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Relative efficiency of fishing gears and investigation of resource availability in tropical demersal scalefish fisheries

FRDC REPORT – PROJECT 2006/031

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Contents

Non-technical summary

2006/031 Relative efficiency of fishing gears and investigation of resource availability in tropical demersal scalefish fisheries

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Objectives

1. Determine the relative catching efficiency of trap and line fishing gears in the NDSF.
2. Determine the availability and spatial distribution of fish resources harvested by the NDSF.
3. Develop a long-term monitoring program for the NDSF that incorporates fishery independent monitoring.

Outcomes achieved to date

This project has provided an understanding of the relative catching efficiency of trap fishing gears used in the Northern Demersal Scalefish Fishery (NDSF) compared to other gears such as baited cameras and fish trawls, including an assessment of whether the catch in the NDSF is representative of the fish available for harvest. It has enabled an initial examination of interactions between fish species and the fishing gear, plus it has determined the nature of resource availability in the NDSF and the spatial distribution of fish resources based on geography and habitat and has directly contributed to improved confidence in current stock assessment models. Important factors that may need to be considered for long term monitoring programs for the assessment of the NDSF including fishery independent indicator surveys were identified.

This project identified that there is substantial spatial variation in the demersal fish assemblages in the NDSF with some species more abundant in the north of the fishery and others in the south. At finer scales within sites and depths there is spatial variation associated with different habitats (e.g. sand vs sponge gardens or reef).

We demonstrated that the fishery independent data collected from stereo-BRUV deployments provide very similar length frequency information for target fishes to those obtained from fish caught in traps. The lack of significant differences in the length structure of the target species between fish traps and stereo-BRUVs indicate that fish collected from commercial fish traps are representative of what is available for capture (assuming stereo-BRUVs are non-selective and are a robust measure (exhibit similar biases).

This finding is important because it indicates that representative samples from trap catches should provide a robust and reliable means of sampling each indicator species for stock assessment. This finding will directly contribute to improved confidence in the results of the current stock assessment models for this fishery.

Stereo-BRUVs sampled many more species (both target and non target) than traps while the trawl survey recorded 30% more species than the stereo-BRUVs. The catch of the fish trawls were highly variable between replicate samples. Fish trawls were undertaken in soft bottom areas away from trapable areas to examine resource availability. The high variability in trawl catches and the habitat in which trawls were used resulted in trawls not being considered to be a cost effective or robust method for developing a long-term monitoring program. Additonally, trawls are perceived as being inappropriate for routine surveys.

By comparison a pilot study demonstrated that stereo-BRUVs had greater statistical power than fish traps to detect changes in abundance. Hence we have recommended the development of a long term monitoring program every four years that utilises stereo-BRUVs as the sampling tool. This program would provide data for the Western Australian EBFM process in this fishery, but also on the relative abundance, length and biomass of target species. This program should occur in predetermined (fixed) locations to minimise variability associated with the fine scale spatial variation in the fish assemblages associated with sampling different habitats. To be cost effective we recommend that the platform for this monitoring program should be commercial vessels using both stereo-BRUVs and fish traps independently.

Cameras placed inside the traps showed that there were a number of commercially valuable species which were seen regularly outside the traps, but which were rarely caught. These fish may be targeted through gear development, which will potentially increase the available catch to fishers in the NDSF.

Keywords: BRUVs, fish traps, demersal fish, fisheries management.

Acknowledgments

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Background

Assessments for sustainable management of tropical multi-species demersal finfish fisheries rely primarily on industry catch records. These essential catch based assessments rely heavily on assumptions about the catchability of the individual species relative to the fishing gear used. In the NDSF, the lack of fishery independent data to validate these assumptions in regard to trap fishing has led to industry concerns that the stock assessments are significantly underestimating stock abundance.

Industry echo-sounder observations of schools of fish in the NDSF, which are 'uncatchable' at the time, have led to a series of requests for research to improve the reliability of the stock assessment process. Resolution of these questions regarding trap efficiency and stock assessment for 'effort' quota setting in the NDSF also has wider value in the management of tropical reef fish across northern Australia. That is, trap fishing is a cost effective and ecologically acceptable method for the sustainable harvesting of these valuable resources. This project has national relevance to other trap fisheries.

Need

There is an urgent need for fishery independent data to improve and calibrate abundance measures of tropical demersal finfish species derived from commercial catch data that underpins stock assessments and quota-setting processes. More specifically, species-specific catchability measures are required for the main target species in the NDSF and other similar fisheries, to determine how the landed catch of each species relates to the overall biomass of the stock in the fishery region. At present the limited understanding of the catchability relationship is allegedly constraining the development of this fishery due to the perception of conservative management effort quota levels. This project used 'baited remote underwater stereo-video' (stereo-BRUVs) and research vessel trawl surveys to directly assess the size composition and abundance of relevant fish species in trap and line fishing areas to generate the necessary data on catchability for each fishing method. The trawl survey derived size composition data for target species will also be used to meet the need for unbiased population samples in the stock assessment models, and will be designed to be replicated in the future (at an appropriate temporal scale). The successful completion of this project will meet the requirement for more precision in the stock size estimates and therefore meet industry's requirement for an optimal and possibly less constraining approach to effort quota setting in the NDSF and similar fisheries.

Objectives

1. Determine the relative catching efficiency of trap and line fishing gears in the NDSF
2. Determine the availability and spatial distribution of fish resources harvested by the NDSF
3. Develop a long-term monitoring program for the NDSF that incorporates fishery independent monitoring

1.0 Determine the relative catching efficiency of trap fishing gears in the NDSF.

1. We compare catches from commercial fish traps to the relative abundances and lengths of fish sampled by baited remote underwater stereo-video.
2. Using imagery recorded by a camera mounted in commercial fish traps we compare the numbers of fish seen outside the trap with the numbers of fish actually caught.

1.1 Methods

1.1.1 Traps

Samples were collected from a commercial fishing vessel from four sites at two depths in the dry seasons (June) of 2007, 2008, and 2009 using the local knowledge of the skipper to select sampling locations. Data were collected from a total 356 traps (185 shallow (70-95 m; mean 84.4 m) and 171 deep (100-130 m, mean 113.6 m) over the three years. For the purpose of comparing catches by traps and fish seen on stereo-BRUVs we have pooled data across sites, depths and years.

Sampling was undertaken from commercial fishing vessels using steel traps of the type used by the commercial fishers in the Northern Demersal Scalefish Fishery. The traps are rectangular with rounded corners measuring 600 mm in height, 1500 mm in length and 1200 mm in width, and were covered by square steel mesh of 50 mm, apart from the side that contained the entrance of the trap. The width of the vertical entrance to the trap was 600 × 200 mm, tapering to 600 × 100 mm internally. The traps were baited using 1 kg of mulched fresh pilchards (*Sardinops sagax*) placed in a mesh box. Bait was still present in all traps when retrieved at the end of sampling. Traps were left to soak for up to 3 hours.

Each fish caught by each individual trap was identified to species level using the descriptions given in Carpenter and Niem (2001), and its fork length measured to the nearest 1 mm. We also follow the nomenclature of Smith and Craig (2007) based on their molecular analyses to resolve the relationships among serranid and percid fishes by adopting the resurrected Family Epinephelidae.

1.1.2 Trap cameras

Video cameras in underwater housings were mounted inside a trap (Plate 1). The cameras were positioned so that fish could be seen entering and exiting the trap. Fish behaviour could be seen in half of the trap and fish outside the trap around the entrance could also be seen. Imagery was collected from 241 traps.

Plate 1. Example of video cameras in underwater housings mounted inside a fish trap.

1.1.3 Stereo-BRUVs

We conducted replicate stereo-BRUVs deployments at each location and depth where the traps were set in dry seasons (June) of 2007, 2008, and 2009. Data were collected from a total 283 stereo-BRUV deployments (183 shallow and 140 deep) over the three years.

Replicate stereo-BRUVs (Plate 2) were deployed at least 250 m apart to minimise the possibility of a fish attracted to the bait at one stereo-BRUV also being recorded on a neighbouring camera (Cappo et al. 2001, 2003, 2007b). Consequently, we are treating each deployment as an independent replicate. Each stereo-BRUV sample was deployed on the seabed for at least one hour. Where longer recordings were made, we analysed the data from the first hour only. While the recording time for stereo-BRUVs was less than trap soak times, this was not perceived as an issue given that we wished to assess the performance of each technique when they were used under their 'typical' sampling conditions.

We used six baited stereo-BRUVs of the configuration detailed in Harvey et al. (2002) and Watson et al. (2005, 2007). Each stereo-BRUV used two Sony handycams (models HC 15E in 2007 and 2008 and HDR-CX7 in 2009) mounted inside underwater housings which were mounted 0.7 m apart on a base bar and inwardly converged at 8° to gain an optimised field of view. We used approximately 800 – 1000 grams of crushed pilchards (*Sardinops sagax*) placed in a bait bag fixed on a pole 1.4 m in front of the cameras to attract fish to the stereo-BRUV. In shallow sites (60-80 m) we used natural lighting. In deeper sites (90-120 m**)** we used a bank of seven Royal Blue Cree XLamps XP-E LEDs each delivering a radiant flux of 350-425 mW at wavelength ranging from 450 to 465 nm to illuminate the field of view. This wavelength was chosen as a compromise between minimising fish repulsion, backscatter and reflection off the

sides of silver coloured fish, which created a flare in the imagery whilst still illuminating a large enough field of view to be able to sample fish. We estimate that with the blue LEDS we could see fish five metres from the camera system.

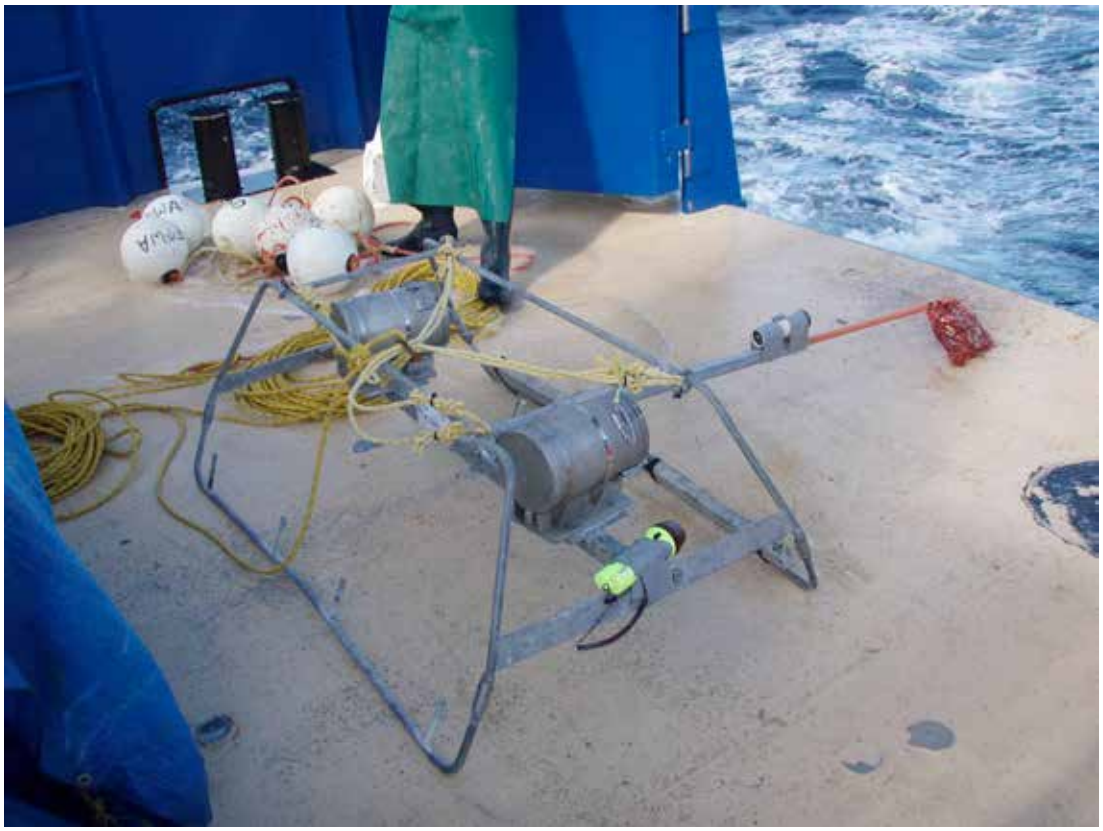

Plate 2. Example of a stereo BRUV unit with bait bag ready for deployment.

1.1.4 Camera calibration

At the beginning and completion of the fieldwork the stereo-BRUVs were calibrated following procedures outlined in Harvey and Shortis (1996, 1998) using Cal software (v1.32, www.seagis.com.au).

1.1.5 Image capture and conversion

In 2007 and 2008 the imagery was recorded on Mini DV tapes (Plate 3). The video images were captured and converted to an Audio Video Interleaved (avi) format using Adobe Premier V6. In 2009 we used Sony CX7 camcorders, which record video imagery in a MPEG Transport Stream format (MTS). This format could not be used in computer programs used for image analysis. We converted the recorded imagery from MTS to a high-definition MPEG format using Elecard conversion software following Harvey et al. (2010).

1.1.6 Image Analysis

In 2007 we analysed both the stereo-BRUV and the trap camera imagery using the "BRUVs database" developed by the Australian Institute of Marine Science and in 2008 and 2009 we used the software EventMeasure (www.seagis.com.au; e.g Plates 4-6). Using the software, we annotated the time that we first saw a species of fish on the video (time of first sighting) and

also kept tally of the maximum number of individuals (MaxN) we were able to view together in the field of view at any one time. Due to the concern that individual fish may be counted repeatedly upon leaving and re-entering the field of view over the 1 hour period of sampling, the maximum number of individuals of the same species appearing at the same time (MaxN, Priede et al. 1994) was used as a conservative estimate of the number of fish seen of any one species on each stereo-BRUV deployment (Cappo et al. 2003; 2004; Harvey et al. 2007). For the trap camera imagery we analysed 3 hours of footage and noted the time of entry and exit for 9 commercially retained species. We also recorded the MaxN of fish seen outside the trap that could have been caught. For stereo-BRUVs, measurements of the length of each MaxN fish and the distance away from the camera were made using PhotoMeasure software (www.seagis.com.au). The program allows for highly accurate and precise measures of fish length when the snout and tail fork of the fish are visibile in both the left and right image. Measurements of fish length from stereo-video images have been shown to be very similar to manually measured lengths of captured fish with an average error 0.16% (see Harvey et al. 2003). Fish were only measured up to a maximum distance of seven metres from the cameras.

Plate 3. Video cameras, chargers and tapes for trap and BRUV deployments.

1.1.7 Statistical analysis

For the relative abundance data on fishes sampled by traps and stereo-BRUVs all multivariate and univariate analyses were done using the PRIMER v6 computer program (Clarke & Gorley 2006) with the PERMANOVA+ add-on package (Anderson et al. 2008).

Multivariate homogeneity of dispersions in assemblage data

To test for homogeneity of dispersions in the trap and stereo-BRUV data at the level of Sampling Technique x Depth we have analysed these within group dispersions using PERMDISP

(Anderson 2006) and 9999 permutations of the data. We were interested in understanding how much of the dissimilarity between factors (Sampling Technique x Depth) was driven by compositional differences (differences in the assemblage structure) and how much was driven by differences in relative abundance. Consequently, we analysed the data using both a Modified Gower (MG) Logbase 2 dissimilarity measure, which places more emphasis on changes in relative abundance and a Modified Gower Logbase 10 dissimilarity measure which places emphasis on compositional change (Anderson et al. 2006).

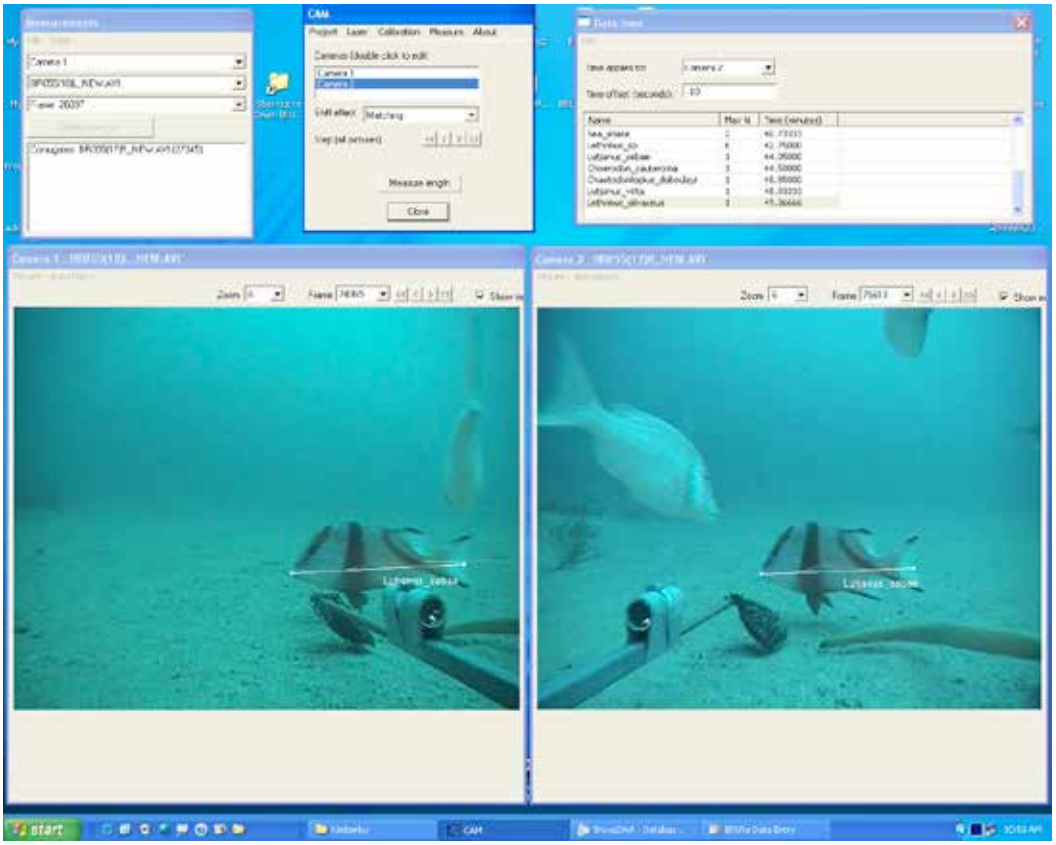

Plate 4. Example of the image analysis software being used to measure an individual red emperor (*Lutjanus sebae*) viewed on a stereo-BRUV deployment.

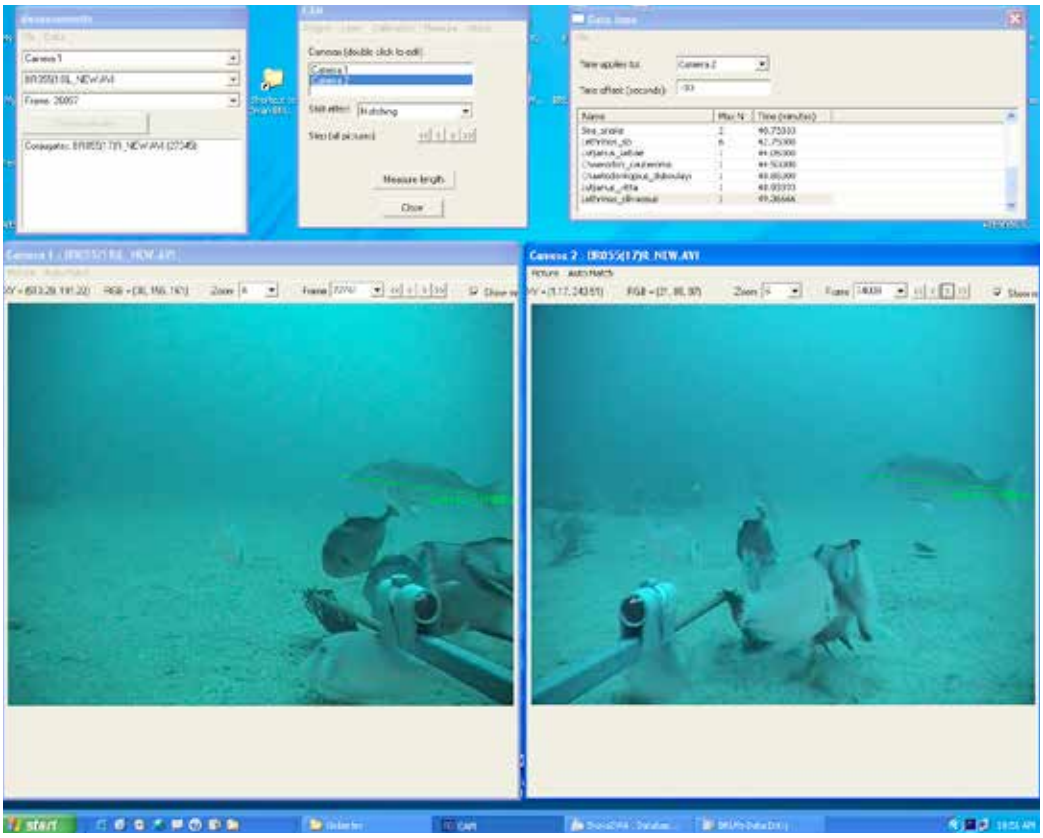

Plate 5. Example of the image analysis software being used to measure an individual longnose emperor (*Lethrinus olivaceus*) viewed on a stereo-BRUV deployment.

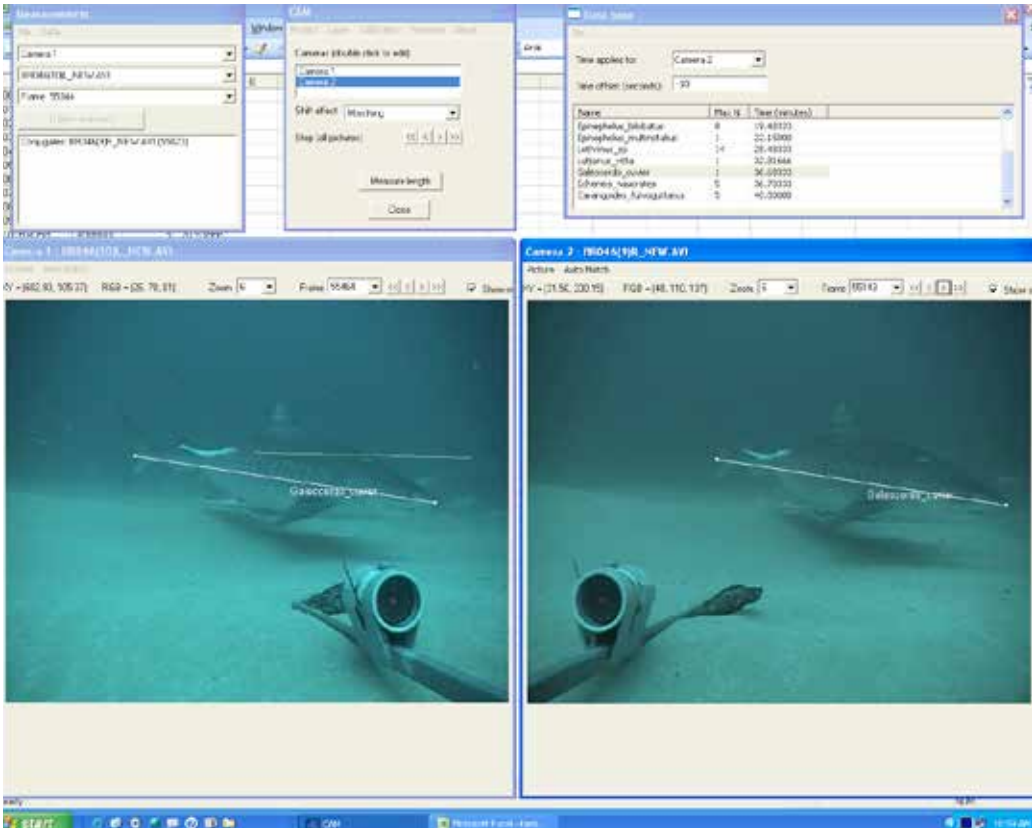

Plate 6. Example of the image analysis software being used to measure an individual tiger shark (*Galeocerdo cuvier*) viewed on a stereo BRUV deployment.

Assemblage composition

We used a two-way non-parametric multivariate analysis of variance (Anderson and Robinson 2003) to test for differences in fish assemblages between Sampling Techniques (2 factors, fixed) and Depth (2 factors, fixed). We analysed the data using a Modified Gower Logbase 10 (compositional data) and Logbase 2 (relative abundance data) resemblance matrices with 9999 permutations of raw data. We also plotted the data using an unconstrained ordination procedure (Principal Coordinate Analysis).

Canonical Analysis of Principal Coordinates (CAP)

CAP is a constrained ordination procedure that can be used to investigate hypotheses. Unlike an unconstrained ordination procedure, which does not use *a priori* hypotheses in any way, but reduces dimensions on the basis of some general criterion, CAP uses an *a priori* hypothesis in order to produce the plot (Anderson and Willis, 2003; Anderson and Robinson, 2003). The CAP analyses were only undertaken on those factors found to be significant from the PERMANOVA analyses on the assemblage data (Sampling Technique x Depth).

Univariate analysis of the total numbers of fish and numbers of species

We choose to conduct all univariate analyses within PERMANOVA basing the analysis on a Euclidean distance matrix with 9999 permutations of appropriate units. The F-ratios used for tests done in this way are equivalent to those of a traditional ANOVA (Anderson, 2001), although the P-values are not obtained using traditional tables. Data on numbers of individual fish and numbers of species were square root transformed and analysed using the same 2-way models described for the assemblage data. Tests using permutations are sensitive to differences in dispersion. Hence, prior to analysis we tested the data for differences in dispersions using PERMDISP. The analysis of a single variable based on a Euclidean distance matrix with PERMDISP using centroids is similar to a Levenes test (Anderson et al. 2008). Significant terms were investigated with *a posteriori* pairwise comparisons, which also used 9999 random permutations to obtain P-values.

Mean length

In selecting species to conduct the comparisons of mean length and length frequency we excluded species that were represented by less than 35 individuals in each of the trap and stereo-BRUV data sets. This left a total of 13 species, 12 of which are retained by commercial fishers and one which is a by-catch species that is released (*Abalistes stellaris*, see Tables 1, 4 and 5).

For all statistical analyses we have pooled the length data for each species across the 3 years to have enough fish of the key target species to make a robust comparison. To test for differences in the mean length we have used a one-way ANOVA. Prior to the ANOVA we conducted a Levenes test to check the homogeneity of the length data for each species. Where data were heterogeneous, the data were square root or 4^{th} root transformed. Where the length data for a species remained heterogeneous we have conducted the analysis on the raw data. We have calculated the mean, standard deviation, maximum and minimum values and the range for each species (Table 5). All univariate analyses were conducted with Minitab (V13).

Length frequency

We used a Kolmorgrov-Smirnov test (Siegel 1956) to test for differences between the two-length frequency distributions ($p = 0.05$). This test calculates the maximum difference (D.max) between a size class for the cumulative frequency distributions of two data sets (Bell et al.

1985). The species selected for analysis were grouped into 20 mm bins following the procedure used for reporting in this fishery. Length frequency has been expressed as a percentage of the total number of fish sampled.

1.2 Results/Discussion

1.2.1 Summary

Overall, the stereo-BRUVs sampled more fish (5201 individuals, mean 18.37 ± 1.00 SE) and species (132 species, mean 7.82 ± 0.31 SE) than commercial fish traps (2413 individuals, mean 8.32 ± 0.45 SE; 56 species, mean 2.86 ± 0.11 SE) (Table 1).

Dispersions

There were no differences within and between group multivariate dispersions at the level of Sampling Technique x Depth in either the Logbase 2 or Logbase 10 Modified Gower data.

Table 1. Relative abundances (mean ± SE) of all fish species observed by stereo-BRUVs and captured in commercial fish traps (- indicates no individuals were observed/caught; commercial species are highlighted in bold).

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Acanthuridae	*Acanthurus grammoptilus*	Inshore Surgeonfish	0.035 ± 0.019	-
Acanthuridae	*Acanthurus mata*	Pale Surgeonfish	0.007 ± 0.005	-
Acanthuridae	*Naso fageni*	Horseface Unicornfish	0.004 ± 0.004	-
Acanthuridae	*Naso hexacanthus*	Sleek Unicornfish	0.057 ± 0.043	-
Acanthuridae	*Naso lopezi*	Slender Unicornfish	0.011 ± 0.008	-
Apogonidae	*Apogon fraenatus*	Spinyeye Cardinalfish	0.007 ± 0.005	-
Ariidae	***Arius thalassinus***	**Giant Sea Catfish**	**0.014 ± 0.007**	-
Balistidae	*Abalistes stellaris*	Starry Trigerfish	0.452 ± 0.051	0.203 ± 0.047
Balistidae	*Balistoides viridescens*	Titan Triggerfish	0.004 ± 0.004	-
Balistidae	*Sufflamen fraenatum*	Bridled Triggerfish	0.074 ± 0.018	-
Blenniidae	*Aspidontus taeniatus*	False Cleanerfish	0.004 ± 0.004	-
Caesionidae	*Caesio cuning*	Yellowtail Fusilier	0.074 ± 0.037	-
Caesionidae	*Pterocaesio chrysozona*	Yellowband Fusiler	0.456 ± 0.216	-

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Carangidae	***Carangoides caeruleopinnatus***	**Onion Trevally**	**0.173 ± 0.046**	**-**
Carangidae	***Carangoides chrysophrys***	**Longnose Trevally**	**1.081 ± 0.195**	**0.009 ± 0.005**
Carangidae	***Carangoides fulvoguttatus***	**Goldspotted Trevally**	**0.283 ± 0.129**	**0.058 ± 0.036**
Carangidae	***Carangoides gymnostethus***	**Bludger Trevally**	**0.657 ± 0.207**	**0.021 ± 0.011**
Carangidae	***Caranx heberi***	**Blacktip Trevally**	**0.039 ± 0.029**	**0.015 ± 0.008**
Carangidae	***Caranx ignobilis***	**Giant Trevally**	**0.018 ± 0.009**	**-**
Carangidae	***Caranx sexfasciatus***	**Bigeye Trevally**	**0.095 ± 0.055**	**-**
Carangidae	***Caranx tille***	**Tille Trevally**	**0.004 ± 0.004**	**-**
Carangidae	*Decapterus sp1*	Scad	0.004 ± 0.004	-
Carangidae	***Gnathanodon speciosus***	**Golden Trevally**	**0.011 ± 0.008**	**0.003 ± 0.003**
Carangidae	*Naucrates doctor*	Pilotfish	0.042 ± 0.042	-
Carangidae	***Seriola dumerili***	**Amberjack**	**0.187 ± 0.044**	**0.021 ± 0.008**
Carangidae	***Seriola rivoliana***	**Highfin Amberjack**	**0.049 ± 0.017**	**0.003 ± 0.003**
Carangidae	***Seriolina nigrofasciata***	**Blackbanded Amberjack**	**0.035 ± 0.011**	-
Carcharhinidae	*Carcharhinus albimarginatus*	Silvertip Shark	0.134 ± 0.027	-
Carcharhinidae	*Carcharhinus amblyrhynchos*	Grey Reef Shark	0.004 ± 0.004	-
Carcharhinidae	*Carcharhinus dussumieri*	Whitecheek Shark	0.028 ± 0.011	0.006 ± 0.006
Carcharhinidae	*Carcharhinus limbatus*	Common Blacktip Shark	0.049 ± 0.013	-
Carcharhinidae	*Carcharhinus plumbeus*	Sandbar Shark	0.039 ± 0.012	-
Carcharhinidae	*Galeocerdo cuvier*	Tiger Shark	0.011 ± 0.006	-
Carcharhinidae	*Loxodon macrorhinus*	Sliteye Shark	0.035 ± 0.015	-

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Carcharhinidae	*Rhizoprionodon acutus*	Milk Shark	0.004 ± 0.004	-
Carcharhinidae	*Triaenodon obesus*	Whitetip Reef Shark	0.049 ± 0.013	-
Chaetodontidae	*Chaetodon assarius*	Western Butterflyfish	0.007 ± 0.007	-
Chaetodontidae	*Chaetodontoplus duboulayi*	Scribbled Angelfish	0.004 ± 0.004	-
Chaetodontidae	*Chaetodontoplus personifer*	Yellowtail Angelfish	0.113 ± 0.028	-
Chaetodontidae	*Heniochus acuminatus*	Longfin Bannerfish	0.449 ± 0.126	-
Dasyatidae	*Taeniura meyeni*	Blotched Fantail Ray	0.007 ± 0.005	-
Echeneidae	*Echeneis naucrates*	Sharksucker	0.081 ± 0.019	-
Ephippidae	*Platax batavianus*	Humphead Batfish	0.021 ± 0.009	-
Ephippidae	*Zabidius novemaculeatus*	Shortfin Batfish	0.081 ± 0.081	-
Epinephelidae	***Cephalopholis sonnerati***	**Tomato Rockcod**	**0.078 ± 0.022**	**0.018 ± 0.009**
Epinephelidae	***Cromileptes altivelis***	**Barramundi Cod**	**0.011 ± 0.006**	**0.003 ± 0.003**
Epinephelidae	***Epinephelus amblycephalus***	**Banded Grouper**	**0.106 ± 0.021**	**0.027 ± 0.01**
Epinephelidae	***Epinephelus areolatus***	**Yellow Spotted Rockcod**	**1.17 ± 0.114**	**1.267 ± 0.143**
Epinephelidae	***Epinephelus bilobatus***	**Frostback Rockcod**	**0.187 ± 0.031**	**0.027 ± 0.01**
Epinephelidae	***Epinephelus bleekeri***	**Duskytail Grouper**	**0.512 ± 0.145**	**0.445 ± 0.074**
Epinephelidae	***Epinephelus coioides***	**Gold Spotted Rockcod**	**0.081 ± 0.02**	**0.039 ± 0.012**
Epinephelidae	***Epinephelus fasciatus***	**Blacktip Rockcod**	**0.039 ± 0.019**	-
Epinephelidae	***Epinephelus malabaricus***	**Blackspotted Rockcod**	**0.064 ± 0.02**	**0.021 ± 0.014**
Epinephelidae	***Epinephelus morrhua***	**Comet Grouper**	**0.071 ± 0.021**	**0.024 ± 0.01**
Epinephelidae	***Epinephelus multinotatus***	**Rankin Cod**	**0.24 ± 0.04**	**0.318 ± 0.05**

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Epinephelidae	***Epinephelus polyphekadion***	**Flowery Rockcod**	**-**	**0.003 ± 0.003**
Epinephelidae	***Epinephelus rivulatus***	**Chinamen Rockcod**	**0.014 ± 0.014**	-
Epinephelidae	***Epinephelus stictus***	**Blackspotted Grouper**	**0.035 ± 0.021**	-
Epinephelidae	*Epinephelus tukula*	Potato Grouper	0.025 ± 0.009	0.003 ± 0.003
Epinephelidae	***Plectropomus maculatus***	**Barcheeked Coral Trout**	**0.078 ± 0.022**	-
Gerreidae	*Gerres oyena*	Blacktip Silverbiddy	0.004 ± 0.004	-
Ginglymostomatidae	*Nebrius ferrugineus*	Tawny Shark	0.018 ± 0.012	0.006 ± 0.004
Glaucosomatidae	***Glaucosoma buergeri***	**Northern Pearl Perch**	**0.007 ± 0.005**	**0.003 ± 0.003**
Haemulidae	***Diagramma labiosum***	**Painted Sweetlips**	**0.053 ± 0.016**	**0.003 ± 0.003**
Haemulidae	***Plectorhinchus gibbosus***	**Brown Sweetlips**	**0.004 ± 0.004**	-
Holocentridae	*Myripristis botche*	Blacktip Soldierfish	0.014 ± 0.014	-
Labridae	***Bodianus bilunulatus***	**Saddleback Pigfish**	**0.007 ± 0.005**	-
Labridae	***Bodianus perditio***	**Goldspot Pigfish**	**0.141 ± 0.025**	**0.045 ± 0.014**
Labridae	***Choerodon cauteroma***	**Bluespotted Tuskfish**	**0.004 ± 0.004**	-
Labridae	***Choerodon zamboangae***	**Eyebrow Tuskfish**	**0.152 ± 0.028**	**0.006 ± 0.006**
Labridae	*Labroides dimidiatus*	Common Cleanerfish	0.046 ± 0.017	-
Labridae	*Thalassoma lunare*	Moon Wrasse	0.004 ± 0.004	-
Lethrinidae	***Gymnocranius elongatus***	**Swallowtail Seabrean**	**0.025 ± 0.011**	-
Lethrinidae	***Gymnocranius grandoculis***	**Robinson Seabream**	**0.601 ± 0.06**	**0.006 ± 0.004**
Lethrinidae	***Lethrinus lentjan***	**Redspot Emperor**	**0.187 ± 0.041**	**0.085 ± 0.026**
Lethrinidae	***Lethrinus nebulosus***	**Spangled Emperor**	**0.212 ± 0.04**	**0.109 ± 0.027**

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Lethrinidae	***Lethrinus olivaceus***	**Longnose Emperor**	**0.3 ± 0.075**	**0.033 ± 0.012**
Lethrinidae	***Lethrinus punctulatus***	**Bluespotted Emperor**	**0.078 ± 0.022**	**0.094 ± 0.035**
Lethrinidae	***Lethrinus ravus***	**Drab Emperor**	**0.194 ± 0.053**	**0.03 ± 0.015**
Lethrinidae	***Lethrinus rubrioperculatus***	**Spotcheek Emperor**	**0.025 ± 0.019**	**0.036 ± 0.017**
Lethrinidae	***Wattsia mossambica***	**Mozambique Seabream**	**0.329 ± 0.089**	**0.067 ± 0.038**
Lutjanidae	***Aphareus rutilans***	**Rusty Jobfish**	**0.124 ± 0.043**	-
Lutjanidae	***Lipocheilus carnolabrum***	**Tang's Snapper**	**0.007 ± 0.005**	**0.003 ± 0.003**
Lutjanidae	***Lutjanus argentimaculatus***	**Mangrove Jack**	-	**0.015 ± 0.008**
Lutjanidae	***Lutjanus bitaeniatus***	**Indonesian Snapper**	**0.269 ± 0.062**	**0.464 ± 0.106**
Lutjanidae	***Lutjanus erythropterus***	**Crimson Snapper**	**0.954 ± 0.191**	**0.13 ± 0.05**
Lutjanidae	***Lutjanus lemniscatus***	**Darktail Snapper**	**0.23 ± 0.059**	**0.145 ± 0.032**
Lutjanidae	***Lutjanus malabaricus***	**Saddletail Snapper**	**0.459 ± 0.07**	**0.312 ± 0.083**
Lutjanidae	***Lutjanus quinquelineatus***	**Fiveline Snapper**	-	**0.003 ± 0.003**
Lutjanidae	***Lutjanus rivulatus***	**Maori Snapper**	**0.117 ± 0.031**	**0.006 ± 0.006**
Lutjanidae	***Lutjanus russelli***	**Moses Snapper**	**0.08 ± 0.012**	**0.267 ± 0.058**
Lutjanidae	***Lutjanus sebae***	**Red Emperor**	**0.795 ± 0.083**	**1.039 ± 0.147**
Lutjanidae	***Lutjanus vitta***	**Brownstrip Snapper**	**0.134 ± 0.033**	**0.315 ± 0.113**
Lutjanidae	*Paracaesio sp*		0.078 ± 0.065	0 ± 0
Lutjanidae	***Pristipomoides filamentosus***	**Rosy Snapper**	**0.332 ± 0.124**	**0.042 ± 0.021**
Lutjanidae	***Pristipomoides multidens***	**Goldband Snapper**	**1.601 ± 0.141**	**1.242 ± 0.136**
Lutjanidae	***Pristipomoides typus***	**Sharptooth Snapper**	**1.071 ± 0.161**	**0.182 ± 0.052**

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Lutjanidae	***Symphorus nematophorus***	**Chinaman Fish**	**0.028 ± 0.01**	-
Monacanthidae	*Aluterus monoceros*	Unicorn Leatherjacket	0.004 ± 0.004	-
Monacanthidae	*Aluterus scriptus*	Scrawled Leatherjacket	0.004 ± 0.004	-
Mullidae	Parupeneus chrysopleuron	Rosy Goatfish	-	0.003 ± 0.003
Mullidae	***Parupeneus heptacanthus***	**Opalescent Goatfish**	**0.032 ± 0.014**	-
Mullidae	***Parupeneus indicus***	**Yellowspot Goatfish**	**0.018 ± 0.009**	-
Muraenidae	*Gymnothorax javanicus*	Giant Moray	0.014 ± 0.007	-
Muraenidae	*Gymnothorax nudivomer*	Yellowmouth Moray	0.021 ± 0.009	-
Nemipteridae	***Nemipterus furcosus***	**Rosy Threadfin Bream**	**0.77 ± 0.134**	**0.006 ± 0.004**
Nemipteridae	*Parascolopsis eriomma*	Rosy Monocle Bream	0.004 ± 0.004	-
Nemipteridae	*Pentapodus nagasakiensis*	Japanese Threadfin Bream	0.332 ± 0.082	-
Nemipteridae	*Scolopsis xenochrous*	Oblique-bar Monocle Bream	0.007 ± 0.005	-
Pinguipedidae	*Parapercis diplospilus*	Doublespot Grubfish	0.021 ± 0.009	-
Pinguipedidae	*Parapercis nebulosa*	Pinkbanded Grubfish	0.025 ± 0.012	-
Pomacanthidae	*Apolemichthys trimaculatus*	Threespot Angelfish	0.007 ± 0.007	-
Pomacanthidae	*Pomacanthus imperator*	Emperor Angelfish	0.018 ± 0.008	-
Pomacanthidae	*Pomacanthus sexstriatus*	Sixband Angelfish	0.004 ± 0.004	-
Pomacentridae	*Chromis fumea*	Smoky Puller	0.057 ± 0.027	-
Pomacentridae	*Pomacentrus nagasakiensis*	Blue Scribbled Damsel	0.028 ± 0.028	-
Pteroidae	*Pterois russelii*	Plaintail Lionfish	-	0.003 ± 0.003
Rachycentridae	***Rachycentron canadum***	**Cobia**	**0.042 ± 0.033**	-

FAMILY	GENUS SPECIES	Common Name	Stereo-BRUVs	Traps
Rhinobatidae	*Rhynchobatus djiddensis*	Whitespotted Guitarfish	0.014 ± 0.007	-
Scaridae	***Scarus ghobban***	**Bluebarred Parrotfish**	**0.014 ± 0.007**	-
Scaridae	***Scarus schlegeli***	**Schlegels Parrotfish**	**0.004 ± 0.004**	-
Scombridae	***Scomberomorus commerson***	**Spanish Mackerel**	**0.011 ± 0.008**	-
Scombridae	***Scomberomorus queenslandicus***	**School Mackerel**	**0.028 ± 0.019**	-
Serranidae	*Pseudanthias sp*	Anthias	0.011 ± 0.011	-
Sparidae	***Argyrops spinifer***	**Frypan Bream**	**0.057 ± 0.022**	-
Sparidae	***Dentex tumifrons***	**Yellowback Bream**	**0.004 ± 0.004**	**0.003 ± 0.003**
Sparidae	***Pagrus auratus***	**Pink Snapper**	**0.004 ± 0.004**	-
Sphyraenidae	*Sphyraena barracuda*	Great Barracuda	0.028 ± 0.017	-
Sphyraenidae	*Sphyraena obtusata*	Striped Barracuda	0.007 ± 0.005	-
Sphyrnidae	*Sphyrna lewini*	Scalloped Hammerhead	0.011 ± 0.006	-
Sphyrnidae	*Sphyrna mokarran*	Great Hammerhead	0.004 ± 0.004	-
Stegostomatidae	*Stegostoma fasciatum*	Zebra Shark	0.004 ± 0.004	-
Terapontidae	*Terapon theraps*	Largescale grunter	0.163 ± 0.115	-
Tetraodontidae	*Feroxodon multistriatus*	Ferocious Puffer	0.004 ± 0.004	-
Tetraodontidae	*Lagocephalus lunaris*	Rough Golden Toadfish	0.17 ± 0.044	0.058 ± 0.019
Tetraodontidae	*Lagocephalus sceleratus*	Silver Toadfish	0.028 ± 0.012	0.018 ± 0.007

1.2.2 Commercial trap and stereo-BRUVs

Assemblage

There was a significant main effect of Depth and an interaction of Sampling Technique x Depth interaction for the Modified Gower Logbase 2 data, while all terms were significant for the Logbase 10 data (Table 2).

Table 2. Results of a two way fixed PERMANOVA analysis testing for differences between traps and stereo-BRUVs across shallow (60-80m) and deep (90-120m) sites with 9999 permutations.

		Modified Gower Logbase 2 Assemblage data				Modified Gower Logbase 10 Assemblage data			
Source	**df**	**SS**	**MS**	**Pseudo-F**	**P (perm)**	**SS**	**MS**	**Pseudo-F**	**P (perm)**
Sampling Technique	1	1.633	1.633	1.124	0.339	8.489	8.489	13.505	< 0.001
Depth	1	12.051	12.051	8.297	< 0.001	7.493	7.493	11.921	< 0.001
Sampling Technique x Depth	1	3.933	3.933	2.708	0.006	1.983	1.983	3.155	< 0.001
Residual	609	884.510	1.452			382.810	0.629		
Total	612	902.080				400.960			

Pairwise comparisons of the interaction term showed that for both the Logbase 2 and Logbase 10 data both sampling techniques detected differences between the depths, but within a depth both techniques were different.

Numbers of individual fish

The PERMDISP analysis indicated there were larger dispersions in the stereo-BRUV samples collected at deep sites than from trap samples from shallow or deep sites ($F = 3.01$, $P = 0.037$). There were significant differences in the numbers of fish sampled between sampling techniques and between depths and a significant Sampling Technique x Depth interaction was evident (Table 3).

Pairwise comparisons of the Sampling Technique x Depth interaction revealed that both sampling techniques detected differences in the numbers of fish between depths, but within a depth there were significant differences between techniques (Figure 1A).

Numbers of species

The PERMDISP analysis revealed there were larger dispersions in the stereo-BRUV samples collected at deep sites than from trap samples from shallow or deep sites ($F = 8.36$, $P < 0.001$). There were significant differences in the numbers of species sampled between sampling techniques and between depths and significant interaction between these factors (Table 3).

Pairwise comparisons of the Sampling Technique x Depth interaction revealed that both sampling techniques detected differences in the numbers of fish between depths, but within a depth there were significant differences between techniques (Figure 1B).

Table 3. Analysis comparing the numbers of individual fish and the numbers of species sampled by stereo-BRUVs and traps.

		Number of Individuals				Number of Species			
Source	**df**	**SS**	**MS**	**Pseudo-F**	**P (perm)**	**SS**	**MS**	**Pseudo-F**	**P (perm)**
Sampling Technique	1	367.740	367.740	146.330	<0.001	173.500	173.500	243.680	<0.001
Depth	1	85.508	85.508	34.026	<0.001	31.880	31.880	44.777	<0.001
Sampling Technique x Depth	1	27.932	27.932	11.115	0.001	6.789	6.789	9.535	0.002
Residual	609	1530.400	2.513			433.600	0.712		
Total	612	2020.100				649.770			

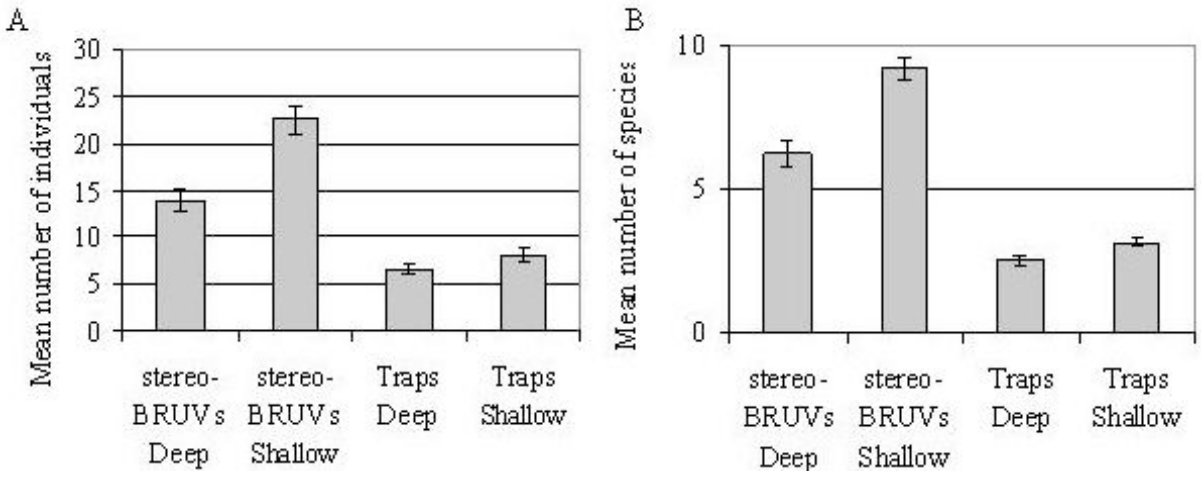

Figure 1. Differences in the mean numbers of individual fish (A), and species (B) sampled by stereo-BRUVs and Traps at shallow and deep sites.

Mean Length

Of the 13 species selected for analysis of mean length, only six had significantly different means between traps and stereo-BRUVs (Table 4). Three of these species had larger mean lengths in traps while three had larger mean lengths on stereo-BRUVs (Table 4). The maximum difference in mean length was 43 mm (*Epinephelus bleekeri*) with the mean difference across all species of less than 4 mm. For all but two species stereo-BRUVs sampled a broader range of sizes (Table 4). Although there were some significant differences in the mean lengths, the actual differences were quite small and were probably driven by the larger range of lengths sampled by the stereo-BRUVs.

Length frequency

Of the 13 species tested, all but one (Figure 2b, *Carangoides gymnostethus*) had similar length frequencies between fish caught in traps and sampled by stereo BRUVs (Kolmorgrov Smirnov test, P = 0.05). This difference for *Carangoides gymnostethus* is most likely due to the low numbers of fish sampled in the traps (36) in comparison to the stereo-BRUVs (277, Table 5).

Table 4. One-way analysis of variance on the mean lengths of 13 species sampled by traps and stereo-BRUVs.

Source	df	MS	F	p	Levenes
Abalistes stellaris	1	10594	3.27	0.072	Homogenous
Error	195	3236			
Total	196				
Carangoides gymnostethus	1	3467	0.74	0.391	Homogenous
Error	311	4696			
Total	312				
Epinephelus areolatus	1	83730	48.57	**<0.001**	Heterogeneous
Error	751	1724			
Total	752				
Epinephelus bleekeri	1	114066	24.47	**<0.001**	Heterogeneous
Error	286	4662			
Total	287				
Epinephelus multinotatus	1	43411	5.78	**0.017**	Homogenous
Error	182	7515			
Total	183				
Lethrinus nebulosus	1	2712	0.53	0.469	Homogenous
Error	126	5148			
Total	127				
Lutjanus bitaeniatus	1	38335	31.04	**<0.001**	Homogenous
Error	231	1235			
Total	232				
Lutjanus erythropterus	1	2981	1.12	0.292	Homogenous
Error	261	2669			
Total	262				
Lutjanus malabaricus	1	1146	0.16	0.685	Homogenous
Error	259	6958			
Total	260				
Lutjanus sebae	1	9201	1.74	0.188	Heterogeneous
Error	702	5290			
Total	703				
Lutjanus vitta	1	7643	5.14	**0.025**	Homogenous
Error	172	1488			
Total	173				
Pristipomoides multidens	1	53060	8.4	**0.004**	Heterogeneous
Error	969	6315			
Total	970				
Pristipomoides typus	1	10118	1.84	0.176	Homogenous
Error	265	5491			
Total	266				

Table 5. A comparison of the mean length, sample size, standard deviation, maximum and minimum length and range of length data collected for 13 species by commercial fish traps and stereo-BRUVs. The D.Max values from the Kolmorgrov Smirnov test of the length frequencies are listed in the last column.

Species		N	Mean (mm)	StDev (mm)	Max (mm)	Min (mm)	Range (mm)	D.Max
Abalistes stellaris	Stereo-BRUV	107	319	63	479	187	292	
	Trap	90	334	49	427	190	237	D.Max =0.058
Carangoides gymnostethus	Stereo-BRUV	277	307	68	624	96	529	
	Trap	36	318	73	570	201	369	D.Max =0.284
Epinephelus areolatus	Stereo-BRUV	232	320	54	469	121	348	
	Trap	521	342	34	451	201	250	D.Max =0.123
Epinephelus bleekeri	Stereo-BRUV	91	410	88	650	260	390	
	Trap	197	453	57	613	219	394	D.Max =0.085
Epinephelus multinotatus	Stereo-BRUV	58	514	96	753	273	480	
	Trap	126	547	82	725	270	455	D.Max =0.092
Lethrinus nebulosus	Stereo-BRUV	48	466	79	719	281	438	
	Trap	80	475	67	633	336	297	D.Max =0.096
Lutjanus bitaeniatus	Stereo-BRUV	45	334	36	422	265	157	
	Trap	188	301	35	416	224	192	D.Max =0.053
Lutjanus erythropterus	Stereo-BRUV	213	428	52	603	228	376	
	Trap	50	437	49	531	329	202	D.Max =0.095
Lutjanus malabaricus	Stereo-BRUV	100	484	85	684	235	449	
	Trap	161	479	83	661	242	419	D.Max =0.079
Lutjanus sebae	Stereo-BRUV	186	474	85	734	288	446	
	Trap	518	466	68	682	265	417	D.Max =0.052
Lutjanus vitta	Stereo-BRUV	59	280	39	426	109	317	
	Trap	115	266	38	400	152	248	D.Max =0.192
Pristipomoides multidens	Stereo-BRUV	347	488	89	847	265	582	
	Trap	634	472	74	658	241	417	D.Max =0.042
Pristipomoides typus	Stereo-BRUV	189	449	77	707	232	475	
	Trap	78	435	67	579	268	311	D.Max =0.071

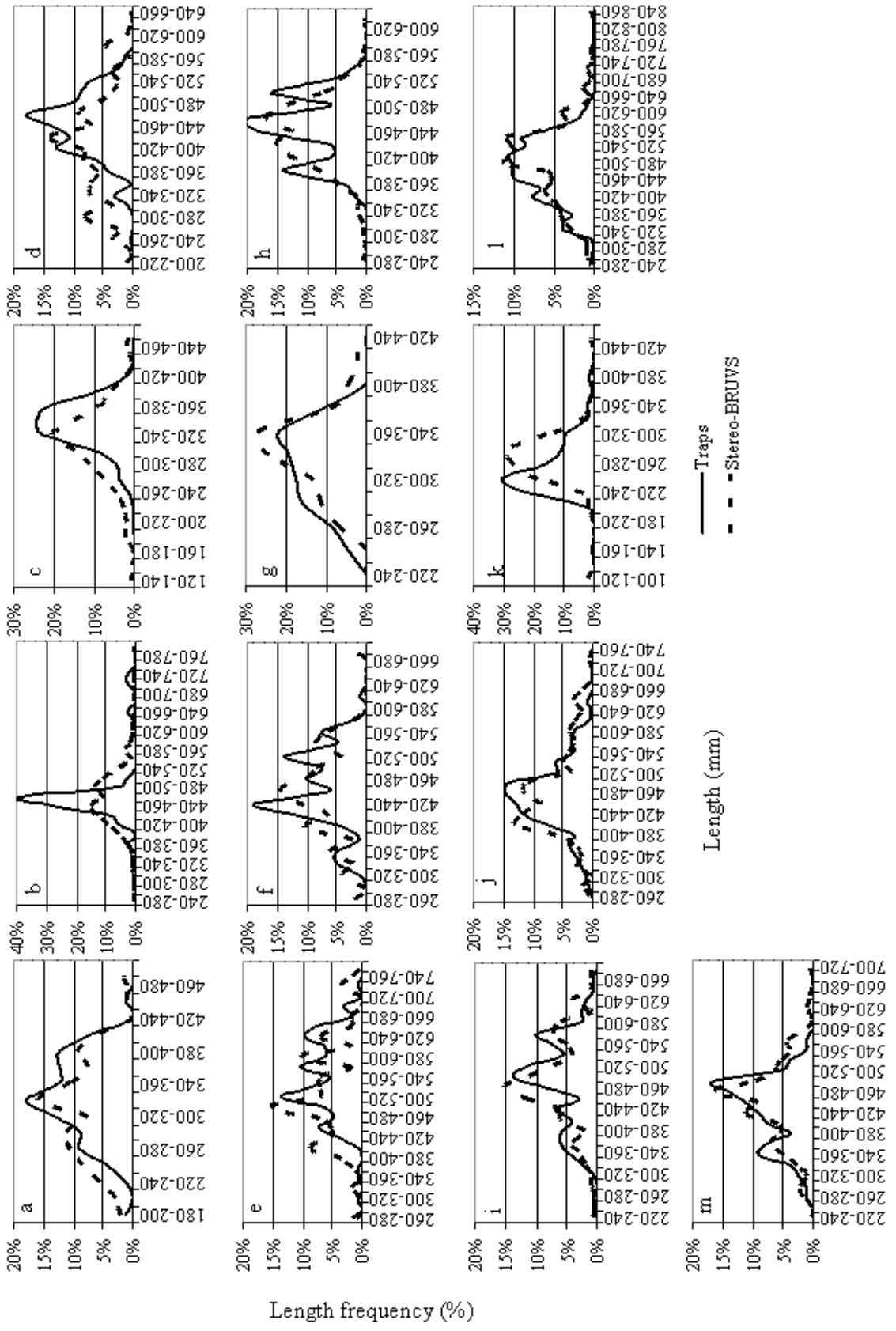

Figure 2. The length frequencies of 13 species plotted in 20 mm bins. a = *Abalistes stellaris*, b = *Carangoides gymnostethus*, c = *Epinephelus aerolatus*, d = *Epinephelus bleekeri*, e = *Epinephelus multinotatus*, f = *Lethrinus nebulosus*, g = *Lutjanus bitaeniatus*, h = *Lutjanus erythropterus*, i = *Lutjanus malabaricus*, j = *Lutjanus sebae*, k = *Lutjanus vitta*, l = *Pristipomoides multidens*, m = *Pristipomoides typus*.

1.2.3 Trap camera

Fish entering and exiting the traps

The traps retained many of the commercially targeted species with only 12% of fish seen to enter being recorded as exiting. It is notable that *Epinephelus* spp. escaped the traps in much higher proportions then *Lethrinus nebulosus* or *Lutjanus* spp. (Table 6).

Table 6. The numbers of fish of target species seen to enter and exit the commercial fish traps (N = 241).

Species	# Entries	# Exits	% Escape
Epinephelus areolatus	316	79	25%
Epinephelus bleekeri	56	11	20%
Epinephelus multinotatus	65	6	9%
Lethrinus nebulosus	36	0	0%
Lutjanus bitaeniatus	94	23	24%
Lutjanus erythropterus	30	0	0%
Lutjanus malabaricus	80	7	9%
Lutjanus sebae	272	16	6%
Pristipomoides multidens	303	36	12%

Fish seen outide the traps

Approximately twice the number of fishes of commercially valuable species remained outside the trap in comparison to the numbers seen entering and remaining in the trap. While traps were particlaurly efficient at catching target species such as *Epinephelus areolatus* and *Lutjanus sebae*, other species such as *Gymnocranius grandoculis*, *Bodianus perditio*, *Lutjanus erythropterus* and *Wattsia mossambica* were caught in relatively low numbers in comparison to the numbers of fish (MaxN) that were actually seen outside the fish trap (Table 7). The potential exists for the commercial fishery to expand its catch by investigating and developing alternative catching techniques, such as either modified trap or line methods.

Table 7. Trap camera data on the numbers of fish seen entering a trap in comparison to the numbers (MaxN) viewed outside the trap.

Species	Common Name	Caught	Seen outside
Aphareus rutilans	Rusty Jobfish	0	24
Bodianus perditio	Goldspot Pigfish	4	68
Carangoides caeruleopinnatus	Onion Trevally	0	64
Carangoides fulvoguttatus	Goldspotted Trevally	16	78
Epinephelus areolatus	Yellow Spotted Rockcod	255	227
Epinephelus bleekeri	Duskytail Grouper	45	84
Epinephelus multinotatus	Rankin Cod	67	69
Gymnocranius grandoculis	Robinson Seabream	3	104
Lethrinus nebulosus	Spangled Emperor	45	59
Lutjanus bitaeniatus	Indonesian Snapper	75	186

Species	Common Name	Caught	Seen outside
Lutjanus erythropterus	Crimson Snapper	31	298
Lutjanus malabaricus	Saddletail Snapper	76	174
Lutjanus sebae	Red Emperor	271	166
Pristipomoides multidens	Goldband Snapper	277	449
Wattsia mossambica	Mozambique Seabream	22	150

1.3 Conclusions

The data collected show that commercial fish traps sampled less species and lower numbers of individuals than stereo-BRUVs. Importantly, the stereo-BRUVs sampled more fish species and larger numbers of individuals than are recorded in traps.

Stereo-BRUV data do provide detailed information on the size structure and biodiversity of much of the fish community in the NDSF that is not captured in fish traps and this is important for assessing the health of the ecosystem and in assisting the ESD assessment process for this and related fisheries.

When data on mean lengths were compared we found that for 6 out of 13 targeted species stereo-BRUVs and traps sampled statistically different mean lengths. These differences in mean length were very small (average 4 mm) and may be due to stereo-BRUVs sampling a greater range of fish lengths within a species than fish caught in commercial fish traps. This is supported by a comparison of the length frequencies for these same 13 species, where the length frequencies of only 1 of 13 species differed significantly between the two sampling techniques. Results therefore indicate that commercial fish traps are catching fish of similar size to those that are both being landed and those that are present in the vicinity of the trap. This is evidence that fish traps are representatively sampling the size structure of targeted fish species in their vicinity. This finding is significant; as it indicates that representative sampling of trap catches provides a robust and reliable means of assessing the length structure of target fish stocks, an important component of stock assessment models that depend on length data and size distributions.

Data from this study has directly contributed to improved confidence in the results of current stock assessment models. No significant differences in size structure between the sampling methods indicate that there is no direct benefit from incorporating additional length data from the stereo-BRUVs into the current stock assessment process.

Data collected by cameras mounted in traps showed that some species have escape rates of up to 25%, however most species were retained in good numbers by the traps. The trap cameras also demonstrated that approximately twice the numbers of fish seen entering and remaining in the trap were seen swimming outside in the vicinity of traps. This estimate is based on MaxN counts, which are conservative. Some species were caught in very low numbers or not caught at all by traps, but were seen outside the traps by the trap cameras and on the stereo-BRUVs indicating that there is potential for expansion of the commercial fishery using other fishing techniques.

It should be noted that fish seen outside traps is a positive – if traps removed all fish available for capture their efficiency would be so high that the fishery would not be sustainable. The indicator species for this fishery (red emperor [*L. sebae*] and goldband snapper [*P. multidens*])

both have low rates of natural mortality (in the range of 0.10-0.14 yr-1). For these species less than 10% of the available stock can be harvested on an annual basis in a sustainable manner (e.g. Newman and Dunk, 2002; 2003). As such, for long lived species (i.e. those with low rates of natural mortality), such as the primary species harvested in the fishery, their needs to be a large proportion of fish left outside the trap that are available for harvest in future trips.

This study revealed that for *L. sebae*, 38% of individuals viewed on trap cameras were attracted into and were caught in the traps compared to 63% for *P. multidens*. This indicates that traps are potentially more effective in attracting and retaining *P. multidens* in comparison to *L. sebae.* This relative capture efficiency needs to be considered in future monitoring and assessment programs.

A number of species of commercial significance do not appear to enter traps readily or are rare in trap catches.

The potential exists for some species to be underexploited and as such, there is an opportunity for gear development in order to attempt to capture those species that do not readily enter traps.

2.0 Determine the availability and spatial distribution of fish resources harvested by the NDSF

We address the question of whether there are temporal, spatial and depth differences in the structure of the demersal fish assemblages sampled by traps, stereo-BRUVs and fish trawls in the NDSF.

2.1 Methods

2.1.1 Traps

Samples were collected from a commercial fishing vessel from four sites at two depths in the dry season (June) of 2007, 2008, and 2009 using the local knowledge of the skipper to select sampling locations (Table 8). Sampling was undertaken from commercial fishing vessels using steel, commercial traps of the type used by the commercial fishers in the Northern Demersal Scale Fishery as described in Section 1.

Table 8. Numbers of trap samples collected.

Year	Depth	Cape Voltaire	Hall Point	Cape Bossut	Emeriau Point
2007	Shallow	18	18	18	18
2007	Deep	18	15	15	12
2008	Shallow	18	18	12	18
2008	Deep	12	18	18	18
2009	Shallow	11	12	12	12
2009	Deep	9	12	12	12

2.1.2 Stereo-BRUVs

A total of 283 stereo-BRUV deployments were collected from the four sites and two depths between 2007 and 2009 (Table 9). The equipment configuration and calibration, and how the stereo-BRUV imagery is analysed is described in Section 1.

Table 9. Numbers of stereo-BRUV samples collected.

Year	Depth	Cape Voltaire	Hall Point	Cape Bossut	Emeriau Point
2007	Shallow	12	18	12	12
2007	Deep	15	12	12	12
2008	Shallow	12	18	12	18
2008	Deep	18	12	18	18
2009	Shallow	3	11	9	6
2009	Deep	4	5	8	6

2.1.3 Fish Trawls

All the trawl surveys were carried out from the fisheries research vessel RV *Naturaliste*. The first trawl survey was conducted in 2007 from the 27 July to 4 August, whilst the second trip was completed between 10 September and 21 September 2009.

Three areas of the Northern Demersal Scalefish Fishery (NDSF) were selected as suitable sites for the trawl survey. These included Emeriau Point, Hall Point and Cape Voltaire/Browse Island. These sites were selected due to the availability of soft bottom and sponge garden habitats suitable for trawling.

At each of these sites, 3 depth zones were sampled; shallow (52- 60 m), medium (78 –88m) and deep (104-118 m) (Table 10). An additional shallower site was added to the trawl survey component to enhance the sampling design.

Table 10. Numbers of trawl samples collected.

Year	Depth	Cape Voltaire / Browse Island	Hall Point	Emeriau Point
2007	Shallow	3	3	3
2007	Medium	3	3	3
2007	Deep	7	2	4
2009	Shallow	3	3	3
2009	Medium	3	3	3
2009	Deep	3	5	2

We used a 36 m demersal fish trawl net with 230 mm mesh in the wings and body of the net and 104 mm in the cod end. The net was constructed of 3 mm mesh made out of polyethylene fibres.

At each depth within a site replicate trawls of approximately 30-minute duration were conducted. On average this trawl time covered a distance of approximately 1.5 nautical miles. The distance covered during each trawl varied depending on the direction of the tide and the prevailing weather conditions at the time. At some sites such as Hall Point Deep only two shots could be completed due to the limited areas of suitable trawl habitat. On several occasions at this site the trawl net hooked up on the bottom of the seabed and the trawl shot had to be abandoned. All of the trawl sampling was completed during daylight hours between 6:30 am and 6:00 pm.

Catches varied considerably in both total volume and number of species between trawl shots. Some trawl shots took over an hour to sort whereas a few took only 15 minutes to sort through. For example, during the Cape Voltaire/Browse Island shallow trawl shots large quantities of sponges and by-catch species were captured increasing the sorting time substantially. Catches such as these restricted the number of replicate trawl shots that could be completed at this site within one day. Due to the large distances between sampling sites, only an average of three trawl shots could be conducted every day. A total of 59 trawls were completed over the two research surveys.

For each trawl the net was emptied onto a central sorting table. The contents of each trawl sample were then separated into baskets on the deck. Once the sample had been roughly sorted, a more refined sort was undertaken to ensure that all species were identified and counted. Where possible the weight of each species was recorded to the nearest gram. Each fish was identified down to species level and measured to the nearest mm (fork length), except when the sample size was large. In these particular cases a sub sample of 100 fish was measured and weighed. The entire remaining sample was then weighed and the total weight recorded, an estimate of the number of individuals was then calculated based on the weight of the sub-sample.

Records were also kept of the time of sampling, the state of the tide, weather conditions and a description of the bottom type. Any protected species and large specimens captured (i.e. large

sharks and rays) that were not feasible to weigh and measure were photographed and returned to the water alive as quickly as practicable.

2.1.4 Statistical analysis

Multivariate homogeneity of dispersions in assemblage data

As we were interested in not only the potential differences between locations, but also the within group (Year × Site × Depth) variability, we have analysed these within group dispersions using PERMDISP (Anderson 2006). Analyses were run for each of the three years using 9999 permutations of the data. We were interested in understanding how much of the dissimilarity between factors (Year × Site × Depth) was driven by compositional differences and how much was driven by differences in their relative abundance. Therefore, the data were analysed using both a Modified Gower Logbase 2 dissimilarity measure, which places more emphasis on changes in relative abundance and a Modified Gower Logbase 10 dissimilarity measure which places emphasis on compositional changes (Anderson et al. 2006).

Assemblage composition

Separate analyses were conducted on the trap, stereo-BRUV, and fish trawl data. For the trap and stereo-BRUV data we used a three-way non-parametric multivariate analysis of variance (Anderson and Robinson 2003) to test for differences in fish assemblages between Years (3 strata, fixed), Sites (4 strata, fixed) and Depth (2 strata, fixed). We analysed the data using a Modified Logbase 10 (compositional data) and Modified Logbase 2 (relative abundance data) resemblance matrices with 9999 permutations of data.

For the trawl data we had less temporal and site data, but an additional depth strata. We used a three factor crossed design testing for differences between the factors Year (fixed; 2 strata (2007, 2009), Site (fixed; 3 strata (Emeriau Point, Hall Point, Cape Voltaire) and Depth (fixed; 3 strata (shallow, medium and deep). We ran 9999 permutations for each analysis and have made pairwise comparisons where appropriate. Because of the relatively low numbers of replicates in the trawl data we have used the Monte Carlo P values when the numbers of unique permutations were below 50. Due to large differences in the abundances of some species (abundances per trawl ranged from 0 to 446 individuals of any one species) data was Log (x+1) transformed prior to analysis. Given the use of a transformation, rather than using a Modified Gower resemblance matrix we used a Bray Curtis resemblance matrix. We plotted the data using an unconstrained ordination procedure (Principal Coordinate Analysis).

Canonical Analysis of Principal Coordinates (CAP)

CAP is a constrained ordination procedure that can be used to investigate hypotheses. Unlike an unconstrained ordination procedure, which does not use *a priori* hypotheses in any way, but reduces dimensions on the basis of some general criterion, CAP uses an *a priori* hypothesis to produce the plot (Anderson and Willis, 2003; Anderson and Robinson, 2003). The CAP analyses were only undertaken on appropriate terms found to be significant from the PERMANOVA analyses on the assemblage data (Year × Site × Depth).

Univariate analysis of the total numbers of fish and numbers of species

All univariate analyses were undertaken within PERMANOVA with analyses based on a Euclidean distance matrix with 9999 permutations of the appropriate units. The F-ratios used for tests done in this way are equivalent to those of traditional ANOVA (Anderson, 2001), although the P-values are not obtained using traditional tables. Data were analysed for each

year separately using the same 3 way models described for the assemblage data. Tests using permutations are sensitive to differences in dispersion. As such, prior to analysis we tested the data for differences in dispersions using PERMDISP. The analysis of a single variable based on a Euclidean distance matrix with PERMDISP using centroids is similar to a Levenes test (Anderson et al. 2008). Where appropriate, significant effects were investigated with *a posteriori* pairwise comparisons, which also used 9999 random permutations to obtain P-values. Data for the numbers of individual fish and numbers of species were square root transformed prior to analysis.

Spatial distribution of fish resources

To determine the spatial distribution of fish resources we have analysed the data for key species. For the trap and stereo-BRUV data the key species used were the same as those selected for comparisons of mean length and length frequency (Tables 4 and 5) and were selected on the basis that there were more than 35 individuals in each of the sets. For the trawl data we have analysed those species which had Pearson correlation values of greater than 0.5 or less than -0.5 from the CAP analysis. Data were analysed for each species in the same way as outlined above for the total numbers of fish and species. To help visualise the pattern, plots of the abundances of fish were made at the appropriate level in the statistical model. All analyses were conducted on square root transformed data.

2.2 Results

2.2.1 Traps: Assemblage data

Tests for homogeneity of multivariate dispersions (Anderson 2006, Anderson et al. 2008) between interactions of Year × Site × Depth on both the compositional data (Modified Gower Logbase 10) and relative abundance data (Modified Gower Logbase 2) showed no differences in the Logbase 10 ($F = 1.5208$, P (perm) = < 0.116), but significant differences in the Logbase 2 data ($F = 1.725$, P (perm) = 0.026) resemblance matrices. Pairwise comparisons of the Logbase 2 data show that 42 of the 276 (15%) pairwise comparisons were significantly different. This can be visualized in the principal coordinate plots for each year using Modified Gower Logbase 10 and Logbase 2 resemblance matrices (Figure 3a, b). The first two axes on both plots account for a small proportion of the total variation (~30-40 %).

A PERMANOVA analysis found that all of the main terms and interactions were significant for both the compositional (Modified Gower Logbase 10) and the relative abundance (Modified Gower Logbase 2) data (Table 11).

Table 11. Results of PERMANOVA analyses of trap data using Modified Gower Logbase 10 and Logbase 2 resemblance matrices for 9999 permutations of the data.

		Composition (MG Log 10)			Abundance (MG Log 2)		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**
Year (Ye)	2	4.302	7.879	**<0.001**	13.845	10.467	**<0.001**
Site (Si)	3	3.774	6.912	**<0.001**	9.090	6.872	**<0.001**
Depth (De)	1	4.238	7.760	**<0.001**	5.445	4.116	**0.001**
Ye × Si	6	1.419	2.599	**<0.001**	3.320	2.510	**<0.001**
Ye × De	2	1.033	1.892	**0.009**	2.864	2.165	**0.013**
Si × De	3	1.505	2.757	**<0.001**	3.013	2.278	**0.003**
Ye × Si × De	6	1.476	2.703	**<0.001**	3.481	2.632	**<0.001**
Residual	306	0.546			1.323		
Total	329						

Pairwise comparisons were used to test these interactions. Many of the differences in the pairwise comparisons for the Logbase 10 data were driven by location differences (Table 12). Cape Bossut and Emeriau Point (the southern sites) were often different when compared to the northern Cape Voltaire sites. However, differences were still present between neighboring sites (e.g. Cape Bossut and Emeriau Point, Hall Point and Cape Voltaire).

The pairwise comparisons in the relative abundance data (Modified Gower Logbase 2) patterns were not as strong as seen in the Logbase 10 data indicating that differences in species composition were driving the discrimination between areas and sites to a greater extent (Table 13). With the exception of the Cape Bossut shallow site there is substantial between-year variability. This is partly driven by spatial differences in sampling locations between years.

On the basis of the PERMANOVA result, a CAP analysis was run on the Year × Site × Depth interaction for both the compositional and relative abundance data. The analysis recorded significant trace statistics for both data sets. The CAP plots generally display a separation of depths within a site and a separation of sites from one another (Figure 3c, d). The overall 'leave one out' allocation success provides a statistical estimate of mis-classification error and demonstrates how distinct groups of samples are in multivariate space (Anderson and Willis, 2003). The overall 'leave one out' allocation success was low for both the compositional (38%) and relative abundance (27%) data (Table 14). While the CAP trace statistic indicated that there were differences between the Year × Site × Depth groups, the leave-one-out success suggests that differences were weak, particularly in the relative abundance data. It is interesting to note that several of the sites in 2009 had high discrimination. This could be due to decreased sample sizes in that year capturing less of the variance.

2.2.3 Traps: Number of individuals and species

We used PERMDISP to test for homogeneity of variance in the univariate data and recorded no differences between Year x Site x Depth for the numbers of individual fish, but there were significant differences for the numbers of species. Eighteen percent of the 276 pairwise comparisons were significantly different. These were entirely associated with location differences combined with depth. The univariate PERMANOVA showed there were significant Year, Site

and Depth main effects for the numbers of individual fish and a Year × Site × Depth interaction for the numbers of species (Table 14).

Almost three times the numbers of individuals were recorded in 2009 (mean = 16.31) in comparison to 2007 (mean = 5.28) and 2008 (mean = 5.34). Differences in sites were driven by a general trend of greater numbers of fish being caught in the shallower sites and higher numbers of individuals being caught at Cape Voltaire (Figure 3).

For species richness data, there were surprisingly few significant pairwise comparisons at the level of Year × Site × Depth (Table 15). The majority of these few significant pairwise comparisons were driven by the Site × Depth interaction or on occasions by variation between Years (e.g. Hall Point Deep).

Table 12. Results of pairwise comparisons of the Year × Site × Depth interaction on a Modified Gower Logbase 10 resemblance matrix for 9999 permutations of the trap data (* = 0.05, ** = 0.01, *** = 0.001; ns = not significant; CB = Cape Bossut, EP = Emeriau Point, HP = Hall Point, CV = Cape Voltaire; D = Deep, S = Shallow; 7 = 2007, 8 =2008, 9 = 2009).

	CBS7	CBS8	CBS9	CBD7	CBD8	CBD9	EPS7	EPS8	EPS9	EPD7	EPD8	EPD9	HPS7	HPS8	HPS9	HPD7	HPD8	HPD9	CVS7	CVS8	CVS9	CVD7	CVD8	CVD9
CBS8	ns																							
CBS9	ns																							
CBD7	***	ns																						
CBD8		**		**																				
CBD9			ns	**	**																			
EPS7	**																							
EPS8		*					*																	
EPS9			*				***	**																
EPD7				**			ns																	
EPD8					***			***		***														
EPD9						**			***	***	***													
HPS7							**			ns														
HPS8		*						*					ns											
HPS9			ns						*				**	**										
HPD7				*						ns			**											
HPD8					***						ns	***		*		**								
HPD9						ns						***			*	**								
CVS7	***						***						***											
CVS8		***						***						**										
CVS9			**						**						***									
CVD7				**						**						**			***					
CVD8					***						**						ns			**				
CVD9						*						***						ns			**	ns		

Table 13. Results of pairwise comparisons of the Year × Site × Depth interaction on a Modified Gower Logbase 2 resemblance matrix for 9999 permutations of the trap data (* = 0.05, ** = 0.01, *** = 0.001; ns = not significant; CB = Cape Bossut, EP = Emeriau Point, HP = Hall Point, CV = Cape Voltaire; D = Deep, S = Shallow; 7 = 2007, 8 =2008, 9 = 2009).

	CBS7	CBS8	CBS9	CBD7	CBD8	CBD9	EPS7	EPS8	EPS9	EPD7	EPD8	EPD9	HPS7	HPS8	HPS9	HPD7	HPD8	HPD9	CVS7	CVS8	CVS9	CVD7	CVD8	CVD9
CBS8	ns																							
CBS9	ns	ns																						
CBD7	*		ns																					
CBD8		*		*																				
CBD9			ns	Ns	**																			
EPS7	ns																							
EPS8		ns					ns																	
EPS9			*				***	**																
EPD7				*			ns																	
EPD8					**			ns		**														
EPD9						**			***	***	***													
HPS7	ns						*			ns														
HPS8								ns			ns		ns											
HPS9									*			**	ns	**										
HPD7				Ns						ns			*				ns							
HPD8					***							**				ns		***						
HPD9						ns											*		ns					
CVS7	**						***						**					ns		***	***	**		
CVS8		**			***			**			*			*							**			
CVS9			**						**															**
CVD7				Ns						*									**				ns	**
CVD8					***						*						ns			*				
CVD9						*						**						ns			**			***

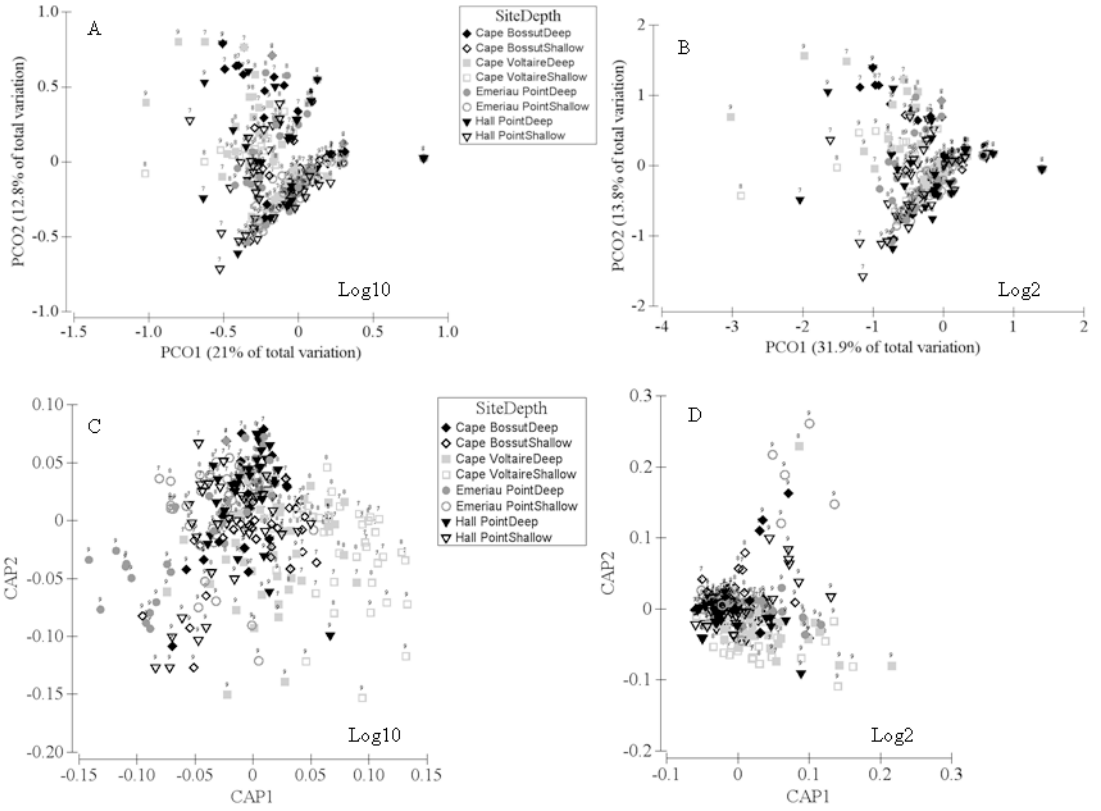

Figure 3. PCO and CAP plots for Log 10 (A, C) and Log 2 (B, D) Modified Gower trap data.

Table 14. PERMANOVA results testing for differences between Year, Site and Depth for the total numbers of fish and number of species sampled in 2007, 2008 and 2009. Data were square root transformed and used a Euclidean resemblance matrix with 9999 permutations of the data.

		Number of individuals			Number of species		
Source	**Df**	**MS**	**F**	**p**	**MS**	**F**	**p**
Year (Ye)	2	28.173	45.554	**<0.001**	12.507	32.907	**<0.001**
Site (Si)	3	6.090	9.848	**<0.001**	2.031	5.343	**0.002**
Depth (De)	1	3.759	6.078	**0.014**	5.395	14.195	**<0.001**
Ye × Si	6	1.250	2.022	0.062	0.909	2.391	**0.026**
Ye × De	2	0.470	0.759	0.470	0.207	0.544	0.588
Si × De	3	0.776	1.255	0.291	1.750	4.604	**0.004**
Ye × Si × De	6	1.147	1.854	0.086	0.816	2.148	**0.045**
Residual	306	0.618			0.380		
Total	329						

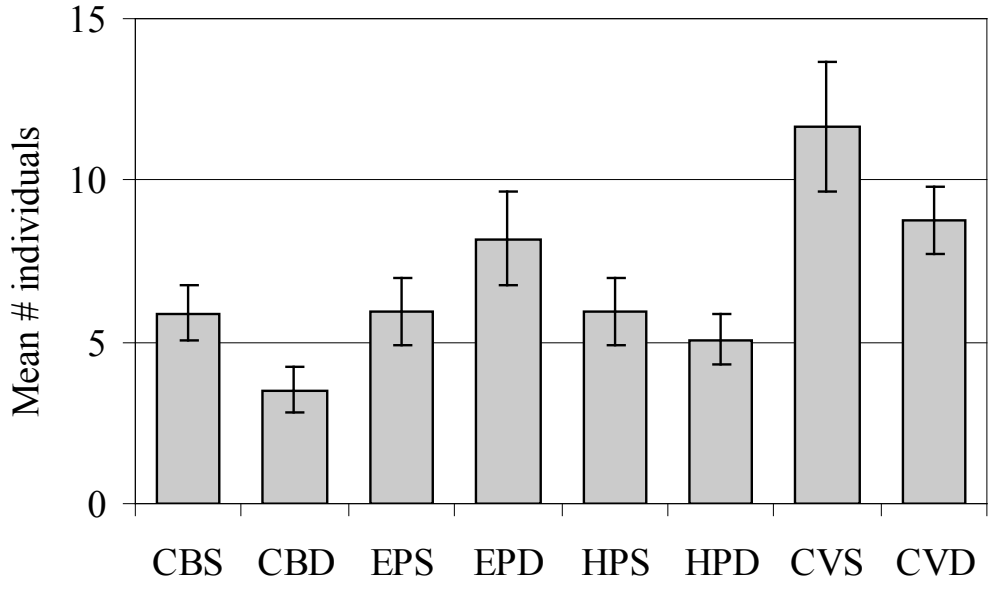

Figure 4. Mean number of individuals sampled in all three years plotted by site (Errors bars ± 1 SE; CV = Cape Voltaire, HP = Hall Point, EP = Emeriau Point, CB = Cape Bossut; D = Deep, S = Shallow).

2.2.2 Spatial distribution of fish resources sampled by traps

PERMDISP showed that there were statistically significant differences in the dispersions of the abundances of the key species. Transformation did not change the heterogeneity of the dispersions.

When the numbers of key species of fish caught in commercial traps were tested for spatial, temporal and depth differences nine of the 13 species tested (*Abalistes stellaris, Carangoides gymnostethus, Epinephelus areolatus, Lethrinus nebulosus, Lutjanus bitaeniatus, Lutjanus malabaricus, Lutjanus vitta, Pristipomoides multidens, Pristipomoides typus*) had significant Year × Site × Depth interactions, two species (*Epinephelus bleekeri, Epinephelus multinotatus*) had Site × Depth interactions and one (*Lutjanus sebae*) had a significant Year × Site interaction (Table 16). *Lutjanus erythropterus* had a significant Depth term with nearly all of the fish being caught in shallower sites (Table 16).

Some of the species were more abundant in the northern regions of the sampling areas (e.g. *Lutjanus bitaeniatus, Lutjanus malabaricus, Lutjanus vitta*, Figures 5H, I, J). These species tended to be caught in higher numbers at the shallower sampling sites within the same region. Similarly, *Epinephelus multinotatus* (Figure 5E and F) tended to be caught in higher numbers in the southern sample sites.

Pristipomoides multidens and *Pristipomoides typus* tended to be caught at the deeper sites (Figures 5L and M).

A number of species displayed great variability between years with more fish caught in 2009 at some sites than in other years (eg. *Epinephelus areolatus, Epinephelus bleekeri, Lethrinus nebulosus,* Figures 5C, D, G).

Table 15. Results of pairwise comparisons of the Year × Site × Depth interaction on a square root transformed species data based on a Euclidean distance resemblance matrix for 9999 permutations of the trap data (* = 0.05, ** = 0.01, *** = 0.001; ns = not significant; CB = Cape Bossut, EP = Emeriau Point, HP = Hall Point, CV = Cape Voltaire; D = Deep, S = Shallow; 7 = 2007, 8 =2008, 9 = 2009).

	CBS7	CBS8	CBS9	CBD7	CBD8	CBD9	EPS7	EPS8	EPS9	EPD7	EPD8	EPD9	HPS7	HPS8	HPS9	HPD7	HPD8	HPD9	CVS7	CVS8	CVS9	CVD7	CVD8	CVD9
CBS8	ns																							
CBS9	ns	ns																						
CBD7	*																							
CBD8		***		*																				
CBD9			ns		**																			
EPS7	ns																							
EPS8		ns					ns																	
EPS9			ns				ns	ns																
EPD7				Ns			ns																	
EPD8					***			ns		Ns														
EPD9						***			ns	***	***													
HPS7	ns						ns																	
HPS8		ns						ns					ns											
HPS9			ns						ns				***	***										
HPD7				Ns						Ns			*		*									
HPD8					***						ns			ns		**								
HPD9						ns						*			ns	**	ns							
CVS7	ns						ns						ns											
CVS8		ns						*						ns										
CVS9			ns						ns			ns			ns	**	*							
CVD7				*						Ns								**	ns					
CVD8					***						ns						ns			ns				
CVD9						ns						***						ns			ns	ns		

Table 16. PERMANOVA results testing for differences between Year, Site and Depth for key fish species sampled by commercial fish traps in 2007, 2008 and 2009. Data were square root transformed and used a Euclidean resemblance matrix with 9999 permutations of the data.

		Abalistes stellaris			*Carangoides gymnostethus*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	4.085	39.798	<0.001	0.100	5.384	0.008
Site (Si)	3	0.997	9.717	<0.001	0.058	3.142	0.042
Depth (De)	1	1.884	18.354	<0.001	0.109	5.876	0.015
Ye × Si	6	1.398	13.621	<0.001	0.065	3.519	0.009
Ye × De	2	0.988	9.626	<0.001	0.133	7.122	0.002
Si × De	3	1.707	16.626	<0.001	0.089	4.764	0.009
Ye × Si × De	6	1.476	14.382	<0.001	0.053	2.849	0.021
Residual	306	0.103			0.019		
Total	329						
		Epinephelus areolatus			*Epinephelus bleekeri*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	8.688	14.576	<0.001	1.377	3.718	0.026
Site (Si)	3	5.503	9.232	<0.001	8.071	21.797	<0.001
Depth (De)	1	0.482	0.809	0.377	13.426	36.258	<0.001
Ye × Si	6	2.541	4.262	<0.001	0.737	1.991	0.071
Ye × De	2	0.724	1.214	0.289	1.337	3.611	0.033
Si × De	3	6.056	10.161	<0.001	7.519	20.305	<0.001
Ye × Si × De	6	3.092	5.188	<0.001	0.709	1.914	0.088
Residual	306	0.596			0.370		
Total	329						
		Epinephelus multinotatus			*Lethrinus nebulosus*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	0.962	5.003	0.008	0.062	0.787	0.466
Site (Si)	3	3.975	20.680	<0.001	0.667	8.441	0.001
Depth (De)	1	1.801	9.372	0.003	0.004	0.045	0.839
Ye × Si	6	1.161	6.039	<0.001	0.172	2.176	0.045
Ye × De	2	0.039	0.200	0.820	0.628	7.953	0.001
Si × De	3	0.900	4.683	0.004	0.096	1.212	0.305
Ye × Si × De	6	0.149	0.775	0.587	0.441	5.587	<0.001
Residual	306	0.192			0.079		
Total	329						
		Lutjanus bitaeniatus			*Lutjanus erythropterus*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	1.295	4.668	0.011	0.070	0.576	0.581
Site (Si)	3	11.958	43.105	<0.001	0.209	1.729	0.155
Depth (De)	1	1.483	5.344	0.022	0.759	6.287	0.014
Ye × Si	6	0.833	3.003	0.009	0.110	0.907	0.479
Ye × De	2	0.340	1.225	0.289	0.061	0.507	0.611

Table 16. Continued.

Si × De	3	2.919	10.521	<0.001	0.154	1.278	0.272
Ye × Si × De	6	0.713	2.570	0.022	0.098	0.813	0.543
Residual	306	0.277			0.121		
Total	329						
		Lutjanus malabaricus			***Lutjanus sebae***		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	1.812	8.332	0.001	0.711	1.190	0.297
Site (Si)	3	4.198	19.298	<0.001	1.659	2.777	0.045
Depth (De)	1	2.183	10.036	0.002	19.376	32.427	<0.001
Ye × Si	6	0.650	2.988	0.010	2.341	3.917	0.001
Ye × De	2	1.031	4.741	0.009	0.300	0.503	0.607
Si × De	3	0.692	3.182	0.027	0.673	1.125	0.335
Ye × Si × De	6	0.735	3.380	0.005	0.999	1.673	0.120
Residual	306	0.218			0.598		
Total	329						
		Lutjanus vitta			***Pristipomoides multidens***		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	3.993	18.410	<0.001	14.017	21.953	<0.001
Site (Si)	3	3.052	14.069	<0.001	6.426	10.064	<0.001
Depth (De)	1	4.147	19.116	<0.001	11.960	18.731	<0.001
Ye × Si	6	1.556	7.171	<0.001	1.563	2.448	0.027
Ye × De	2	1.153	5.314	0.006	0.279	0.437	0.644
Si × De	3	1.941	8.946	<0.001	0.856	1.341	0.259
Ye × Si × De	6	1.136	5.235	0.001	2.795	4.377	0.001
Residual	306	0.217			0.639		
Total	329						
		Pristipomoides typus					
Source	**df**	**MS**	**F**	**P**			
Year (Ye)	2	1.737	14.194	<0.001			
Site (Si)	3	0.444	3.625	0.017			
Depth (De)	1	1.865	15.238	<0.001			
Ye × Si	6	0.398	3.250	0.008			
Ye × De	2	0.766	6.262	0.003			
Si × De	3	0.881	7.198	<0.001			
Ye × Si × De	6	0.758	6.193	<0.001			
Residual	306	0.122					
Total	329						

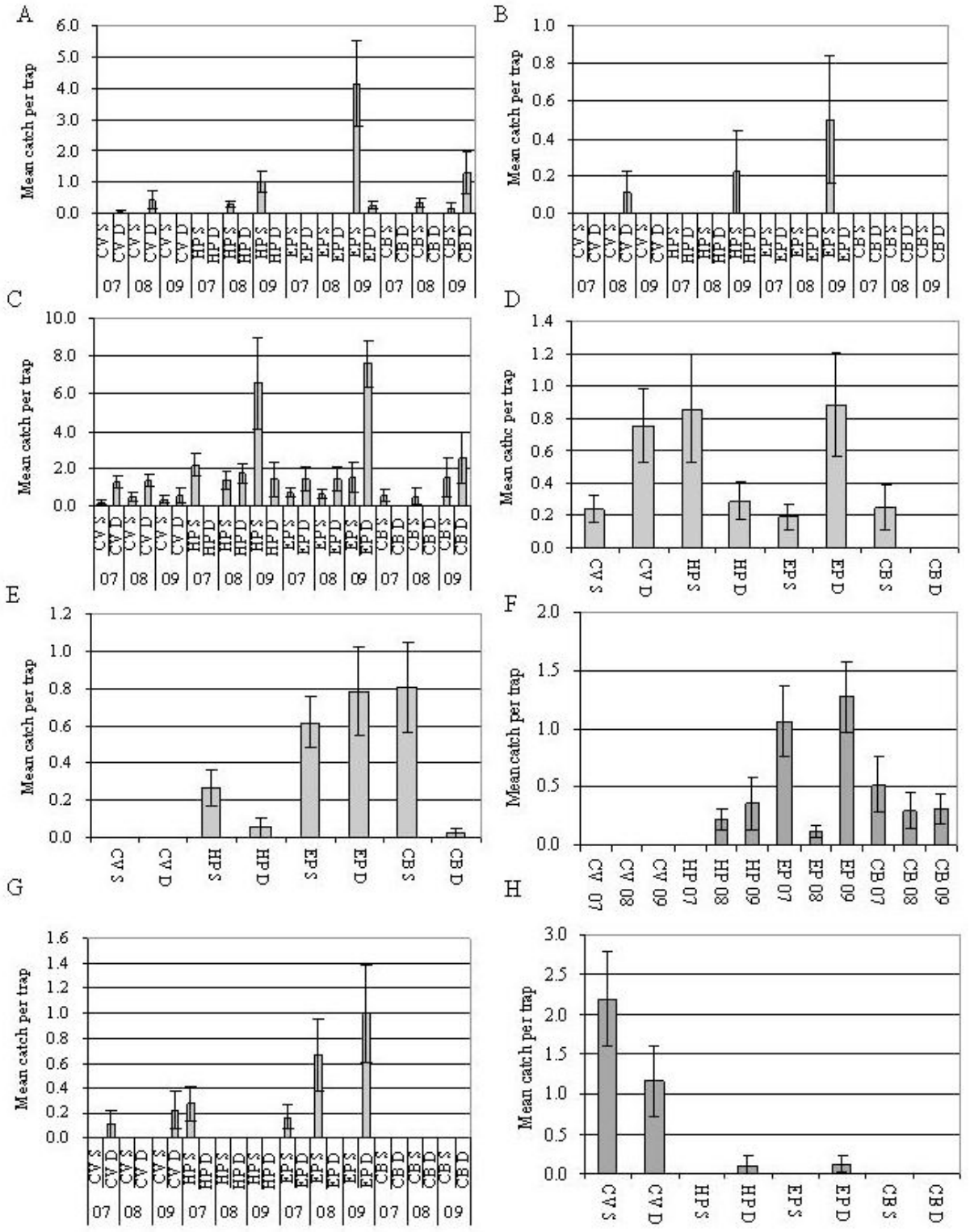

Figure 5. Mean number of key species sampled in commercial fish traps. NB the plot has been drawn at the appropriate term detailed in Table 16. Errors bars = ± 1 SE; CV = Cape Voltaire, HP = Hall Point, EP = Emeriau Point, CB =Cape Bossut; D = Deep, S = Shallow; 07 = 2007, 08 = 2008, 09 = 2009. A = *Abalistes stellaris*, B = *Carangoides gymnostethus*, C = *Epinephelus areolatus*, D = *Epinephelus bleekeri*, E and F = *Epinephelus multinotatus*, G = *Lethrinus nebulosus*, H = *Lutjanus bitaeniatus*, I = *Lutjanus malabaricus*, J = *Lutjanus sebae*, K = *Lutjanus vitta*, L = *Pristipomoides multidens*, M = *Pristipomoides typus*.

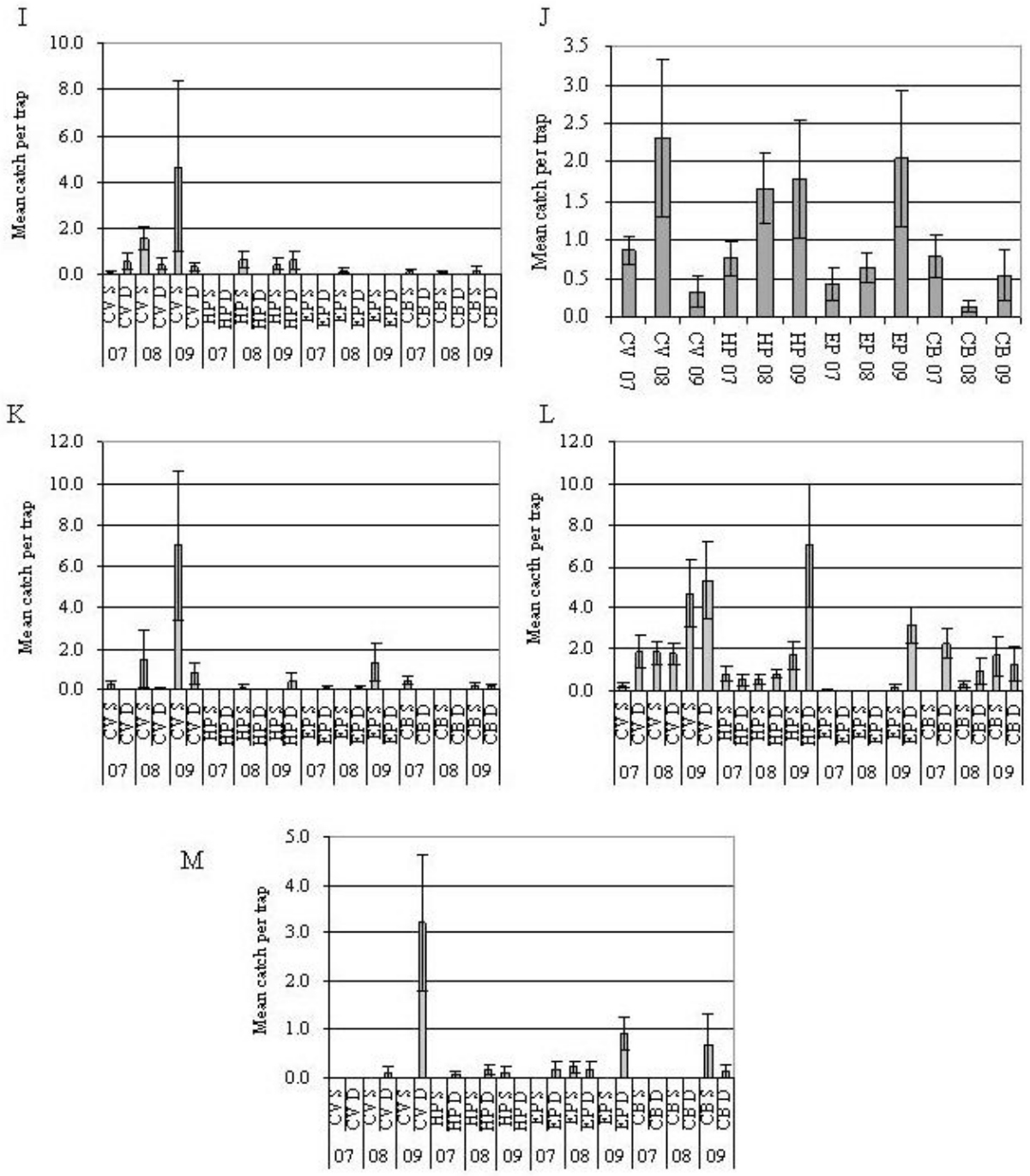

Figure 5. Continued.

2.2.3 Stereo-BRUVs: Assemblage data

Tests for homogeneity of multivariate dispersions (Anderson 2006, Anderson et al. 2008) between Year × Site × Depth on both the compositional data (Modified Gower Logbase 10) and relative abundance data (Modified Gower Log 2) showed significant differences in the Logbase 10 (F = 2.407, P (perm)= 0.015), but no significant differences in the Logbase 2 data (F = 1.765, P (perm)= 0.063) resemblance matrices. Pairwise comparisons of the Logbase 10 data show that 37 of the 276 (13.5%) pairwise comparisons were significantly different. This can be visualized in principal coordinate plots for each year using Modified Gower Logbase 10 and Logbase 2 resemblance matrices (Figure 6a, b). The first two axes on both plots account for a small proportion of the total variation (~30-40%).

PERMANOVA tests showed that all of the main terms and interactions were significant for both the compositional (MG Logbase 10) and the relative abundance (MG Logbase 2) data (Table 17).

Table 17. Results of PERMANOVA analyses of stereo BRUVs data using MG Logbase 10 and Logbase 2 resemblance matrices for 9999 permutations of the data.

		Composition (MG Log 10)			Abundance (MG Log 2)		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**
Year (Ye)	2	1.949	3.948	**<0.001**	4.307	3.819	**<0.001**
Site (Si)	3	3.178	6.436	**<0.001**	5.564	4.934	**<0.001**
Depth (De)	1	3.606	7.304	**<0.001**	8.564	7.593	**<0.001**
Ye × Si	6	1.403	2.841	**<0.001**	2.456	2.178	**<0.001**
Ye × De	2	1.022	2.069	**<0.001**	2.035	1.804	**0.003**
Si × De	3	1.727	3.497	**<0.001**	3.532	3.132	**<0.001**
Ye × Si × De	6	1.101	2.230	**<0.001**	2.139	1.897	**<0.001**
Residual	259	0.494			1.128		
Total	282						

Pairwise tests were used to explore these significant interactions. Many of the differences in the pairwise comparisons for the Logbase 10 data were driven by location differences (Table 18). Cape Bossut and Emeriau Point (the southern sites) were often different when compared to the northern Cape Voltaire site. However, differences were still present between neighboring sites (e.g. Cape Bossut and Emeriau Point, Hall Point and Cape Voltaire).

The pairwise comparisons in the relative abundance data (Modified Gower Logbase 2) patterns are not as strong as seen in the Logbase 10 data indicating that differences in species composition were driving the discrimination between areas and sites (Table 19). With the exception of the Cape Bossut shallow site, there is substantial between year variability. This is driven in part by spatial differences in sampling between years.

On the basis of the PERMANOVA result, the CAP analysis was run on the Year × Site × Depth interaction for both the compositional and relative abundance data. The analysis recorded significant trace statistics for both data sets. The CAP plots generally display a separation of depths within a site and a separation of sites from one another (Figure 6c, d). The overall 'leave one out' allocation success provides a statistical estimate of mis-classification error and demonstrates how distinct groups of samples are in multivariate space (Anderson and Willis, 2003). The overall 'leave one out' allocation success was moderate for both compositional (54%) and relative abundance (45%).

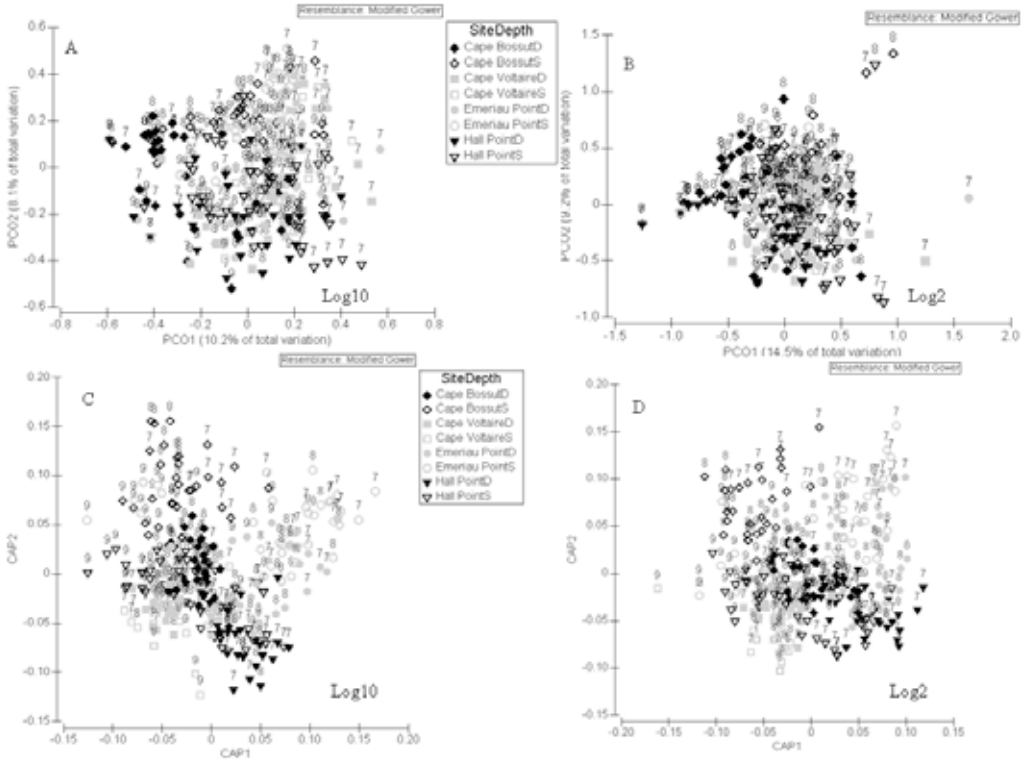

Figure 6. PCO and CAP plots for Modified Gower Logbase 10 (A, C) and Logbase 2 (B, D) stereo-BRUVs data.

2.2.4 Stereo-BRUVs: Number of individuals and species

The PERMDISP routine was used to test for homogeneity of variance in the square root transformed data on the numbers of individual fish and numbers of species. No significant differences were found between Year x Site x Depth factors for the numbers of individual fish ($F = 1.574$, P (perm) = 0.107) or the numbers of species ($F = 1.510$, P (perm) = 0.197).

The univariate PERMANOVA showed there were significant Year, Site and Depth main effects for the numbers of individual fish and a Year × Site × Depth interaction for the numbers of species (Table 20).

Differences between sites were driven by a general trend of greater numbers of fish being recorded in the shallower depths with higher numbers of individuals and higher numbers of species being caught at Emeriau Point (Figure 7).

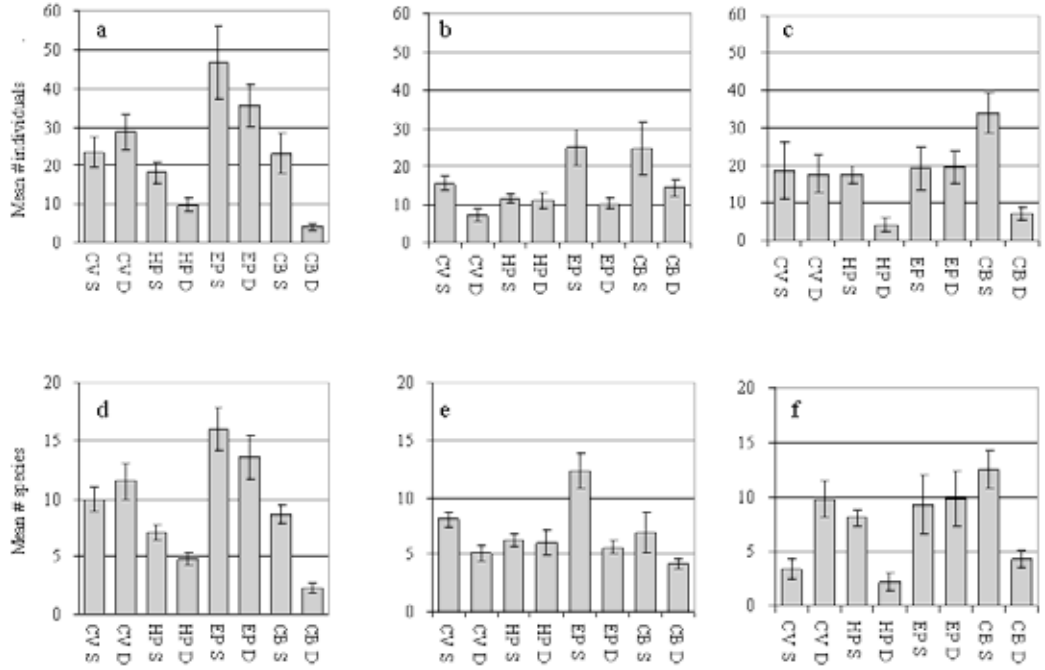

Figure 7. Plots of the total numbers of fish (a, b, c) and species (d, e and f) sampled by stereo-BRUVs in 2007, 2008 and 2009 (Error bars = ± 1 SE; CB = Cape Bossut, EP= Emeriau Point, HP = Hall Point, CV = Cape Voltaire; S = Shallow, D = Deep).

Table 18. Results of pairwise comparisons of the Year x Site x Depth interaction on a Modified Gower Logbase 10 resemblance matrix for 9999 permutations of the data for stereo-BRUVs (* = 0.05, ** = 0.01, *** = 0.001; ns = not significant; CB = Cape Bossut, EP = Emeriau Point, HP = Hall Point, CV = Cape Voltaire; D = Deep, S = Shallow; 7 = 2007, 8 =2008, 9 = 2009).

	CBS7	CBS8	CBS9	CBD7	CBD8	CBD9	EPS7	EPS8	EPS9	EPD7	EPD8	EPD9	HPS7	HPS8	HPS9	HPD7	HPD8	HPD9	CVS7	CVS8	CVS9	CVD7	CVD8	CVD9
CBS8	***																							
CBS9	***																							
CBD7	***	***																						
CBD8		*		Ns																				
CBD9			***	*	ns																			
EPS7	***																							
EPS8		***					***																	
EPS9			***				***	***																
EPD7				***			***																	
EPD8					***			***		***														
EPD9						**			***	***	***													
HPS7	***						***			***														
HPS8		***						***					***											
HPS9			***						ns				***	ns										
HPD7				***						***			***											
HPD8					**						**			***										
HPD9						ns						ns												
CVS7	***						***						***											
CVS8		***						***						***										
CVS9			***						**						*									
CVD7				***						***									***					
CVD8					***						***									***				
CVD9						***						ns						ns			ns	*	ns	

Table 19. Results of pairwise comparisons of the Year x Site x Depth interaction on a Modified Gower Logbase 2 resemblance matrix for 9999 permutations of the data stereo-BRUVs (* = 0.05, ** = 0.01, *** = 0.001; ns = not significant; CB = Cape Bossut, EP = Emeriau Point, HP = Hall Point, CV = Cape Voltaire; D = Deep, S = Shallow; 7 = 2007, 8 =2008, 9 = 2009).

	CBS7	CBS8	CBS9	CBD7	CBD8	CBD9	EPS7	EPS8	EPS9	EPD7	EPD8	EPD9	HPS7	HPS8	HPS9	HPD7	HPD8	HPD9	CVS7	CVS8	CVS9	CVD7	CVD8	CVD9
CBS8	ns																							
CBS9	*	ns																						
CBD7	***																							
CBD8		*		Ns																				
CBD9			***	Ns	ns																			
EPS7	***																							
EPS8		**					**																	
EPS9			*				***	***																
EPD7				***			***																	
EPD8					ns			***																
EPD9						**			**	***	***													
HPS7	***						***																	
HPS8		**						***					***											
HPS9			***						ns				***	**										
HPD7				**						***			***											
HPD8					ns									***										
HPD9						ns						ns					ns							
CVS7	***																							
CVS8		***						***						***										
CVS9			**						ns							**								
CVD7				***						***														
CVD8					ns						***													
CVD9						*						ns												

Table 20. PERMANOVA results testing for differences between Year, Site and Depth for the total numbers of fish and number of species sampled in 2007, 2008 and 2009. Data has been Square Root transformed and uses a Euclidean resemblance matrix with 9999 permutations of the data.

		Number of individuals			Number of species		
Source	**df**	**MS**	**F**	**p**	**MS**	**F**	**p**
Year (Ye)	2	27.862	13.108	**<0.001**	6.399	11.019	**<0.001**
Site (Si)	3	26.360	12.401	**<0.001**	11.695	20.138	**<0.001**
Depth (De)	1	84.605	39.802	**<0.001**	19.337	33.298	**<0.001**
Ye × Si	6	10.983	5.167	**<0.001**	2.935	5.053	**<0.001**
Ye × De	2	0.830	0.390	0.670	0.600	1.032	0.343
Si × De	3	16.444	7.736	**<0.001**	5.977	10.292	**<0.001**
Ye × Si × De	6	4.199	1.975	0.073	2.313	3.983	**<0.001**
Residual	259	2.126			0.581		
Total	282						

2.2.5 Spatial distribution of fish resources sampled by stereo BRUVs

PERMDISP showed that there were statistically significant differences in the dispersions of the abundances of the key species. Transformation of the data did not change the heterogeneity of the dispersions.

When the numbers of key species of fish recorded on stereo BRUVs were tested for spatial, temporal and depth differences eight of the 13 species tested (*Abalistes stellaris, Epinephelus areolatus, Epinephelus multinotatus*, *Lethrinus nebulosus, Lutjanus bitaeniatus, Lutjanus sebae, Pristipomoides multidens, Pristipomoides typus*) had significant Year × Site × Depth interactions and *Lutjanus erythropterus* had a significant Site × Depth, Year x Depth and Year x Site interaction (Table 21). *Carangoides gymnostethus* had significant Site × Depth and Year x Depth interactions, while *Epinephelus bleekeri* had a significant Site × Depth interaction and *Lutjanus vitta* had a significant Year x Site interaction.

Lutjanus malabaricus had significant Depth and Site terms with the majority of the fish being recorded in shallower sites, with fish numbers decreasing from the northern to the southern shallower sampling sites.

Some of the species were more abundant in the northern regions of the sampling areas, e.g. *Lutjanus bitaeniatus, Lutjanus malabaricus* and *Lutjanus sebae* (Figures 8I, M, N). These species tended to be caught in higher numbers at the shallower sampling sites within the same region. Similarly, *Carangoides gymnostethus* (Figure 8B, C) and *Epinephelus multinotatus* (Figure 8G) tended to be caught in higher numbers in the southern sampling sites.

As shown in the trap data *Pristipomoides multidens* and *Pristipomoides typus* tended to be caught at the deeper sites (Figures 8P and Q).

Table 21. PERMANOVA results testing for differences between Year, Site and Depth for key fish species sampled by stereo BRUVs in 2007, 2008 and 2009. Data has been Square Root transformed and uses a Euclidean resemblance matrix with 9999 permutations of the data.

		Abalistes stellaris			*Carangoides gymnostethus*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	5.716	34.166	**<0.001**	1.377	3.718	0.026
Site (Si)	3	0.644	3.851	**0.011**	8.071	21.797	**<0.001**
Depth (De)	1	2.224	13.294	**<0.001**	13.426	36.258	**<0.001**
Ye × Si	6	1.649	9.856	**<0.001**	0.737	1.991	0.071
Ye × De	2	0.011	0.066	0.934	1.337	3.611	**0.033**
Si × De	3	4.027	24.072	**<0.001**	7.519	20.305	<0.001
Ye × Si × De	6	0.377	2.255	**0.042**	0.709	1.914	0.088
Residual	259	0.167			0.370		
Total	282						
		Epinephelus areolatus			*Epinephelus bleekeri*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	3.199	6.898	**0.001**	3.132	8.488	**0.001**
Site (Si)	3	3.208	6.918	**0.001**	1.838	4.980	**0.006**
Depth (De)	1	0.016	0.034	0.859	0.001	0.004	0.950
Ye × Si	6	4.172	8.996	**<0.001**	1.035	2.804	**0.017**
Ye × De	2	0.351	0.758	0.469	0.014	0.039	0.962
Si × De	3	3.837	8.275	**<0.001**	1.010	2.738	**0.048**
Ye × Si × De	6	3.334	7.189	**<0.001**	0.384	1.041	0.401
Residual	259	0.464			0.369		
Total	282						
		Epinephelus multinotatus			*Lethrinus nebulosus*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	0.258	1.641	0.196	0.525	3.663	**0.025**
Site (Si)	3	1.800	11.437	**<0.001**	1.802	12.572	**<0.001**
Depth (De)	1	1.307	8.302	0.005	0.010	0.072	0.791
Ye × Si	6	0.102	0.649	0.686	0.254	1.774	0.102
Ye × De	2	0.366	2.326	0.095	0.719	5.020	**0.009**
Si × De	3	0.443	2.815	**0.040**	0.323	2.252	0.087
Ye × Si × De	6	0.738	4.692	**<0.001**	0.792	5.524	**<0.001**
Residual	259	0.157			0.143		
Total	282						
		Lutjanus bitaeniatus			*Lutjanus erythropterus*		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	0.720	3.818	**0.021**	2.472	4.619	**0.012**
Site (Si)	3	1.289	6.837	**0.001**	5.086	9.505	**<0.001**
Depth (De)	1	0.085	0.449	0.505	10.383	19.404	**<0.001**
Ye × Si	6	0.387	2.054	0.062	1.489	2.783	**0.015**
Ye × De	2	0.751	3.985	**0.023**	2.583	4.826	**0.009**
Si × De	3	0.127	0.673	0.556	2.471	4.617	**0.005**

Table 21. Continued.

Ye × Si × De	6	0.456	2.421	**0.029**	1.052	1.966	0.073
Residual	259	0.188			0.535		
Total	282						
		Lutjanus malabaricus			***Lutjanus sebae***		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	0.115	0.384	0.688	2.218	5.724	**0.004**
Site (Si)	3	2.274	7.585	**<0.001**	1.407	3.633	**0.011**
Depth (De)	1	3.083	10.284	**0.002**	7.118	18.370	**<0.001**
Ye × Si	6	0.346	1.153	0.325	1.018	2.626	**0.019**
Ye × De	2	0.313	1.043	0.350	0.380	0.981	0.375
Si × De	3	0.653	2.179	0.091	0.320	0.826	0.483
Ye × Si × De	6	0.438	1.461	0.195	1.089	2.810	**0.013**
Residual	259	0.300			0.387		
Total	282						
		Lutjanus vitta			***Pristipomoides multidens***		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Year (Ye)	2	0.312	3.123	**0.043**	1.207	2.107	0.124
Site (Si)	3	0.530	5.312	**0.004**	7.877	13.753	**<0.001**
Depth (De)	1	0.251	2.517	0.118	4.027	7.031	**0.009**
Ye × Si	6	0.869	8.702	**<0.001**	2.292	4.001	**0.001**
Ye × De	2	0.208	2.081	0.132	1.526	2.665	0.070
Si × De	3	0.087	0.871	0.448	1.651	2.882	**0.040**
Ye × Si × De	6	0.080	0.800	0.569	1.725	3.012	**0.007**
Residual	259	0.100			0.573		
Total	282						
		Pristipomoides typus					
Source	**df**	**MS**	**F**	**P**			
Year (Ye)	2	1.999	3.593	**0.031**			
Site (Si)	3	5.955	10.702	**<0.001**			
Depth (De)	1	5.690	10.225	**0.002**			
Ye × Si	6	1.767	3.174	**0.007**			
Ye × De	2	1.153	2.072	0.129			
Si × De	3	2.390	4.295	**0.007**			
Ye × Si × De	6	2.830	5.085	**<0.001**			
Residual	259	0.556					
Total	282						

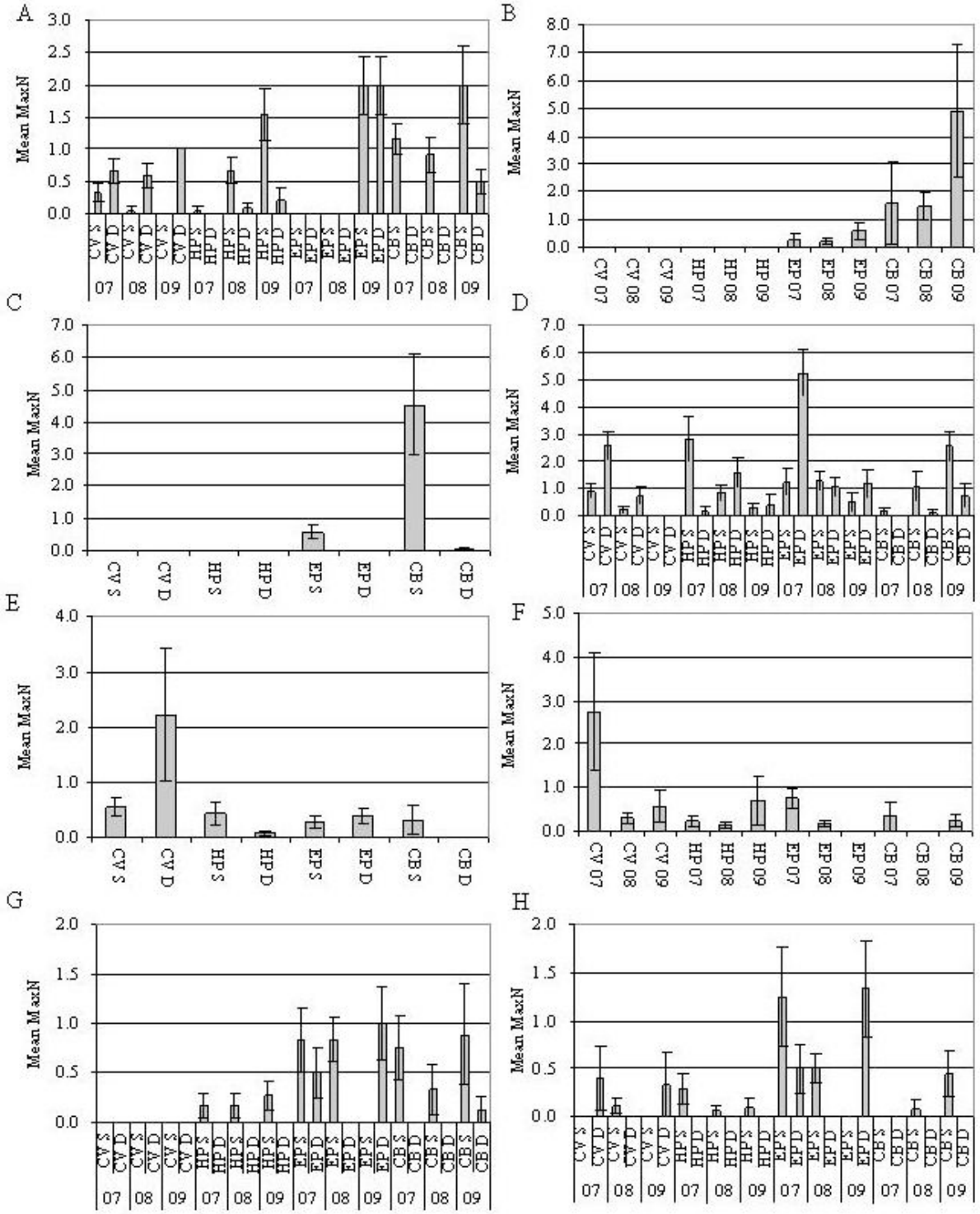

Figure 8. Mean number (mean MaxN) of key species sampled sampled by stereo BRUVs. NB the plot has been drawn at the appropriate term detailed in Table 21. Errors bars = ± 1 SE; CV = Cape Voltaire, HP = Hall Point, EP = Emeriau Point, CB = Cape Bossut; D = Deep, S = Shallow; 07 = 2007, 08 = 2008, 09 = 2009. A = *Abalistes stellatus*, B, C = *Carangoides gymnostethus*, D = *Epinephelus areolatus*, E, F = *Epinephelus bleekeri*, G = *Epinephelus multinotatus*, H = *Lethrinus nebulosus*, I = *Lutjanus bitaeniatus*, J, K, L = *Lutjanus erythropterus*, M = *Lutjanus malabaricus*, N = *Lutjanus sebae*, O = *Lutjanus vitta*, P = *Pristipomoides multidens*, Q = *Pristipomoides typus*.

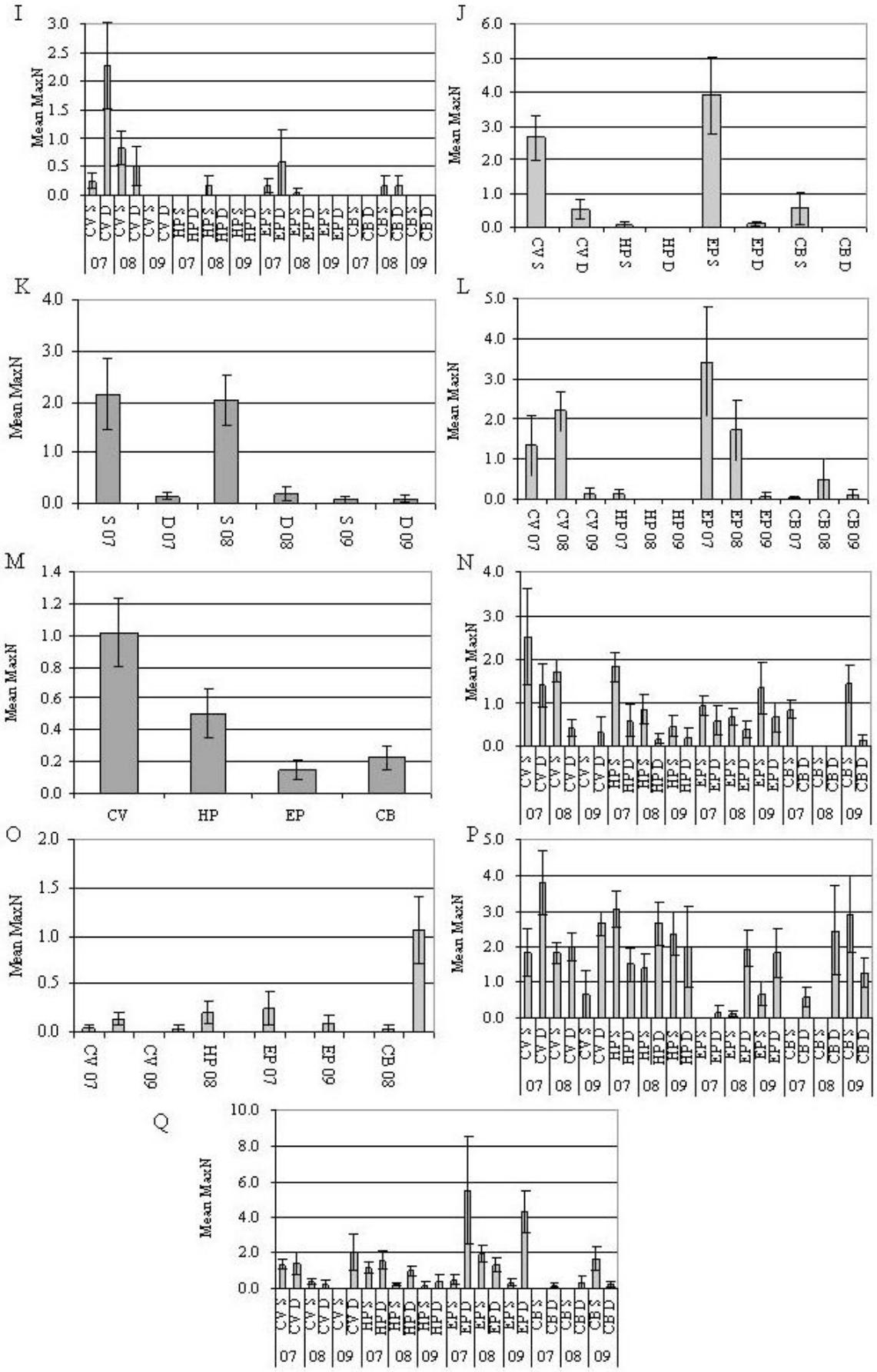

Figure 8. Continued.

2.2.6 Fish Trawl data

The 59 fish trawls throughout the NDSF sampled a total of 223 species and 37,993 individual fish.

A PERMDISP analysis indicated there were significant (p = <0.001) differences in the dispersions between combinations of Year × Site × Depth. Ten percent of the 153 pairwise comparisons were significant and showed that the differences in dispersions were between shallow and deep sites at Cape Voltaire to the north east and Hall Point (the middle site) to the south west.

The three-way PERMANOVA on the abundance data (Table 22) showed significant main effects and interactions at all levels of the model.

Table 22. A three way PERMANOVA testing for temporal, spatial and depth differences in trawl data. Data is Log (x+1) transformed and analysed using a Bray Curtis resemblance matrix (Ye = Year, Si = Site and De = Depth).

Source	Df	SS	MS	Pseudo-F	P(perm)
Year (Ye)	1	5009.7	5009.7	3.1319	**<0.001**
Site (Si)	2	38695	19348	12.095	**<0.001**
Depth (De)	2	36755	18377	11.489	**<0.001**
Ye × Si	2	8461.6	4230.8	2.6449	**<0.001**
Ye × De	2	6580.8	3290.4	2.057	**<0.001**
Si × De	4	33623	8405.9	5.255	**<0.001**
Ye × Si × De	4	15492	3873.1	2.4213	**<0.001**
Residual	41	65583	1599.6		

Pairwise comparisons of the Year × Site × Depth interaction term for Year revealed that the only differences that existed between 2007 and 2009 were at the Emeriau Point Deep and Cape Voltaire Medium depth sites. Trawls for the Emeriau Point Deep were separated by 16 km between 2007 and 2009 that may explain the difference for that site.

Pairwise comparisons of the Year × Site × Depth interaction term for Site showed that there were no differences between Emeriau Point and Hall Point at Shallow and Medium depth sites. Differences existed between all locations at deep sites. Emeriau and Hall Point Shallow and Medium sites were closer (~ 130 and 150 km respectively) to one another than to Cape Voltaire (EPS to CVS = ~ 430 km).

For Cape Voltaire pairwise comparisons of the Year × Site × Depth interaction term for depth showed significant differences between all three-depth strata for both years. At Hall Point there were significant differences between all three depths in 2009, but in 2007 only between shallow and deep with the other pairwise test tending towards a significant result (p = 0.08 and 0.07). For Emeriau Point significant differences existed between shallow and deep and medium and deep trawls for both years. A Non Metric Multidimensional Scaling plot (Figure 9) and CAP plot (Figure 10) visualize these trends.

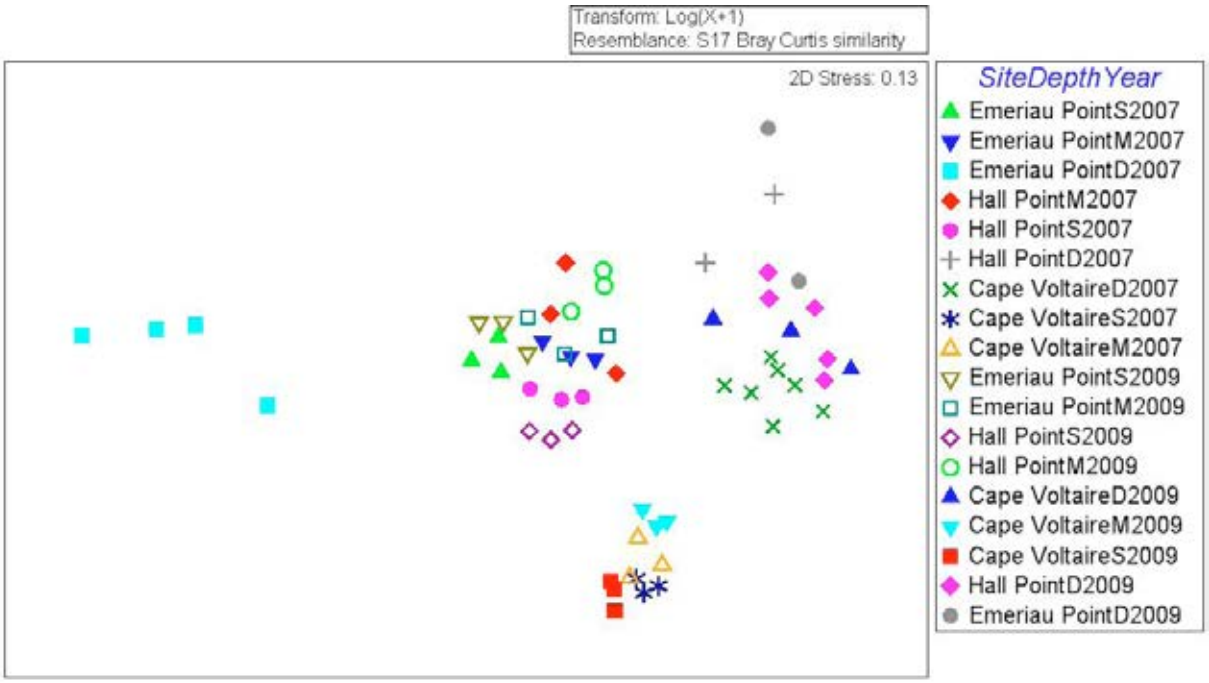

Figure 9. An nMDS plot based on relative abundances from trawl data for two different years (2007, 2009), three sites and three depths (Shallow, Medium and Deep).

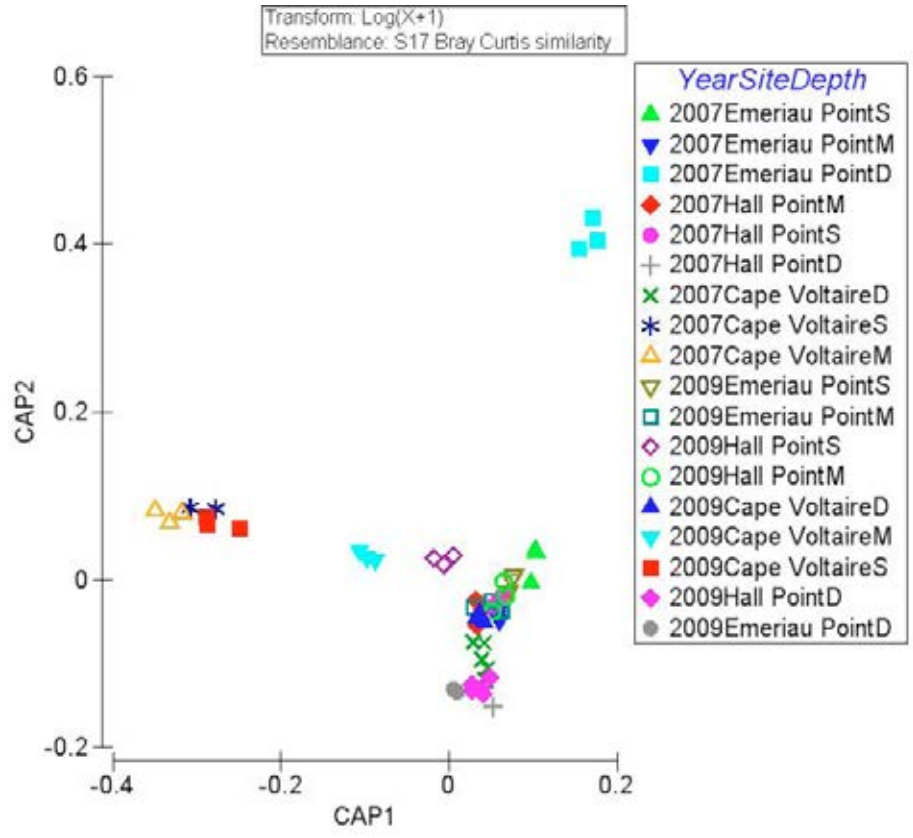

Figure 10. A Canonical Analysis of Principal coordinates plot based on relative abundances from trawl data for two different years (2007, 2009), three sites and three depths (Shallow, Medium and Deep).

2.2.7 Fish Trawl: Key species

There were 26 species (Table 23, species a-z) with Pearson correlation values of greater than 0.5 or less than -0.5. These species accounted for 55.7% (21 151 fish) of the total catch. We have also listed the numbers of individuals caught of an additional six species of commercial interest (species 1-6). We highlight these species because they had 50 or greater individuals represented in the catch. These six species comprised 8% of the total catch (2905 fish). Note that species a (*Arius thalassinus*), e (*Caranx bucculentus*), h (*Lutjanus malabaricus*), j (*Nemipterus hexodon*), k (*Nemipterus peronii*), m (*Pomadasys kaakan*), n (*Pomadasys maculatum*) and o (*Priacanthus tayenus*) are retained commercially. When the numbers of fish caught were tested for spatial, temporal and depth differences; 16 of the 32 species (species b, c, d, f, g, i, k, l, m, n, o, t, v, w, x, y, z) had significant Year × Site × Depth interactions and 15 (species a, e, h, j, n, p, q, r, s, u, 1, 2, 3, 5, 6) had Site × Depth interactions. One species (4, *Lutjanus russelli*) had significant differences in abundances between sites.

Many species were restricted to the northern regions (e.g. species a, d, e, i, m, n, p, q, s, v, w, x and y) and were found to be most abundant in medium and shallow waters. A number of species were caught in shallow water in the mid sampling area (Hall Point) in 2009 (f, g, j, k, l, o, r, t and z), but greater numbers were caught in the northern shallow or medium depth sites. One species (c, *Bleekeria viridianguilla*) was only present in the southern sites at Emeriau Point and was caught in greater numbers at deep sites. One of the commercial species (2, *Lethrinus punctulatus*) was not recorded at all in the northern sites and was most abundant in the medium and shallow sites at Emeriau Point in the south. Three of the other five commercially retained species were caught across the majority of the range sampled (species 1, 4 and 5). *Epinephelus areolatus* (1) was caught in low abundances throughout the sites sampled with the exception of shallow southern sites and shallow northern sites where it was not caught at all. *Lutjanus russelli* (4) was caught in the highest numbers in the northern deep and medium sites while *Lutjanus vitta* (5) was caught in the greatest numbers in the Hall Point shallow trawls.

For some species there were notable differences in the numbers of fish caught between years. For example, there was a mean of 500 *Carangoides malabaricus* (d) caught at the medium depth sites at Cape Voltaire in 2007, but none in 2009 despite replicate trawls in 2007 and 2009 being undertaken within a 2 km radius of one another.

Table 23. The mean catch of those species with Pearson correlation values greater than 0.5 or less than 0.5 (species a-z) and six commercially retained species (1-6) with ± 1 SE (CV = Cape Voltaire, HP = Hall Point EP = Emeriau Point; D = Deep, M = Medium, S = Shallow).

	a) Arius thalassinus	*b) Atule mate*	*c) Bleekeria viridianguilla*	*d) Carangoides malabaricus*	*e) Caranx bucculentus*	*f) Carcharhinus dussumieri*	*g) Gazza minuta*	*h) Lutjanus malabaricus*	*i) Megalops cyprinoides*	*j) Nemipterus hexodon*	*k) Nemipterus peronii*
CV D 07								5.6 ± 4.8			
CV D 09								1.3 ± 1.3			
CV M 07	1.3 ± 0.9	8.7 ± 2.7		500.3 ± 155	1.7 ± 1.2	5.3 ± 1.2	295.0 ± 39.4	41.7 ± 17.5	2.7 ± 1.7	11.3 ± 0.9	2.0 ± 1.0
CV M 09	1.3 ± 0.3	0.7 ± 0.7					4.0 ± 2.6	10.3 ± 5.4		22.7 ± 9.7	2.0 ± 1.5
CV S 07	0.3 ± 0.3	2.7 ± 2.2		103.7 ± 50.7	36.7 ± 0.6	1.0 ± 0.6	7.3 ± 4.5	1.7 ± 0.9	0.7 ± 0.3	20.0 ± 11.1	4.7 ± 2.4
CV S 09	0.3 ± .3	0.7 ± 0.3		2.3 ± 1.2	49.3 ± 1.5	2.3 ± 1.5	76.3 ± 21.6	4.3 ± 0.3	0.3 ± 0.3	49.0 ± 14.0	22.7 ± 5.5
HP D 07											
HP D 07											
HP D 09											
HP M 07											
HP M 09								1.3 ± 1.3			
HP S 07		0.3 ± 0.3						0.7 ± 0.7			
HP S 09		1.3 ± 0.9				0.7 ± 0.3	1.7 ± 1.7			1.0 ± 0.6	0.3 ± 0.3
EP D 07			20.5 ± 8.2								
EP D 09											
EP M 07								2.7 ± 1.3			
EP M 09								8.0 ± 1.2			
EP S 07			3.0 ± 2.1					0.3 ± 0.3			
EP S 09		1.0 ± 1.0						2.0 ± 1.5			
Total # fish	10	46	91	1819	263	28	1153	270	11	312	95

	l) Pentaprion longimanus	*m) Pomadasys kaakan*	*n) Pomadasys maculatum*	*o) Priacanthus tayenus*	*p) Psettodes erumei*	*q) Rastrelliger kanagurta*	*r) Rhynchostracion nasus*	*s) Saurida tumbil*	*t) Saurida undosquamis*	*u) Selar boops*	*v) Seriolina nigrofasciata*
CV D 07									0.3 ± 0.2		
CV D 09											
CV M 07	87.7 ± 87.7	288.3 ± 54.0	34.7 ± 29.8	20.0 ± 4.2	0.7 ± 0.3	1.7 ± 0.9	1.0 ± 0.6	9.3 ± 1.9	2.3 ± 2.3	23.0 ± 6.1	1.3 ± 0.7
CV M 09	119.3 ± 21.7	3.0 ± 1.2		6.0 ± 3.2	0.3 ± 0.3	0.7 ± 0.3	1.0 ± 0.6	6.0 ± 3.1	15.7 ± 1.8	3.7 ± 0.7	
CV S 07	74.7 ± 38.2	3.7 ± 2.7	211.7 ± 115.1	12.0 ± 5.0	0.7 ± 0.7		8.7 ± 4.3	11.0 ± 4.9		34.3 ± 17.9	
CV S 09	371.3 ± 69.6	28.7 ± 27.2	42.7 ± 18.5	45.3 ± 15.1		1.0 ± 0.6	8.3 ± 3.3	13.0 ± 2.6	28.3 ± 3.3	6.3 ± 4.3	0.3 ± 0.3
HP D 07											
HP D 07											
HP D 09											
HP M 07							0.3 ± 0.3		0.3 ± 0.3		
HP M 09											
HP S 07							0.7 ± 0.3				
HP S 09	0.3 ± 0.3			4.0 ± 2.0			4.0 ± 1.2				
EP D 07											
EP D 09											
EP M 07									1.0 ± 0.3		
EP M 09									0.3 ± 0.3	3.0 ± 3.0	
EP S 07									3.3 ± 1.5		
EP S 09							0.3 ± 0.3		2.0 ± 2.0		
Total # fish	1960	971	867	262	8	10	73	118	162	211	5

	w) Terapon theraps	*x) Trichiurus lepturus*	*y) Upeneus sulphureus*	*z) Zabidius novaemaculatus*	*1) Epinephelus areolatus*	*2) Lethrinus punctulatus*	*3) Lutjanus bitaeniatus*	*4) Lutjanus russelli*	*5) Lutjanus vitta*	*6) Pristipomoides multidens*
CV D 07		0.1 ± 0.1			2.3 ± 0.9		3.6 ± 1.4	71.1 ± 32.1	0.7 ± 0.5	2.9 ± 1.2
CV D 09					2.0 ± 1.0		4.7 ± 3.7	29.0 ± 28.0	0.7 ± 0.7	1.0 ± 1.0
CV M 07	175.0 ± 52.5	12.0 ± 4.0	924.0 ± 343.7	32.3 ± 16.3	0.3 ± 0.3		1.7 ± 0.9	28.0 ± 8.2	37.0 ± 20.4	3.7 ± 1.3
CV M 09	0.3 ± 0.3						0.3 ± 0.3	33.0 ± 19.1	19.0 ± 4.5	6.3 ± 0.9
CV S 07	2.7 ± 1.2	0.7 ± 0.7	176.0 ± 94.2	20.3 ± 15.0				10.0 ± 2.6	19.7 ± 7.7	
CV S 09	3.7 ± 2.0		2784.7 ± 1069.2	2.7 ± 1.5				6.7 ± 2.4	14.7 ± 8.0	
HP D 07					0.5 ± 0.5			0.5 ± 0.5	1.0 ± 0.5	
HP D 07					0.5 ± 1.2			0.5 ± 1.0		
HP D 09					3.0 ± 2.0		17.3 ± 13.4	1.3 ± 0.3		1.3 ± 0.7
HP M 07					3.7 ± 0.9	0.3 ± 0.3		1.7 ± 1.7	31.7 ± 12.5	
HP M 09					2.7 ± 0.9				6.7 ± 6.2	
HP S 07					0.7 ± 0.3	4.3 ± 1.9	75.7 ± 72.7	2.0 ± 1.2	102.0 ± 85.6	
HP S 09				0.7 ± 0.7	1.7 ± 1.2	3.0 ± 1.0	11.7 ± 1.8	0.7 ± 0.7	172.0 ± 59.3	
EP D 07										
EP D 09					0.5 ± 0.4			0.5 ± 0.4		0.5 ± 0.4
EP M 07					0.7 ± 0.3	19.7 ± 3.8		3.7 ± 1.9	13.3 ± 9.4	
EP M 09					1.3 ± 0.7	8.0 ± 2.3		0.7 ± 0.7	10.0 ± 8.0	
EP S 07						44.0 ± 19.1		1.3 ± 0.9	2.3 ± 1.3	
EP S 09						8.3 ± 6.3		0.7 ± 0.7	1.00.6	
Total # fish	545	39	11654	168	70	263	359	857	1297	59

2.3 Conclusion

The trap, stereo-BRUV and trawl data all show similar patterns. There are significant differences between Years, between Sites and between Depths. The differences between years was largely driven by differences in the numbers of fish (abundances of fish caught or seen), however there was some compositional differences which were associated with sampling different sites and habitats within a Site × Depth combination between years. The location differences were largely driven by compositional differences in the fish assemblage with different species being more abundant in the north or south, or in shallower or deeper waters.

These changes in the demersal fish assemblage composition over spatial and depth scales have been documented in this region by Hutchins (2001) and also more recently by Travers et al. (2010). The changes in the structure of the fish assemblage between locations and depths at a scale of tens to 100s of kms and between habitats at scales of 100s of metres to tens of kilometres has implications for long-term monitoring which will be discussed in the next section.

The 59 trawls sampled the greatest number of species (223 species and a total of 37,993 fish), but there was very high variance between trawls. The vast proportion of the species caught were bycatch, with only 18% of the fish caught being comprised of those that would be commercially retained.

Overall, the stereo-BRUVs sampled more fish and species than commercial fish traps, but both displayed similar spatial patterns in the relative abundances of fish and species richness.

Clearly, there are a plethora of species in the NDSF that are available for harvest that do not enter fish traps (and hence are not sampled by that gear). However, only a small proportion of these fish are presently of any commercial importance.

As noted under Objective 1 (above), some of this suite of species may be available for capture using alternate gears or fishing techniques.

The important conclusion from this study is that there is a large amount of spatial variability in fish assemblage structure both longshore (along the coast) and with depth (cross shelf). This finding has implications for any monitoring programs.

Individual species showed variability in the numbers of fish caught in traps and recorded by the stereo-BRUVs between years, sites and with depth. Some of the commercial species displayed specific patterns on spatial distribution with greater abundances in shallower (e.g. *Epinephelus multinotatus*) or deeper sites (e.g. *Pristipomoides multidens*) or at the northern (*Lutjanus malabaricus*) or southern (*Epinephelus multinotatus*) extent of the areas sampled.

Furthermore, we attempted to evaluate the suggestion by some members of industry that there were potentially large schools of fish in the NDSF as determined from echo-sounder observations (which are ‘uncatchable’ at the time), which may indicate a larger standing stock or alternative fish resources available for harvest. During this study, we did not see these putative schools. As such, we do not know definitively what comprises these putative fish schools. They may represent many potential possibilities including concentrations of bait fish, plankton, salps, pelagic urochordates or other invertebrates or possibly species that are not amenable to trap or line capture. Fishers have reported that when they see these putative fish soundings, all attempts at capture using baited traps and lines have been fruitless. As such, we conclude that they are unlikely to be species currently exploited in the NDSF.

3.0 Proposed long-term monitoring plan for the NDSF incorporating fishery independent monitoring.

In Section 1 (Objective 1 – *Determine the relative catching efficiency of trap fishing gears in the NDSF*) we reported that a number of commercial species seen on the trap cameras were caught in very low numbers, or not caught at all by traps. Hence, there is the potential for expanding the catch in the NDSF through gear modification and development, which would allow those species to be caught. Similarly, we saw many additional species (both commercial and non-commercial) on the stereo-BRUVs which were not caught by the traps or which were caught in low numbers.

The trawl surveys undertaken in this project had high variance and we would need a large number of replicate trawl samples to obtain a reasonable level of statistical power for target species. Additonally, trawl surveys are time consuming to conduct and hence are expensive. In addition, trawl surveys are perceived as being destructive as they can damage the benthos and can result in the incidental capture and/or mortality of by-catch, undersized species and protected species (e.g Moran and Stephenson 2000, Stephenson and Chidlow 2003, Stephenson et al. 2006). For this reason we are not recommending the use of trawling for long-term monitoring. In a pilot study for this project we demonstrated that for many species stereo-BRUV data had greater statistical power than trap data.

The introduction of Ecosystems Based Fishery Management (EBFM) and Ecological Sustainable Development (ESD) approaches into Fishery Management Plans (Fletcher 2005, 2006, Fletcher et al. 2005, Fletcher et al 2010, Norse 2010) means 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 to the need for non destructive fishery independent data (Harvey and Cappo 2001) there has been a recent expansion in the application of baited video techniques to overcome the fish sampling limitations imposed by depth, fish behaviour, seafloor rugosity and the selectivity inherent in hook, trap and trawl methods (Cappo et al. 2003, 2007, Harvey et al. 2007, Murphy and Jenkins 2010).

The use of remote, baited 'video fishing' techniques offer standardised, non-extractive methodologies for estimating the relative abundance of a range of marine fish (Cappo et al. 2003, 2004, 2007, Watson et al. 2005, Harvey et al. 2007, Langlois et al. 2010, Watson et al. 2010). When stereo-camera pairs are used very precise and accurate length estimates are possible (Harvey and Shortis 1996, Harvey et al 2001a, b, 2002 a, b, Shortis et al 2009, Watson et al 2009, Harvey et al. 2010).

The development of a long term monitoring plan that utilizes fishery independent surveys using techniques and gears that are non-selective such as stereo-BRUVs allows for ecosystems based assessments. It also facilitates an assessment of species that are not vulnerable to capture in traps. Furthermore, it allows an objective assessment of the status of protected species such as potato cod, *Epinephelus tukula*.

We identified that there is considerable variation in the fish assemblage within the NDSF within both Site and Depth combinations. We also identified that within a Site and Depth combination there was the need to minimize the variability caused by sampling different habitats (e.g. sand vs sponge habitat). Therefore, we recommend that any monitoring program that is implemented be based around fixed Site and Depth combinations with sampling randomized within that

combination. Given the demersal fish assemblage differences across the NDSF, sampling undertaken in the context of ecosystem based fisheries management (EBFM) should encompass the different assemblages in the different locations. Similarly, different fish assemblages were identified with increasing depth. Travers et al. (2010) identified that in the shallower waters of the NDSF depth is a major driver of fish assemblage composition. In this program we sampled only two depths with traps and stereo-BRUVs and three depths with trawls. A long-term montoring program should increase the range to match those depths fished commercially. Therefore, we recommend that the depth range be extended into shallower and deeper waters.

To develop a long-term monitoring program that had statistical power to detect changes in the relative abundances and size frequency of the rare target species in the catch (e.g. *Plectropomus maculatus*), a pilot study suggested we should aim at a minimum of 20 replicate stereo-BRUV deployments per site.

We recommend that a minimum of four longshore locations be sampled to account for the different faunal provinces in the region, with 4-6 depth zones across the continental shelf (in order to achieve coverage across all zones of the fishery). These depth zones are proposed to extend from nearshore waters across the continental shelf to deep slope waters. A minimum 20 replicates BRUVs would be required at each Location x Depth sampling site.

A new strategy to assess all the northern finfish fisheries is underway. This strategy is the Northern Monitoring and Assessment Plan (NorthMAP). This plan has changed the operational fishery monitoring and assessment programs for the Finfish Branch in the Northern Bioregions. NorthMAP is based on the risks to sustainability of resources as documented in the Finfish Risk Assessment Framework (DoF, 2011), which provides information into the Department's EBFM and RiskBase for determining Departmental priorities and investment.

The strategy seeks to rotate monitoring and assessment resources among the three major demersal scalefish resources supporting the major northern finfish fisheries – Pilbara Demersal Scalefish Fishery (PDSF), Northern Demersal Scalefish Fishery (NDSF) and Gascoyne Demersal Scalefish Fishery (GDSF) – plus allow research personnel and resources to focus on other assets (e.g. nearshore, pelagic, estuarine) which support smaller commercial fisheries (e.g. Mackerel Fishery, Kimberley Gillnet and Barramundi Fishery (KGBF)) and recreational fisheries that currently receive a low level of resourcing. NorthMAP will lead to the development of a more transparent and refined monitoring and assessment schedule for all northern finfish fisheries. NorthMAP aims to assess all fisheries on a rotational cycle. This cycle is being modelled as part of the outputs from FRDC Project 2009/037.

To be cost effective monitoring should occur at regular cycles, or should be implemented when fisheries assessments indicate a need. We recommend the monitoring of the fish assemblage structure occur every four years in line with the NorthMAP assessment paradigm. However, once the fixed sites are established it would be beneficial to undertake surveys in consecutive years initially in order to estimate variability and establish a baseline against which future surveys could be compared.

Cost effectiveness will be improved if monitoring is implemented on a commercial vessel as the length of the survey time will be decreased due to the experience of the skipper and crew and the functionality of the vessel.

An indicative cost to monitor four locations with six depths and 20 replicates is in the order of $120 000 per year (this include processing, analysing and reporting time). This cost does not include hire/charter of the vessel.

In addition, the results of FRDC Project 2009/037 - ‘Sustaining productivity of tropical red snappers using new monitoring and reference points’ will also need to be incorporated into any long term monitoring program for the NDSF. The results of this project will have a wide application across many of finfish fisheries of northern Australia.

In addition, the results of FRDC Project 2009/037 - ‘Sustaining productivity of tropical red snappers using new monitoring and reference points’ will also need to be incorporated into any long term monitoring program for the NDSF. The results of this project will have a wide application across many of finfish fisheries of northern Australia.

4.0 Management Outcomes

The results of this project will allow increased confidence with the outcomes of the assessment processes in the NDSF. The report provides an enhanced understanding of the interaction between the target species and the fishing gear, which will potentially benefit management decisions in the future. The development of increased confidence in the stock assessment processes established in the NDSF may enhance commercial harvest arrangements for the demersal fish resources of the NDSF. One of the key fishery management outcomes for this project will be the potential for enhanced collaborative and complimentary management arrangements for the NDSF.

As the outcomes of this research project have established the catching efficiency of trap fishing gears in the NDSF relative to nonselective gears such as baited cameras and fish trawls, an assessment was undertaken to determine if the catch is therefore representative of the available fish biomass (as determined by non-selective gears). As the catch is representative of the available biomass, stock assessment processes will remain unchanged. Therefore, the provision of research advice into the management process will be maintained and reinforced.

Many species of commercial importance display specific spatial distribution patterns within the NDSF. For example, Rankin cod *(Epinephelus multinotatus)* are more abundant in the shallower sites sampled. In contrast, goldband snapper *(Pristipomoides multidens)* were more abundant in the deeper sites sampled. In addition, the saddletail snapper *(Lutjanus malabaricus)* were more abundant in the northern sites sampled, whereas Rankin cod were more abundant at the southern extent of the areas sampled. Increased knowledge of the spatial distribution of fish resources across zones and the establishment of a long-term monitoring program for stock assessment in the NDSF will assist the rational development of the NDSF into the future.

There is potential to explore alternate gears within the NDSF to increase the harvest of those species that are under-exploited by traps. The opportunity also exists for complimentary management arrangements to divert fishing activities to more productive species through a redistribution of effort across zones.

5.0 Benefits and adoption

This study has achieved the following.

- Demonstrated the spatial and temporal variability of the fish assemblage in the NDSF.
- Shown additional commercial fishes can be targeted in the NDSF.
- Demonstrated that the lengths frequencies of target species caught in traps are very similar to those drawn from fishery independent data collected by stereo-BRUVs.
- Trained and familarised fisheries scientists in contemporary techniques for analysing quantitatively video data and refining aspects of those techniques.
- This project has acted as a catalyst to further potentially develop tropical demersal fishery resources.
- This project has directly contributed to a more in depth understanding of the continental shelf fish communities in the Kimberley region of Western Australia and the species-specific behaviour of fishes in relation to trap fishing.
- It has highlighted how some species appear abundant and yet they are absent or rare in trap catches, indicating that there are additional species available for capture in the NDSF if appropriate fishing gears are modified or developed.

6.0 Further Development

The TrapCamera was very effective at demonstrating that some species of fish use the trap as habitat actively coming in and out of the trap and even chasing smaller species in so they can hunt them more effectively. It would be beneficial for the industry to undertake some research into trap design and bait placement. The TrapCamera showed that the position where the bait was placed in the cage influenced the number of fish caught and how quickly they were caught.

Opportunistically, as an addition to this project, a study by Newman et al. (2011) has shown that in the NDSF traps that are lost at sea have the potential to self-bait and may continue fishing for a considerable time. It would be beneficial for the fishery to look at the development of systems such as a biodegradable panel that breaks down over a period of days to release fish if traps are lost.

There is potential to explore alternate gears or to modify existing fishing gears in the NDSF to increase the harvest of those species that are only lightly exploited by traps.

7.0 Planned outcomes

The results produced by this study will provide the Department of Fisheries (WA) with more certainty around the stock assessment advice and provide additional information regarding the amount of fish available for harvest in the NDSF. The outcomes of this research are:

1. An understanding of the catching efficiency of trap fishing gears in the NDSF relative to non-selective gears such as baited cameras and fish trawls. This has included an assessment of whether the catch in the NDSF is representative of the fish available for harvest.
2. This project has begun to examine the interactions between fish and fishing gear.
3. This project has allowed the determination of some aspects of temporal variation in the catching efficiency of fishing gears for key indicator species in the NDSF.
4. This project has determined some key aspects of the nature of resource availability in the NDSF and the spatial distribution of fish resources.
5. This project has proposed important factors to be considered for long-term monitoring programs for the assessment of the NDSF including fishery independent indicator surveys where applicable.

Specific outcomes of significance include:

- The lack of significant difference in the length structure of target species sampled by fish traps and stereo-BRUVs indicate that the fish traps are adequately sampling the length-structure of the fish population for target species.
- Representative sampling of trap catches provide a robust and reliable means of assessing the length structure of adult target fish stocks, an important component of stock assessment models that depend on length data and size distributions.
- Data from this study has directly contributed to improved Departmental confidence in the results of the current stock assessment models.
- No significant differences in the length structure between the sampling methods indicate that there is no direct benefit from incorporating any additional length data from stereo-BRUVs into the current stock assessment process.
- Importantly, the stereo-BRUVs sample more fish species than are recorded in traps. Higher numbers of individuals are recorded on stereo-BRUVs as compared to traps. Many non-commercial species and species of little commercial interest do not enter traps.
- The stereo-BRUVs data do provide detailed information on the size structure and biodiversity of much of the fish community in the NDSF that is not captured in fish traps and this is important for assessing the health of the ecosystem and in assisting the ESD assessment process for this and related fisheries.
- A number of species of commercial significance do not appear to enter traps readily or are rare in trap catches.
- The potential exists for some species to be underexploited and there is opportunity for gear development in order to attempt to capture those species that do not readily enter traps.

This project has also served to build capacity and expertise in researchers in the use and analysis of video technology that can be used to underpin ecosystem approaches to fisheries.

This project has led to an improved understanding of stock sustainability in demersal trap fisheries.

8.0 Conclusions

We identified that there is spatial variation in the target species and in the demersal fish assemblage in the NDSF with some targeted species more abundant in the north of the fishery and others in the south. There is fine scale (10s of kms) spatial variation evident in the fish assemblage structure associated with sampling different habitats.

We demonstrated that the fishery independent data collected from stereo-BRUV deployments provide very similar length frequency information for target fishes to those constructed from fishes caught in the traps. The lack of significant differences in the length structure of the target species between fish traps and stereo-BRUVs indicate that the fish traps are adequately sampling the adult length-structure of the fish population for target species.

This finding is significant; as it indicates that representative sampling of trap catches provides a robust and reliable means of assessing the length structure of target fish stocks, an important component of stock assessment models that depend on length data and size distributions. This study has directly contributed to improved confidence in the results of the current stock assessment models.

Stereo-BRUVs sampled many more species (both target and non target) than traps while the trawls record 30% more species than the stereo-BRUVs. The trawls had high variance between replicate samples and hence were not considered to be a cost effective or robust method for developing a long-term monitoring program.

By comparison a pilot study (Harvey et al. in press) demonstrated that the stereo-BRUVs had greater statistical power than fish traps to detect changes in abundance. Hence we have recommended the development of a long-term monitoring program every four years. This program would provide data for the Western Australian EBFM process in this fishery, but also on the relative abundance, length and biomass of target species. This program should occur in predetermined (fixed) locations to minimise variability associated with fine scale (10s of kms) spatial variation in the fish assemblages associated with sampling different habitats. To be cost effective we recommend that the platform for this monitoring program should be a commercial vessel.

Cameras placed inside the traps showed that there were a number of commercial species which were seen outside the traps regulary, but which were rarely caught. Therefore, the potential exists for alternative gears to be explored within the NDSF to increase the harvest of those species that are under-exploited by traps.

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10.0 Appendices

10.1 Appendix 1: Intellectual Property

There is no intellectual property created as a result of this project.

10.2 Appendix 2: Staff

Principal Investigator	Dr. Stephen Newman	DOFWA
Co-Investigator	Dr. Euan Harvey	UWA
	Mr. Ben Rome	DOFWA
	Dr. Dianne McLean	UWA
	Mr. Craig Skepper	DOFWA

DOFWA = Department of Fisheries, Western Australia; UWA = The University of Western Australia

10.3 Appendix 3:

Data generated by the project is stored with the Principal Investigator and the Co-Investigator of this project and their respective institutions using appropriate access arrangements and security to ensure data integrity. Over 8 terra bytes of video data were collected by this project.