera	Family	Common Name	Total length (cm)	Habit and morphology
<i>Carcharhinus</i> , <i>Sphyrna</i>	Carcharhinidae, Sphyrnidae	whaler and hammerhead sharks	200–350	pelagic, fusiform carnivores
<i>Rhynchobatus</i> , <i>Rhina</i> , <i>Stegastoma</i> , <i>Dasyatis</i>	Rhynchobatidae, Stegastomatidae, Dasyatididae	shovelnose and shark rays, stingrays	200–350	demersal, dorso-laterally flattened benthic carnivores of macro-invertebrates
<i>Gymnothorax</i> , <i>Muraenesox</i> , <i>Conger</i>	Muraenidae, Congridae, Muraenesocidae, Ophichthidae	moray, conger, snake eels	150	demersal, burrowing, elongate carnivores
<i>Euristhmus</i>	Plotosidae	eel-tail catfish	75	demersal, elongate, heavy venomous spines
<i>Saurida</i> , <i>Trachinocephalus</i> , <i>Parapercis</i>	Synodontidae, Pinguipedidae	lizardfish, grubfish	20–60	demersal, cryptic, carnivorous ambush predators, somewhat dorso-laterally flattened
<i>Antennarius</i>	Antennariidae	anglerfish	5	sedentary, demersal, ball-shaped ambush predators
<i>Fistularia</i>	Fistularidae	cometfish	50	extremely elongate, hovering ambush predators
<i>Dactyloptena</i> , <i>Lepidotrigla</i> , <i>Dactylopus</i>	Dactylopteridae, Triglidae, Callionymidae	flying gurnards, gurnards, dragonets	10–30	demersal, casque-like or flattened shape, bony or spiny heads; some venomous or toxic; broad or wing-like pectoral or dorsal fins used to perch or glide
<i>Centriscus</i>	Centriscidae	razorfish	10	armoured, extremely laterally compressed, elongate
<i>Elates</i> , <i>Suggrundus</i> , <i>Apistus</i>	Platycephalidae, Scorpaenidae	flathead, scorpionfish	10–40	demersal, sedentary and cryptic, dorso-ventrally flattened, heavy head spination (sometimes venomous)
<i>Pseudochromis</i> , <i>Epinephelus</i>	Pseudochromidae, Serranidae*	dottybacks, groupers	10–30*	demersal, carnivorous, sedentary
<i>Terapon</i>	Teraponidae	grunters	25	mobile, schooling, demersal omnivores and scavengers
<i>Priacanthus</i>	Priacanthidae	bigeyes	25	nocturnal planktivore; thick rough skin, heavy spines

<i>Apogon</i>	Apogonidae	cardinalfish	5–10	nocturnal, schooling; hovering planktivore
<i>Carangoides, Selaroides, Alepes, Rachycentron</i>	Carangidae, Rachycentridae	jacks, trevallies, cobia	20–150	gregarious, pelagic, laterally compressed or fusiform, fast-moving carnivores and planktivores
<i>Echeneis</i>	Echeneidae	remoras	70	pelagic scavenger
<i>Leiognathus, Pentaptrion</i>	Leiognathidae, Gerreidae	ponyfish, mojarras	10–15	schooling, deep-bodied, laterally compressed benthic carnivores of invertebrate infauna and epifauna
<i>Lutjanus, Pomadasys, Argyrops</i>	Lutjanidae*, Haemulidae, Lethrinidae, Sparidae, Sciaenidae	snappers, grunts, emperors, porgies, croakers	15–40*	laterally compressed, heavily scaled, mobile, demersal carnivores of epibenthic invertebrates and fishes
<i>Nemipterus, Pentapodus, Scolopsis</i>	Nemipteridae	threadfin breams	20–35	mobile, schooling benthic predators of invertebrates
<i>Upeneus</i>	Mullidae	goatfish	15–30	mobile, predators of benthic invertebrate infauna
<i>Pristotis</i>	Pomacentridae, Caesionidae	damselfish, fusiliers	5–30	schooling planktivores
<i>Sphyraena, Scomberomorus</i>	Sphyraenidae, Scombridae	barracuda, spanish mackerels	38–70	pelagic, fusiform piscivores
<i>Choerodon, Xiphocheilus</i>	Labridae	wrasse	10–15	demersal, benthic carnivores of invertebrates
<i>Yongeichthys</i>	Gobiidae, Blenniidae	gobies, blennies	5–10	demersal, sedentary carnivore; in holes and burrows
<i>Siganus</i>	Siganidae	rabbitfish	20	schooling, demersal herbivores with venomous spination
<i>Engyprosopon, Pseudorhombus, Grammatobothus</i>	Bothidae, Psettodidae	flounders, soles	20–40	demersal, sedentary, cryptic ambush predators and carnivores of benthic invertebrates
<i>Paramonacanthus, Anacanthus, Pseudotriacanthus</i>	Monacanthidae, Triacanthidae, Balistidae	filefishes, triplespines, triggerfishes	10–50	demersal, omnivorous, heavy barbed spines, thick rough skin or heavy scales, laterally compressed
<i>Lagocephalus, Torquigener</i>	Tetraodontidae, Ostracidae	puffers, boxfishes	15–30	demersal, ball-shaped, slow-moving, omnivorous with thick or armoured skin; some with toxic flesh

Table 11

The percentage error in prediction of group membership, with Standard Deviation shown in brackets, for reduction in BRUVS fleet size along the one nautical mile transects.

Number of principal coordinates	Number of BRUVS			
	4	3	2	1
1, 2	13.3 (7.2)	14.9 (9.3)	16.7 (8.2)	24.3 (11.7)
1, 2, 3	15.3 (9.7)	16.7 (8.6)	16.6 (6.9)	24.9 (9.7)
All	21.9 (6.6)	23.5 (8.8)	22.4 (8.7)	26.4 (9.4)

The “drop-out” analyses were based on simulations in the existing data of repeated random selection of reduced fleet configurations.

could be conducted to refine decisions on sampling effort, but this is likely to vary with habitat type.

#### 4. Discussion

Studies of status and trends in multiple-use zones of marine protected areas require accurate estimates of species richness and abundance. A theoretical basis for the relationships between collecting effort and the number and abundance of species recorded provides both a planning tool for sampling expeditions and a predictive tool for conservation and biodiversity studies (Soberon and Llorente, 1993). A first step in the planning process is to explore alternative or complementary sampling techniques, and we argue that the ability of different techniques to distinguish spatial and temporal patterns is of prime importance in most monitoring studies, and might be assessed with less field sampling than the intensive effort needed to establish definitive species accumulation curves in diverse faunas.

The field comparison of baited remote underwater video stations (BRUVS) and industry-standard prawn trawls showed that both techniques detected the same spatial and temporal patterns in assemblages of fish biodiversity despite sampling quite different portions of the fish fauna inhabiting commercial prawn trawl grounds. The relatively small sample size was insufficient to derive definitive species accumulation curves, and total species richness estimates, for the different assemblages, but important conclusions can be drawn from the curve shapes. Diversity, in terms of Simpson’s and Shannon–Weiner indices, is positively correlated with the initial slope of species accumulation curves (Thompson et al., 2003), so the curves for BRUVS and trawls were expected to cross if one sampling technique recorded a high proportion of both rare and abundant species compared with the other with a more even distribution of abundance amongst species. Instead, both curves were parallel and had very similar slopes and shapes, with BRUVS consistently about 11 species behind trawls for any extra transect, low inflection points on the ordinate axis and a long upward slope to the asymptote. This curve shape is characteristic of faunas with a high proportion of rare species and a few abundant species (see Thompson and Withers, 2003; Magurran and Henderson, 2003).

Teleost and elasmobranch faunas of soft-sediment trawl grounds in the tropics are characterised by high diversity (e.g. Ramm et al., 1990), and the limited sampling with



BRUVS and prawn trawls recorded less than half (128 species) the number of species recorded in more extensive studies of similar habitats. In latitudes further north (11–16 °S), Wassenberg et al. (1997) caught over 340 species of teleosts and elasmobranchs (243 by prawn trawl), and Stobutzki et al. (2001a) recorded over 350 species of these two groups in prawn trawls. These inventories were dominated by species that occurred rarely and in low abundance and biomass. Stobutzki et al. (2001a) found that 75% of species occurred in less than 10% of prawn trawls and were caught at low rates ( $<10$  individuals  $\text{h}^{-1}$  and  $<1$  kg  $\text{h}^{-1}$ ). Like estuarine fish faunas (Magurran and Henderson, 2003), the teleosts and elasmobranchs on tropical trawl grounds probably comprise “core species” which are persistent, abundant and biologically associated with particular habitats and “occasional species” which occur infrequently in sampling records, are typically low in abundance and have different habitat requirements. The different distributions of these two groups can markedly increase the sampling effort needed to encounter the rarer species and those that have very small home ranges or avoid the sampling gear (Thompson and Withers, 2003).

As expected, the diverse assemblages on the Scott Reef grounds, south of Cape Grafton, were distinct from the northern grounds off Double Island, and day–night differences were significant. Significant offshore differences in fish assemblages were also detected between the shallow, inshore Double Island (18–23 m) and deeper, offshore Double Island Wide (31–33 m) grounds. Even when analyses were restricted to the fish species common to both techniques, the same six fish assemblages were distinguished, but with marked differences in the relative abundance of many species. There were only five small, mobile species common to both techniques in the lists of top indicator species for these assemblages. The somewhat lower taxonomic resolution of the BRUVS would tend to reduce the statistical power to discriminate between community types, yet the BRUVS technique more precisely and accurately described and predicted the fish assemblages in the field comparison. The BRUVS data produced greater separation of the fish assemblages than trawls, with the grouping into six fish assemblages accounting for 78.9% of the distance variation in the BRUVS data and 68.9% in the trawl data. The BRUVS also had a lower error rate in discriminating between the six fish species assemblages.

Both techniques showed selectivity in distinguishing the fish assemblages, but without a better knowledge of the true composition of the fish fauna in the study locations it was not possible to precisely identify these biases to adequately assess “rarity” and other biodiversity indices. The trawl nets fitted with bycatch reduction devices exclusively sampled small (mainly  $<300$  mm), demersal, sedentary or cryptic species—such as bothids, platycephalids, apogonids, synodontids, triglids and callionymids. The BRUVS recorded more larger, mobile species from a much wider size range of families, including large sharks and shovelnose rays, many more pelagic species (such as carangids and scombrids) and numerous mobile eels. Herbivorous siganids were rarely recorded by BRUVS, but were more common in trawls. Mobile scavengers and benthic carnivores such as nemipterids and teraponids were abundantly recorded on BRUVS and caught in lesser numbers in trawls. The occurrence of some small mobile species was common to both techniques, but most showed marked differences in relative abundance. The BRUVS performed best in the day, and trawls caught more species at night.

Some aspects of these differences can be expected on the basis of how each technique operates. Trawls disturb the seabed sufficiently to scare flatfish and other

sedentary or resting species upward and into their aperture (Stobutzki et al., 2001b). Small, diurnal schooling species, such as the pomacentrid *P. jerdoni*, and small, diurnal territorial species (possibly labrids like *Choerodon* sp2) might therefore be expected in larger numbers in trawls—especially at night. Large shovelnose rays and sharks may have been excluded from the nets by the bycatch reduction devices, but the total lack of eels in trawls is less readily explained. The small moray *Gymnothorax minor* was ubiquitous on BRUVS sets along many transects. Eels may have sheltered in holes in the seabed upon the approach of a trawl footrope, or may have escaped the trawl net by squeezing through the meshes. The cryptic and sedentary habits of the bothids and platycephalids explains their absence from BRUVS records, but the lack of relatively large priacanthids and small schooling apogonids that feed in the water column was unexpected. It may be that these fish shelter by day on the seabed, or in holes formed by bioturbators of the sediments.

The specific differences in species richness reported here are similar to a comparison of the catches made by Frank and Bryce fish trawls and prawn trawls in the far northern section of the GBRMP (Wassenberg et al., 1997). The fish trawl was expected to sample fish more effectively, because it had a higher headline opening (4–5 m) and was linked to the otter boards by very long bridle wires known to herd fish toward the net (Ramm and Xiao, 1995). Wassenberg et al. (1997) recorded 236 species of teleosts and elasmobranchs in the fish trawls and 243 species in prawn trawls, with 141 species common to both techniques. Like the BRUVS, the species caught only by the fish trawl were mainly pelagic species (scombrids, carangids) or large specimens of large species (lutjanids, sharks, rays)—while the fish caught only by the prawn trawl were small benthic species, such as apogonids, platycephalids, scorpaenids and flatfish. For seven species, the prawn trawl caught significantly smaller specimens, and over 80% of the fish caught by both nets were small (< 300 mm standard length). There were also significant day–night differences in vulnerability to capture.

Baited videos record species attracted to the bait plume or camera station, species attracted to the commotion caused by feeding and aggregation at the station, and species indifferent to the station but present in or passing through the field of view. The dynamics of visitation, attraction (or repulsion) and species replacements are species-specific and largely unknown (Sainte-Marie and Hargrave, 1987; Armstrong et al., 1992). Strongly site-attached and territorial species might have been unavailable for survey by BRUVS settling outside their territory. Agonistic behaviour may have repelled, or caused competition for, visitation opportunity by other species and conspecifics (Armstrong et al., 1992). Indications of some of these factors were available from the footage.

Whilst BRUVS may have better described the spatial patterns of relative abundance for fish biodiversity assessments, their results could not be simply expressed in terms of absolute density or biomass. The “biomass per swept area” of each species can be readily calculated from timed trawls, but this statistic can be severely biased by the behaviour, size, body shape and position in the water column of different fish species (Adams et al., 1995; Ramm and Xiao, 1995). The “area fished” by BRUVS was unknown, and the depth and width of the field of view was not fixed. The use of stereo–video camera systems can overcome some of these deficiencies by providing range, aspect, bearing and size of

subjects. Fields of view can therefore be readily fixed, and fish within them can be precisely and accurately measured (Harvey et al., 2002b, 2003) for length (and weight) estimates.

Robust models of bait plume dynamics and fish visitation rates will be needed to estimate the sampling areas of BRUVS and convert the counts of fish sightings to density estimates. Models using fish swimming speed, current velocity, *TFAP* and *MaxN* at given time periods have been developed by Priede and Merrett (1996) and Sainte-Marie and Hargrave (1987) to estimate density of abyssal scavengers. The model proposed by Priede and Merrett (1996) has an inverse relationship between fish abundance and the square of the average arrival time at the bait station. This complicates its direct application to the data for shallow-water fishes in short sets, because small changes in rapid arrival times cause major changes in theoretical density estimates (see Yau et al., 2001), and shallower deployments produce far larger numbers of fish in the field of view.

The  $n_{\text{peak}}$  of Priede et al. (1994), the *MAXNO* of Ellis and DeMartini (1995), the *MAX* of Willis and Babcock (2000) and the *MaxN* of the current study are all homologous. This statistic under-estimates the true abundance of visiting fish in the bait plume. The occurrence of separate visits by different individuals of the same species is recorded as *MaxN* = 1, and only a portion of a partially visible fish school contributes to *MaxN*. This usage implies more conservative estimates of abundance in high-density locations, and therefore differences detected between locations of high and low abundance are also likely to be more conservative.

Priede and Merrett (1996) and Priede et al. (1990) have argued that *MaxN* is invalid as an estimator of abundance, because the number of fish visible is the result of an equilibrium between arrivals and departures, and the staying time of an animal at an exhaustible food source is inversely related to the probability of finding an alternative food source. Thus Priede et al. (1994) found the  $n_{\text{peak}}$  of abyssal grenadiers was higher at an oligotrophic location with low fish population and low food abundance because individuals stayed longer at the bait, whereas in a food rich area with high population density the arrival rate was high because of the higher population, but  $n_{\text{peak}}$  was low because individuals gave up and left within an hour.

In contrast, Ellis and DeMartini (1995) found that *MaxN* for a juvenile lutjanid and a tetraodontid was highly correlated with the total duration on film and time to first appearance of the respective species. *MaxN* and *TFAP* were highly correlated, suggesting the greater the fish density, the faster the fish arrived at the bait. They also found a correlation between *MaxN* and long-line catch rates, and concluded that baited video studies on shallow, productive grounds (<80 m) with short soak times could not be compared directly with the work on scavengers in abyssal waters with very long sets. Willis and Babcock (2000) and Willis et al. (2000) found that *MaxN* was correlated with abundance of a sparid and a parapercid, and the parapercid responded to bait so well that *TFAP* did reflect abundance accurately.

The spacing of the BRUVS 450 metres apart along transects was designed to minimise the possibility of large-scale interference of the replicates in our study. Ellis and DeMartini (1995) proposed that at distances  $\geq 100$  m their replicate 10 min sets of baited videos were independent, because the greatest distance of fish attraction was only 48–90 m for a

200 mm fish in a current velocity of  $0.1\text{--}0.2\text{ m s}^{-1}$ . This assumed a maximum swimming speed of approximately three body lengths per second for a 200 mm fish ( $V_f = 0.6\text{ ms}^{-1}$ ). Given a seasonal prevalence of current of  $\sim 0.2\text{ m s}^{-1}$  in our study locations ( $V_c$ ), the 60 min ( $S_t$ ) soaks of the BRUVS may have had an effective range of attraction ( $AR$ ) of  $\sim 480\text{ m}$  for fish of  $\sim 200\text{--}300\text{ mm}$  length. This comprises 40 min of advection of the bait plume down-current and 20 min of fish swimming time up-current to reach the field of view in time to be recorded on the BRUVS. We formalised this relationship as  $AR = 60 \times (S_t) \times ((V_f \times V_c) - V_c^2)/V_f$ . It is possible that some large, mobile species may have visited more than one BRUVS replicate within a transect, but confusion of catch amongst trawling locations was also possible when there was inadequate removal of fish from the net wings between trawls.

There may be a particular role for baited video techniques in studies of large elasmobranchs and teleosts (e.g. serranids) of special conservation interest. These groups have undergone global decline (Myers and Worm, 2003) and non-extractive, fishery-independent sampling techniques are desirable to assess their population status (Greenstreet and Rogers, 2000). Stobutzki et al. (2002) proposed that the elasmobranchs least likely to sustain populations in one prawn fishery were demersal batoids that feed on benthic organisms and are highly susceptible to capture in trawls. Some of these more vulnerable species have been recorded by BRUVS, but the rarer ones will always remain difficult to assess because the sampling unit cannot match their distribution and low abundance. The use of stereo-video pairs would improve the information gained from such rare sightings by providing morphometric measurements and recognition of individuals (Harvey et al., 2003).

There is unlikely to be much potential for the use of BRUVS in assessing status and trends in the individual populations of teleost “bycatch species” most vulnerable to prawn trawling in this region. Using meta-analysis of life history traits and susceptibility to capture, Stobutzki et al. (2001b) concluded that these teleosts came from the families Apogonidae, Ariidae, Bathysauridae, Callionymidae, Congridae, Diodontidae, Labridae, Opisthognathidae, Plotosidae, Synodontidae and Tetraodontidae. Our comparison showed that BRUVS were not as useful as prawn trawls in recording many species from these families. A Frank and Bryce fish trawl might offer a better sampling technique than a combination of BRUVS and prawn trawls to accumulate species inventories, but catch rates are so high ( $395 \pm 141.3\text{ kg h}^{-1}$  in Wassenberg et al., 1997) that their routine scientific use in the GBRMP would be undesirable.

Trawls can be used in most currents, sea states and any time of day and levels of turbidity. The performance of BRUVS was limited most by prevailing clarity of the water column and light levels. The ability to more accurately identify retained trawl specimens enabled a refinement of species identifications made from the BRUVS imagery. Logistically, trawls are attractive to survey fish biodiversity on suitable seabeds because they can be deployed and the catch partially processed whilst the research vessel is continually steaming toward new stations. BRUVS can be deployed from smaller, less costly platforms by unskilled operators, but the easy completion of many transects produces a much larger workload for skilled observers in tape interrogation than that needed to process trawl samples. Greater gains in efficiency of the BRUVS technique can be made by assessing the accumulation of new species sightings with a

reduced number of BRUVS replicates and with reduced set times. These relationships are likely to be habitat-specific.

The ability to rapidly, precisely and non-extractively sample reef edges and bases, hard outcrops and shoals is a major advantage offered by BRUVS for comprehensive surveys of seafloor biodiversity. Research trawls are not accomplished easily on such seabed topographies, nor are they permitted in many zones of the GBRMP. Trawls cannot detect small-scale variation in species composition and abundance along transects, nor do they provide any information about the immediate habitat that fish are taken from. [Watson and Goeden \(1989\)](#) concluded that the soft-sediment fish fauna in the GBRMP is abruptly distinct from the fauna inhabiting complex topography such as reef bases. The use of BRUVS provides imagery of the benthos and sediments inhabited by the fish targets, allowing detection of such small-scale (metres to hundreds of metres) differences in species composition and behaviour, and providing a basis for explanation of the existence of distinct fish assemblages in terms of directly measured environmental covariates.

## 5. Conclusions

Prawn trawls caught mainly small, sedentary, demersal species and baited video records were biased toward larger, mobile, demersal and pelagic species. These techniques would complement one another in a comprehensive assessment of fish biodiversity. Despite their biases, both techniques had species accumulation curves of similar shape and both detected the same spatial and temporal groupings of fish assemblages on commercial trawl grounds. Whilst the use of baited videos alone might provide a more precise assessment of such spatial patterns in waters of suitable clarity in the Great Barrier Reef Marine Park, they could not replace trawls to make ecological risk assessments for the most sensitive teleosts taken as bycatch in the prawn trawling industry. In this regard the baited video technique might offer supplementary information on some mobile species—particularly the larger, rarer elasmobranchs and teleosts of greater vulnerability to the effects of fishing. The area sampled by the baited video must be modelled to convert estimates of relative abundance from video sightings to density estimates. The greatest advantage of the baited videos lies in their ability to non-extractively sample a wider range of fish functional groups on any seabed topography.

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