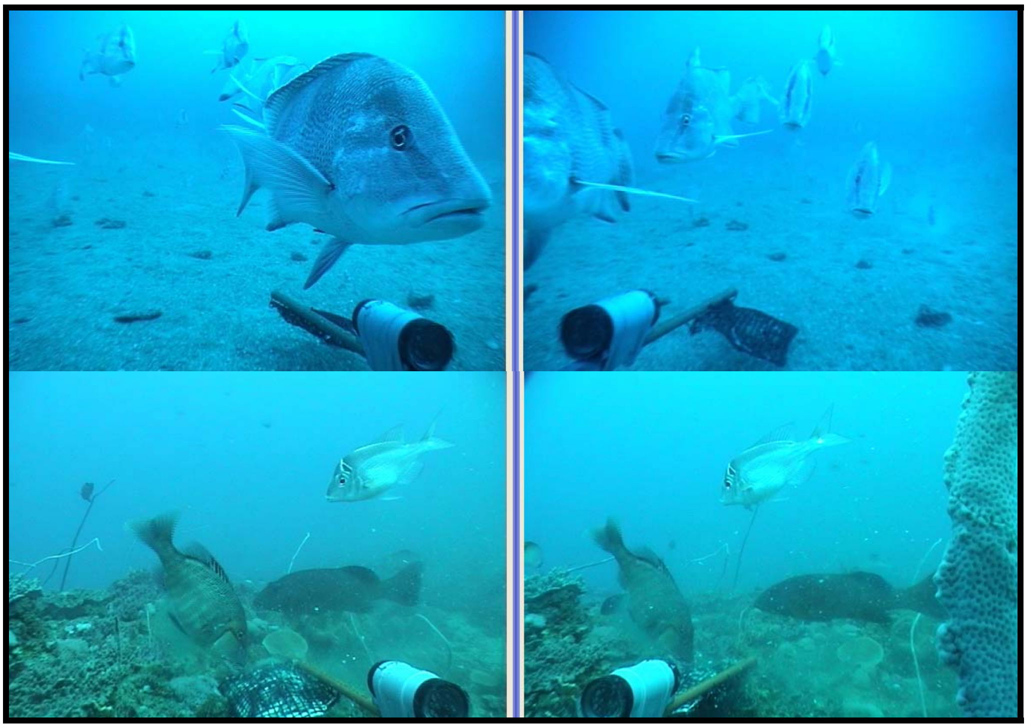
The use of stereo BRUVS for measuring fish size



Charlotte Johansson, Marcus Stowar and Mike Cappo

Australian Institute of Marine Science, Townsville

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Reef & Rainforest RESEARCH CENTRE

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Acronyms and Abbreviations

BRUVS.......... Baited Remote Underwater Video Stations
FL.................. Snout to fork length (of fish)
GBRMPA ...... Great Barrier Reef Marine Park Authority
LED .... Light-emitting diode
m .... metre
MaxN............. Maximum number of individuals for each species visible at one particular time
mm................ millimetre
MTSRF.......... Marine and Tropical Sciences Research Facility
PVC............... Polyvinyl chloride
RAP............... Representative Areas Program
SBRUVS .... Stereo Baited Remote Underwater Video Stations
SE.................. Standard Error
UVC............... Underwater Visual Census

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Executive Summary

Stereo Baited Remote Underwater Video Stations (SBRUVS) were deployed as part of a larger study of the fish communities of the Great Barrier Reef Marine Park in response to zoning changes by the Great Barrier Reef Marine Park Authority in 2004. Here we assess the use of SBRUVS as a tool for precise measurements of fish length to supplement comparisons based simply on visual observations of diversity and/or abundance. Twenty-four pairs of stereo imagery were processed from SBRUVS sets made between 2006 and 2007 off Townsville on the Magnetic Shoals which are closed to fishing, three nearby shoals open to fishing, and on two shoals (Southern Shoals) to the north of the Capricorn-Bunker group, Karamea Bank (open) and Barcoo Bank (closed):

- A total of 128 fish from twelve species targeted by fishers were measured with a mean precision of 7 ± 0.5 mm (1SE). When standardised for fish length, this equated to less than two percent error in measured length.
- The precision of the measurements varied in a predictable linear inverse relationship with distance from the cameras so that precision declined as fish were measured at increasing distances from the cameras. Mean precision values were achieved for fish at a two metre distance from the stereo cameras.
- Precision was influenced in a generic way due to the inclination of certain species to approach the bait (e.g. emperor, lutjanids) while others remained at greater distance and rarely fed (e.g. serranids).
- On average, 42% of fishes that were counted were successfully measured. In general, the measurement rate (number measured / number counted) was inversely proportional to the abundance and schooling behaviour of a species. Too many fish in the field of view caused loss of individual identity and/or obscuring of standard measurement points (snout and tail fork).
- Red emperor (*Lutjanus sebae*), a highly targeted species that was variably encountered in relatively large groups in the deeper ‘fern gardens’ of the southern shoals had the lowest measurement rate (18%). However, due to their willingness to approach and feed from the bait station they were the most precisely measured.
- On average, 71% of the fishes in shallow sets (< 30m) were measured while only 26% of fishes in deep sets (> 30m) at the Southern Shoals were measured.
- Measurement rates were negatively influenced by light and by low contrast in deeper water and standard reference points therefore became difficult to distinguish from the background.

Fish counts (*MaxN*) from deployments of BRUVS and SBRUVS indicated that adequate sampling for fish size of species commonly targeted by fishermen may require high numbers of replicate deployments of SBRUVS. When length estimates are precise, length-weight relationships obtained from published studies may provide a means of converting size to biomass estimates. The current configuration of SBRUVS requires a relatively lengthy process of transferring between tape and digital storage media and substantial efficiency gains, largely linked to technological improvements, are required to address these labour costs before researchers can use SBRUVS as a preferred tool for simultaneously counting and measuring fish. The overheads suggest that size measurements will be a less cost-effective way of detecting fishing impacts from spatial management arrangements than simply increasing the replication of single cameras. Stereo measurements should be reserved for specific questions requiring accurate information on the sizes of relatively few individual fish.

Introduction

Stereo imagery has become an accepted tool for making precise linear measurements of fish (Harvey *et al.* 2003). It is non-destructive and in addition to measurements, provides relative counts that can be converted to estimates of fish biomass. SBRUVS have a lower impact on fish behaviour than counts using underwater visual census (UVC) techniques and return more precise estimates of abundance for some species (Watson and Harvey 2007). Some issues of observer bias and variability in both count (Thompson and Mapstone 1997) and size estimates (e.g. Harvey *et al.* 2001a, b) that can confound UVC are also reduced. Importantly, SBRUVS can be deployed for extended bottom times at much greater depths and without the inherent in-water risk than are possible with diver based techniques (Harvey *et al.* 2002).

Harvey and others (2003) compared measurements of caged southern bluefin tuna (*Thunnus maccoyii*) made by stereo imaging and associated measurement software prior to harvest and manually post harvest and found that the mean error of the stereo measurement was as a low 1.72 mm. They also found that a single measurement, fish length, explained 99% of the fish's weight. Based on species specific morphology additional morphometric measurements can improve weight estimates. In contrast, size estimates by divers tend to underestimate actual size, which, in the case of exponential length-weight relationships, will lead to large errors in biomass (e.g. Edgar *et al.* 2004).

The precision of a measurement is greatly affected by the size of the fish and its distance from the camera. A range of different variables must be taken into consideration when interpreting the results of a measurement. Harvey and others (2003) showed that the orientation of the fish to the camera will influence the precision and repeated measurements will provide a more precise estimate of length by tempering poor measurements due to range and orientation. Also, measurements should be taken without flexing of the fish to obtain the best length estimate.

Surveys by the Marine and Tropical Sciences Research Facility inter-reefal shoals project (Project 4.8.2[1]) routinely included deployment of SBRUVS as part of a broader program of survey work. This report analyses this stereo imagery to measure a select group of species that are commonly targeted by commercial and recreational anglers. We comment on the use of these data for monitoring fish sizes in and outside zones protected from fishing as designated by the Representative Areas Program (RAP) of the Great Barrier Reef Marine Park Authority (GBRMPA).

Objectives

- To evaluate stereo video imagery for measuring fish size; and
- To evaluate the sampling effort required to deliver adequate numbers of target species for size monitoring.

[1] See http://www.rrrc.org.au/mtsrf/theme_4/project_4_8_2.html

Materials and Methods

Stereo imagery was utilised from a total of 24 stereo cameras – twelve SBRUVS sets on Magnetic Shoal and three adjacent blue zone sites from November 2006, March 2007 and November 2007, and twelve sets on the Southern Shoals, Karamea Bank and Barcoo Bank in February and August 2007. Two depths for the Southern Shoals were considered to account for variations in habitats, *tops* (< 30m) and *bottoms* (> 30m). The Townsville Shoals were comprised of several sites within the 'closed' and 'open' areas (Figure 1). However, due to low number of individuals, all sites within a zone have been pooled.

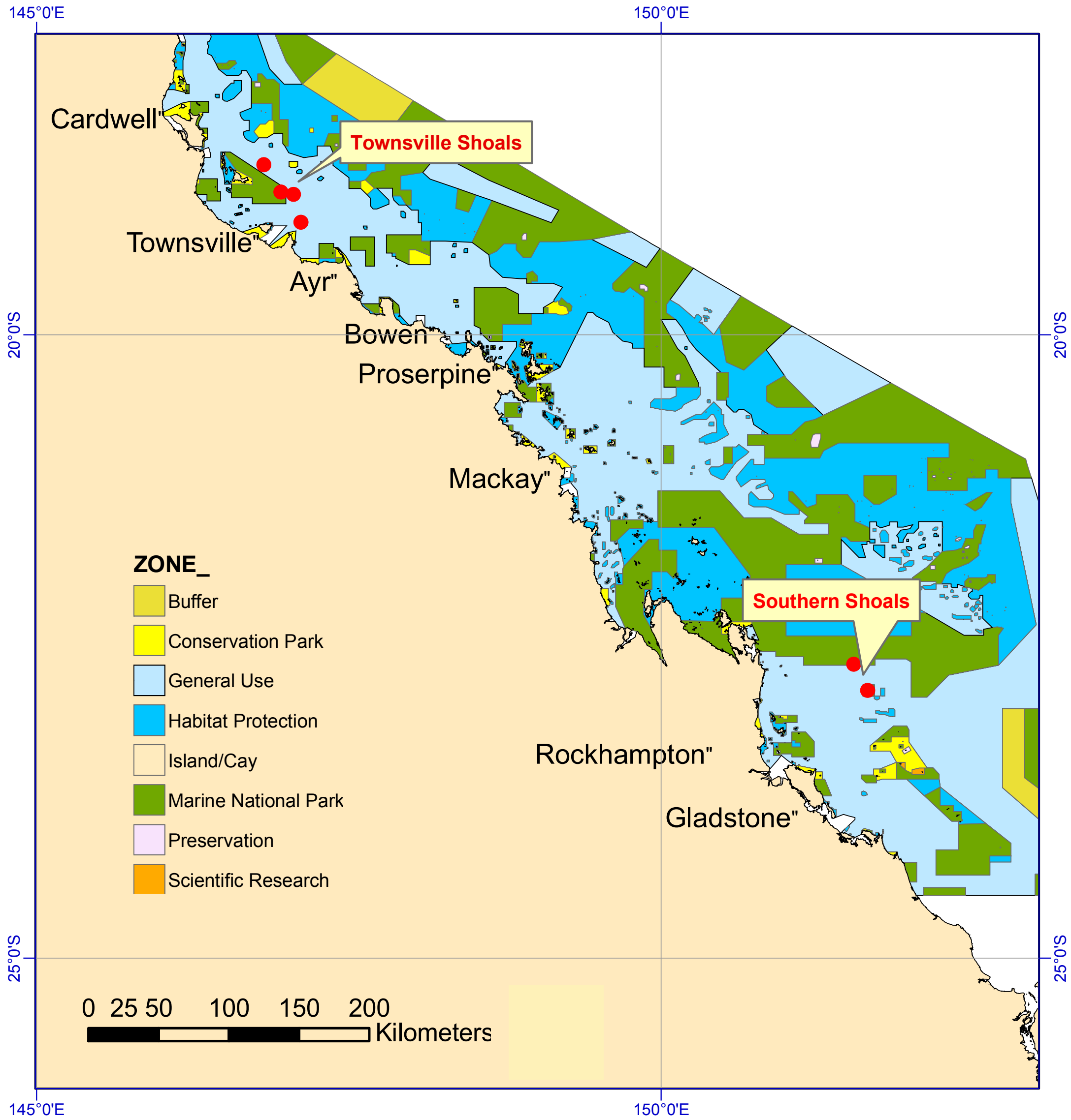

Figure 1: Study sites within the Great Barrier Reef Marine Park: Townsville Shoals and Southern Shoals.

SBRUVS consist of depth-rated PVC camera housings in a paired stereo arrangement bolted and aligned on steel frames. Each SBRUVS, which includes a dedicated pair of video cameras, requires in-water calibration prior to use and our protocol included recalibration before each field trip to ensure the highest degree of accuracy. Each SBRUV has its own unique calibration to account for variations in construction including vertical and horizontal alignment of cameras and separation as well as complex optical properties for each camera (Figure 2). Frame synchronisation, essential for capturing time paired images from each camera, was achieved with the use of a flashing LED sequence attached to the bait arm. Each camera (SONY handycam) ran for sixty minutes. As for BRUVS, each SBRUVS was fitted with a bait bag holding approximately one kilogram of crushed pilchards at approximately 700-1,000mm from the cameras.

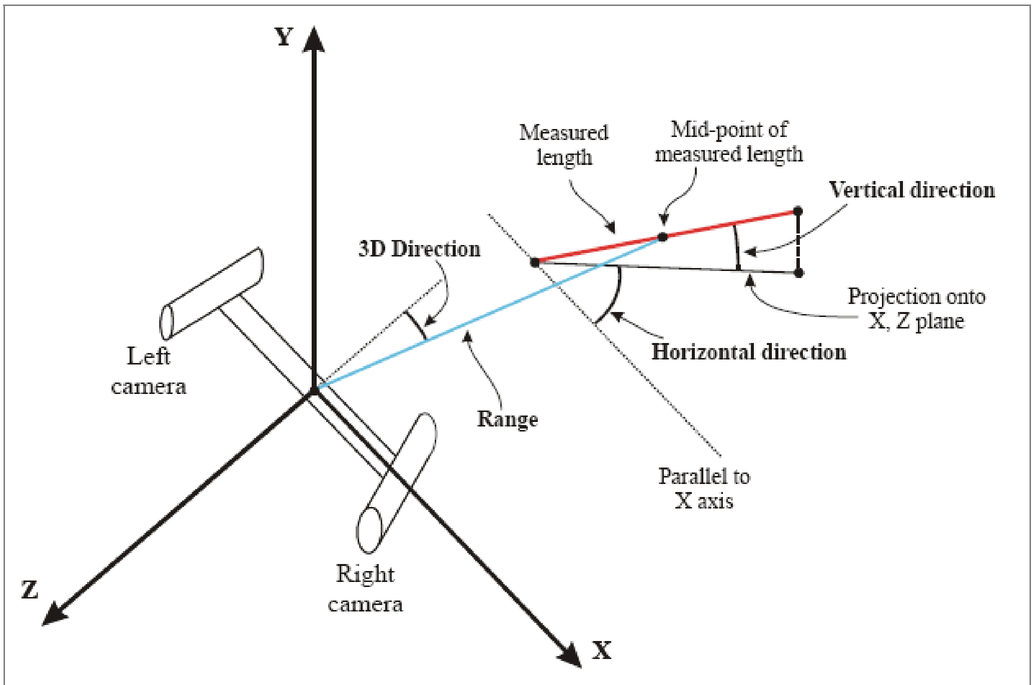

Figure 2: Schematic diagram of stereo imagery configuration and factors to consider in optimising the accuracy of linear measurements. Reproduced from SeaGis PhotoMeasure™ manual (2008).

Each sixty-minute miniDV tape required realtime transfer to digital file prior to being available to the measurement software, PhotoMeasure^{TM}. In addition to facilitating linear measurements of objects, this software has been interfaced with the Australian Institute of Marine Science BRUVS database to enable extraction of time codes when the maximum number of a particular species (*MaxN*) occurred. In this way, a nominated list of species to be measured is extracted from the BRUVS database, delivered to the measurement software and subsequent measurements attached to each species and individual.

A list of species targeted by fishers, their corresponding *MaxN*s and times of *MaxN*s were extracted and measurements of snout to fork length (FL) made against this list (Appendix 1). To ensure that each measurement was assigned to the correct individual, measurements were only performed on individuals that could clearly be distinguished from one another within the same video frame, adjacent frames or by differences in size. Five independent measurements were attempted for each individual fish to account for flexure, orientation and range (Harvey *et al.* 2003). As this was not always possible, three measurements from sequential frames were set as the minimum criterion for initial acceptance. A fish was also rejected if repeated measurements varied by more than twenty millimetres. Measurements were predominantly made on fish that were perpendicular to the camera.

The output file from PhotoMeasure^{TM} for each stereo pair included repeated measurements of individual fish FL, precision, range, tape reader, identification code and time *MaxN*. These records were first screened for outliers and fish with unacceptable variation in FL measurements were discarded.

Results

Precision

A total of 128 individual fish from twelve species were measured. Fish distance from the cameras (range) varied from 0.8m to five metres and the repeated measurements produced a mean precision of 7 ± 0.45mm (1 SE) at a two-metre range (Figure 3). Precision varied in direct proportion to distance from the camera:

$$\text{Precision} = 0.0052 * \text{Range} - 3.5 \ (r^2 = 0.70)$$

This result can be translated into sub-millimetre precision when fish are at the bait bag, < 5mm at a range of 1.5m and rejection due to unacceptable precision (> 20mm) at a range of 4.5m.

As precision of measurement is effectively independent of the linear measurement (in this instance FL), it was expressed as a ratio of FL for each fish in order to be able to assign a measurement error that relates to the size of fish being measured. This ratio, error of measurement or error ratio, varied in a similar manner to precision:

$$\text{Error} = 1.29 * 10^{-5} * \text{Range} - 0.0084 \ (r^2 = 0.53)$$

This produced a mean error of two percent of measured length for the 128 fish at an average range of 2.2m (Figure 4). As the majority of measurements were made within a range of 3.5m, this equated to a maximum 3.7% error in FL.

There was a species-specific component to measurement precision that corresponded to range. Lutjanids had a tendency to approach the bait bag and measurements could be made at a closer range (Tables 1 and 2). Species that were reluctant to approach were measured at greater range with a resultant consequence for precision. The red emperor, *Lutjanus sebae*, had the highest precision as a consequence of its willingness to approach and feed whereas coral trout, *Plectropomus leopardus* and *P. maculatus*, were more inclined to limit their proximity to the bait.

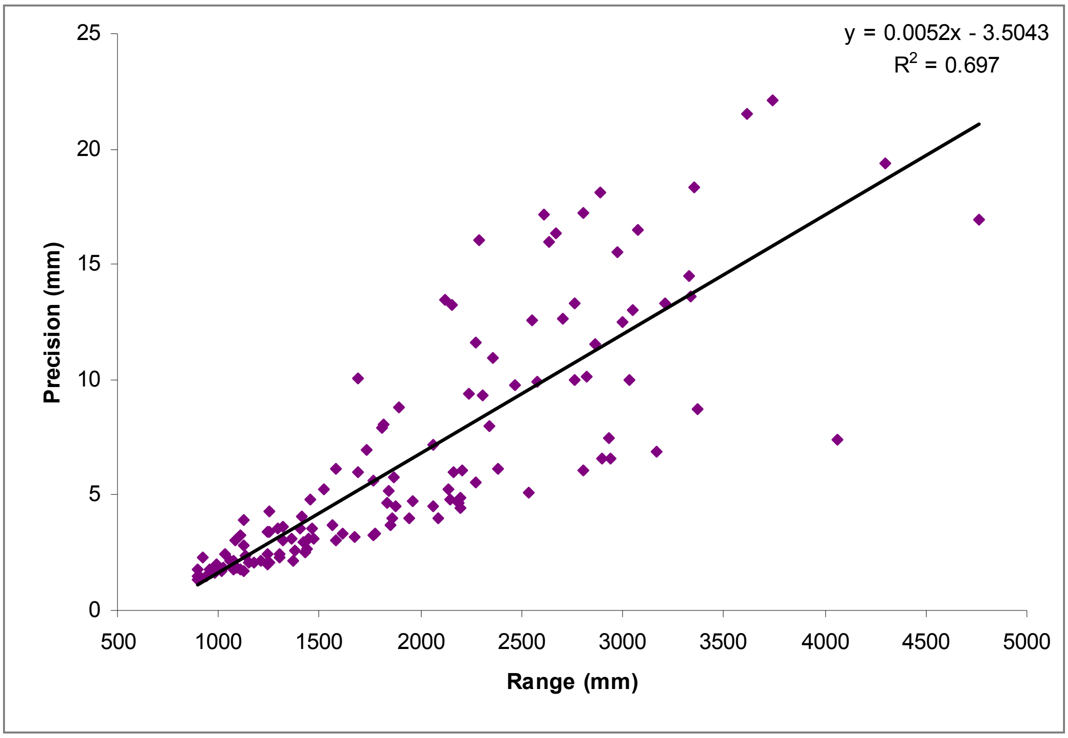

Figure 3: The linear relationship between precision and range for measurements of fish standard length.

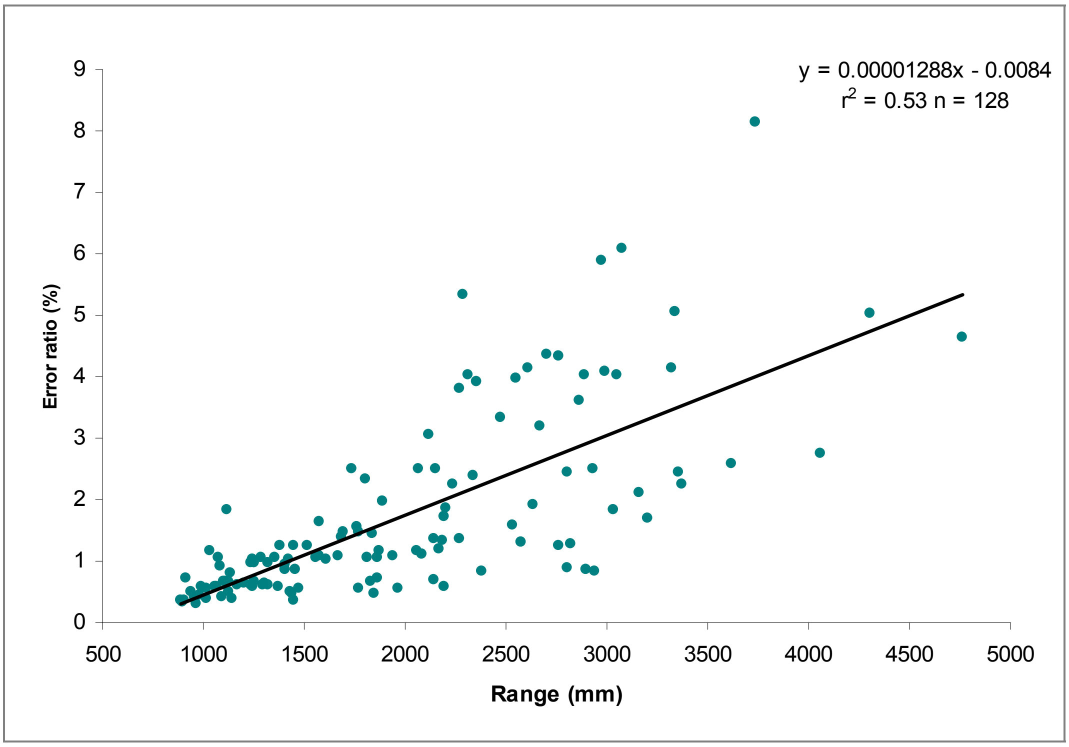

Figure 4: Precision expressed as a percentage of measured fish length (percent error ratio) in relation to the range of a measurement.

Table 1: Mean precision and range for target species from shoals off Townsville.

Species	Blue		Green		Pooled	
	Precision	Range	Precision	Range	Precision	Range
Carangoides fulvoguttatus	-	-	8.84	2289.12	**8.84**	**2289.12**
Carangoides gymnostethus	7.75	2137.39	2.80	1277.97	**5.93**	**1820.76**
Gnathanodon speciosus	8.81	2470.97	5.20	2216.75	**6.40**	**2301.49**
Lethrinus laticaudis	9.37	2237.75	-	-	**9.37**	**2237.75**
Lethrinus nebulosus	8.00	2580.87	-	-	**8.00**	**2580.87**
Lutjanus erythropterus	5.17	1486.85	-	-	**5.17**	**1486.85**
Lutjanus malabaricus	3.97	1504.27	-	-	**3.97**	**1504.27**
Lutjanus sebae	2.50	1149.06	2.61	1118.59	**2.52**	**1142.97**
Plectropomus maculatus	19.40	4301.10	6.86	1857.31	**10.00**	**2468.25**

Table 2: Mean precision and range for highly targeted species on Barcoo and Karamea Bank.

Species	Karamea		Barcoo		Pooled	
	Precision	Range	Precision	Range	Precision	Range
Choerodon venustus	6.86	2134	8.35	2270	**7.71**	**2212**
Lethrinus miniatus	-	-	7.96	1965	**7.96**	**1965**
Lutjanus sebae	5.09	1482	5.91	1227	**5.41**	**1384**
Plectropomus leopardus	10.75	2831	9.76	2706	**10.13**	**2753**

Measurement success

Relative abundance estimates (*MaxN*s) indicate the maximum number of fish potentially available for measurements. Various factors conspired to limit the number of fish measured to less than *MaxN* for each species. Measurement success (number measured/*MaxN*) was evaluated for four highly targeted species recorded from the six shallow and six deep SBRUV sets on Karamea Bank and Barcoo Bank.

An average of 42% of the fish of these four species seen in the videos was measured (Table 3). Success in obtaining measurements from the stereo video deployed in the shallow waters was far greater (71%), than in deep water at the base of the shoals where only 26% of fish captured in the video could be measured. For individual species, the highest percentage of measurement of available individuals in the videotape was achieved for Venus tuskfish (*Choerodon venustus*) in the shallow water (82%) and the lowest for the red emperor (18%) and coral trout (22%) in the deeper waters. Success in measurement of coral trout varied greatly between depths with measurements obtained from 74% of individuals seen in shallow water on the tops of the shoals. Similarly, twice as many measurements of tuskfish were obtained from shallow water deployments than from those at the base of shoals at thirty- to sixty-metre depths.

Table 3: The proportion of counted fish measured for shallow and deep habitats at Barcoo and Karamea Banks.

Species	***Choerodon venustus***	***Lethrinus miniatus***	***Lutjanus sebae***	***Plectropomus leopardus***	**Total**
Shallow (6 sets)					
∑ Fish measured	9	4	-	14	**27**
∑ *MaxN* for sets	11	8	-	19	**38**
Measurement ratio	0.82	0.50	-	0.74	**0.71**
Deep (6 sets)					
∑ Fish measured	6	3	7	2	**18**
∑ *MaxN* for sets	15	7	38	9	**69**
Measurement ratio	0.40	0.43	0.18	0.22	**0.26**
∑ Fish measured	**15**	**7**	**7**	**16**	**45**
∑ *MaxN* for sets	**26**	**15**	**38**	**28**	**107**
∑ Measurement ratio	**0.58**	**0.47**	**0.18**	**0.57**	**0.42**

Sample size

Given the proportion of fish that could be measured of those seen in the video, effort (number of deployments) on Karamea Bank and Barcoo Bank and the relative abundances of all species across all sets, calculations were made to determine the number of individuals of the four species preferentially targeted by fishers that could be successfully measured if all cameras deployed in the MTSRF project were SBRUVS. The ∑*MaxN*s for these four highly targeted species indicated that there were substantial numbers of each, potentially available for measurement. Their distributions between shallow and deep sets further indicated their respective habitat preferences and also highlighted the low likelihood of recovering adequate size sampling from the non-preferred habitats for *Lethrinus miniatus*, *Plectropomus leopardus* and *Lutjanus sebae* (Table 4). The latter species, which was more abundant in the deep water, had low measurement success (i.e. few fish seen in the video could be successfully measured); although those measurements that could be made were very precise as these species were willing to approach closely to the bait bag.

Table 4: The number of individuals of four highly targeted species recorded from Barcoo and Karamea Banks, and the anticipated sample sizes from calculated measurement ratios if all sets were SBRUVS.

Species	***Choerodon venustus***	***Lethrinus miniatus***	***Lutjanus sebae***	***Plectropomus leopardus***
Shallow (33 sets)				
Measurement ratio	0.82	0.5	-	0.74
∑*MaxN* for all sets	85	51	21	107
Number of measurable fish	70	26	-	79
Deep (54 sets)				
Measurement ratio	0.40	0.43	0.18	0.22
∑*MaxN* for all sets	104	22	189	42
Number of measurable fish	42	9	35	9
Number of measurable fish	**111**	**35**	**35**	**89**
∑*MaxN* for all sets	**189**	**73**	**210**	**149**
Total measurement ratio	**0.59**	**0.48**	**0.17**	**0.59**

Discussion

Precision of measurement estimates obtained by SBRUVS are influenced by a number of variables, notably distance of the fish from the camera, mobility and attitude (flexure and orientation), water visibility, contrast and available natural light (Figures 5-8). By limiting acceptable precision of measurements and provided that an adequate number of individuals are seen in the video, robust estimates of the population mean for species of interest can be produced by the SBRUVS technique.

Some of the uncontrolled factors impacting on precision might be addressed through gear adjustments and additional technology. The bait bag was set at 700-1,000mm from the cameras to entice fish closer to the camera for unambiguous identification. High precision of measurement extends to roughly two metres and it may be appropriate to move the bait further out if the bulk of the stereo equipment is a deterrent for species such as trout and tuskfish. The relatively low measurement success in situations where low light resulted in poor contrast might be improved by deployment of artificial light with the SBRUVS. However, the substantial power demands required by artificial light to illuminate to ~3.5m range for underwater stereo video might be problematic and associated costs would also be substantial. For these reasons, high resolution digital still imagery combined with artificial light might provide a practical alternative. Pilot studies with this approach have shown improvements in species richness and taxonomic resolution (Figures 9 and 10). Stereo still cameras with dedicated strobes, illuminating the zone of required precision may overcome constraints associated reduction in light with depth however will result in a reduced ability to track individuals between imaging intervals in comparison to a SBRUV.

The average two percent error (operational maximum of 3.7% at 3.5m range) for any given length of fish can be converted to mass and, subsequently, to an index of biomass provided that reliable and representative estimates of relative abundance can be obtained.

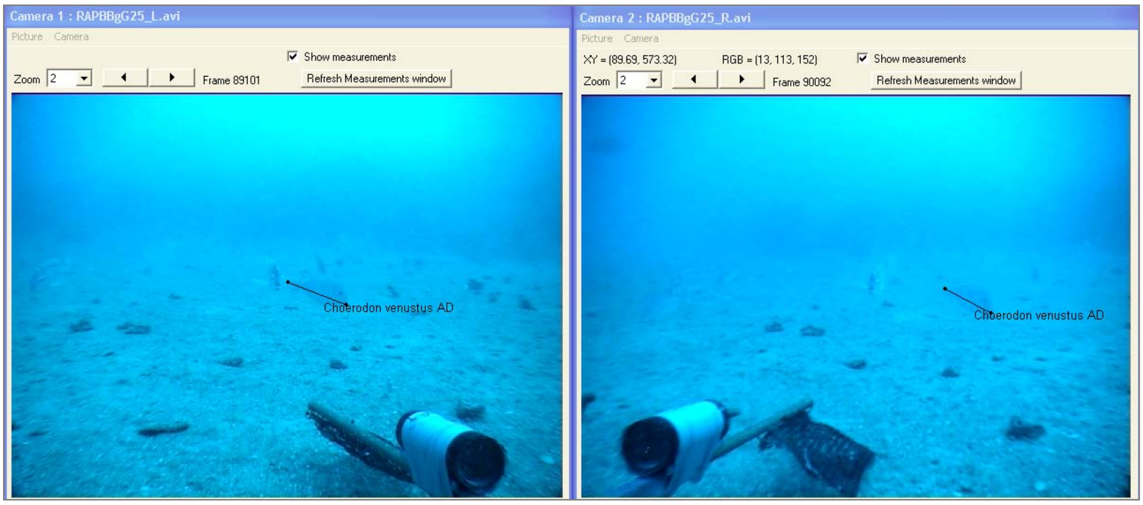

Figure 5: Stereo images of a Venus tuskfish (*Choerodon venustus*) where precision was compromised by a lack of contrast between the fish and the background.

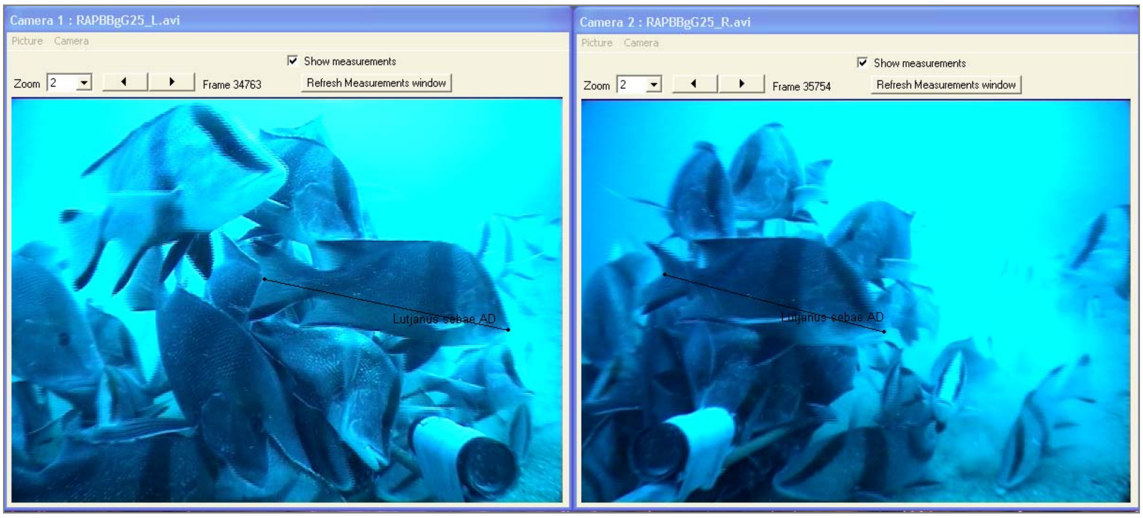

Figure 6: Stereo images of red emperor (*Lutjanus sebae*) where a high value of *MaxN* does not contribute to a similar number of fish being measured due to problems with tracking individuals, visual loss of measurement points and fish orientation.

Figure 7: Stereo images displaying how measurement precision diminishes with distance / range for trouts (*Plectropomus* sp.).

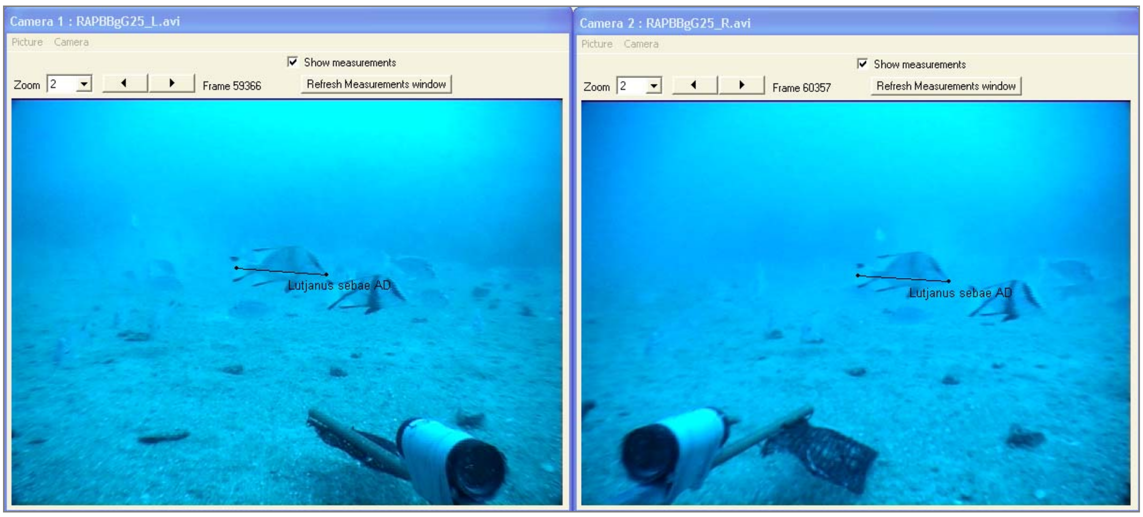

Figure 8: Approaching the ideal situation with several target species normal to the visual axis, measurement points unobscured and within acceptable range for precise measurement.

Figure 9: High resolution and high contrast digital stills image with moderately powerful (GN20) optically triggered strobe from deep water off Barcoo Bank. Note, improved caudal fin definition.

Figure 10: Low resolution and low contrast video frame from the same stereo set as in Figure 8, with relatively poor definition of measurement points.

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Appendix 1: Species sought-after by Fishers

Family	Genus	Species
Carangidae	*Carangoides*	*fulvoguttatus*
	Carangoides	*gymnostethus*
	Gnathanodon	*speciosus*
Labridae	*Bodianus*	*perditio*
	Choerodon	*cephalotes*
	Choerodon	*schoenleinii*
	Choerodon	*venustus*
Lethrinidae	*Lethrinus*	*laticaudis*
	Lethrinus	*miniatus*
	Lethrinus	*nebulosus*
Lutjanidae	*Aprion*	*virescens*
	Lutjanus	*erythropterus*
	Lutjanus	*malabaricus*
	Lutjanus	*sebae*
	Pristipomoides	*multidens*
Serranidae	*Epinephelus*	*coioides*
	Epinephelus	*undulatostriatus*
	Plectropomus	*laevis*
	Plectropomus	*leopardus*
	Plectropomus	*maculatus*
	Variola	*albimarginata*
	Variola	*louti*
Sparidae	*Pagrus*	*auratus*