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SEDAR68-RD43

May 2020

Fisheries Research 161 (2015) 145–155

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Length selectivity of commercial fish traps assessed from in situ comparisons with stereo-video: Is there evidence of sampling bias?

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ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 4 June 2014
Accepted 12 June 2014
Handling Editor P. He

Keywords:
Lutjanidae
Epinephelidae
Fishery independent
Length frequency
Stereo BRUV
Kimberley

ABSTRACT

Stock assessments of tropical demersal teleost fisheries generally rely on fishery-dependent samples of age structure. Baited remote underwater stereo-video (stereo-BRUV) systems can provide fishery independent information on the biases and selectivity of particular fishing gears in relation to the length distribution of what is potentially available for capture. In the tropical demersal fishery off northwestern Australia the length distributions of 12 species sampled by standard commercial fish traps and stereo-BRUVs were compared using kernel density estimation techniques. We found no significant differences in the shape of the length distributions sampled by either method. However, the location (mean length) of the length distribution of seven of the 11 target species and the one bycatch species differed between the sampling methods. A family-specific trend was exhibited, likely due to the ambush behaviour of larger epinephelids in traps and the saturation of the field of view of stereo-BRUV by schools of smaller lutjanids. However, the difference in mean length was not biologically significant for these families. These results indicate that samples of target species derived from commercial trap catches are likely to provide representative and robust estimates of vital population statistics and life history parameters.

1. Introduction

Stock assessments for tropical multi-species finfish rely primarily on fisheries dependent data, including catch records and biological samples (Miller, 1989; Magnuson, 1991; Recksiek et al., 1991). Historically much emphasis was placed on using readily available length data to estimate life history parameters such as age, growth rate and fishing mortality for the assessment of many tropical fisheries (Pauly and Morgan, 1987; Hilborn and Walters, 1992). However, it is recognised that direct measures of age from otolith sections are far more reliable to calculate these life history parameters (Jones and Hynes, 1950; Newman, 2002; Wakefield et al., 2010), but entail a greater cost to obtain (Hilborn and Walters, 1992). Regardless of the data used to estimate these parameters, it is generally assumed fisheries dependent methods sample all individuals equally above the size at which they are considered fully recruited to the fishery.

Commercial fishing methods are generally designed to limit the retention of individuals below the minimum legal length (e.g. Otway et al., 1996). Mesh sizes in traps, trawls and nets, and hook sizes in line fishing methods, have all been shown to influence the length distribution of the fish retained (Bertrand, 1988; Newman and Williams, 1995; Wakefield et al., 2007). Ages of teleosts are broadly related to length (von Bertalanffy, 1934); but for most tropical demersal species there is a large degree of overlap in lengths at each age after maturity (Newman et al., 1996, 2000). This relationship is also complicated by some species having marked differences in growth trajectories between sexes. For example, in the red

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http://dx.doi.org/10.1016/j.fishres.2014.06.008
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emperor *Lutjanus sebae*, the major target species for the trap fishery in northwestern Australia, males attain a much larger length than females at the same ages and there is no evidence of sexual dimorphism or dichromatism (Newman and Dunk, 2002; Newman et al., 2010). Given that fishing methods are typically selective towards larger size-classes (Fogarty and Borden, 1980; Ali and Abugideiri, 1984; Bertrand, 1988), estimation of age-structure from fishery-dependent samples would be expected to have a bias towards older and in some cases different sexes of individuals. However, there is typically little information available on the biases and selectivity of particular fishing gears in relation to what is potentially available for capture in tropical multi-species fisheries (Whitelaw et al., 1991; Travers et al., 2006, 2010). As such there is a need for studies to compare fishery-independent data with what is caught by fishing gears, so that biases can be understood and therefore the utility of fishery-dependent data can be evaluated for stock assessment purposes.

Baited remote underwater stereo-video (stereo-BRUV) can provide fisheries independent information on the abundance (Langlois et al., 2010, 2012a,b,c; Watson et al., 2010) and length composition of fish assemblages (Watson et al., 2010; Langlois et al., 2012a,b,c). Baited video assessments have demonstrated a capacity to sample both a greater number of individual fish and a greater number of species than experimental traps, in marine embayments in southwestern Australia (Wakefield et al., 2013); and standard commercial fish traps, within tropical demersal fish assemblages in the northwest of Australia (Harvey et al., 2012b). It can be assumed that stereo-BRUV samples represent the fish assemblage attracted to bait, without the size-selective and behavioural 'trap' biases likely to occur with standard commercial baited fish traps (Table 1, Cappo and Brown, 1996; Newman et al., 2011). Likewise the same 'sampling' and 'bait' biases that occur with commercial baited fish traps are found or suggested to occur with baited video (see Table 1). Video based methods also have their own particular 'video' biases, related to fish movement in and out of the field of view (MaxN, Cappo et al., 2009) and error related to stereo-measurement techniques (Harvey et al., 2010). In all cases, particular biases may be due to various interactions of singular or multiple processes, but essentially result in influencing the representation of species composition, abundance or length distribution sampled by each of the specific methods.

In a comparison of standard commercial baited fish traps and stereo-BRUVs, Harvey et al. (2012b) found significant differences in the mean length of five targeted species using univariate analysis of variance. However, these differences may have been influenced by the small sample sizes obtained during the single sampling event. Indeed, Harvey et al. (2012b) noted that the lack of difference in a sixth targeted species (*Plectropomus maculatus*), was attributable to the low number of fish sampled. The current study was designed to obtain larger sample sizes of fisheries species from concurrent trap and stereo-BRUV samples by pooling across three annual sampling trips, independent of the original study by Harvey et al. (2012b).

Comparisons of mean length using analysis of variance (ANOVA) is sensitive to small sample sizes and often require powerful transformations to account for heterogeneity of variance, which may be due to differences in the shape of the length distribution. Kernel density estimates (KDEs) have been demonstrated by Langlois et al. (2012a) to provide a non-parametric test for differences in shape and/or location (mean) of length distributions, without the use of data transformation. This KDE test is robust to small samples sizes and uses the geometric mean between the bandwidths of the distributions compared, which removes any effect of differences in sample size (Bowman and Azzalini, 1997). Langlois et al. (2012a) also found that the KDE test for shape and/or location returned almost identical results to the widely used Kolmogorov–Smirnov (KS) test (see Moore et al., 2013). With KS tests, length distribution data are usually represented using histograms with length classes chosen arbitrarily or via bootstrapping from very large independent samples (Miranda, 2007). In contrast, KDE tests provide a data-driven method for approximating length distributions with probability density functions and indicate variation from the null model with a confidence band. Langlois et al. (2012a) did not find a significant difference in either the shape or location of the length distribution, sampled by line fishing and stereo-BRUV, for one temperate and one sub-tropical demersal fished species, but found a greater length distribution of a second temperate species when sampled by stereo-BRUV.

The objective of the current study is to statistically compare both the shape and location of length distributions obtained for 11 target species and one by-catch species, which are commonly caught in the commercial trap fishery off the Kimberly region in northwestern Australia, from an extensive comparison across three years of concurrent sampling with stereo-BRUV and standard commercial fish traps. Two of these species, *L. sebae* and *Pristipomoides multidens*, are the principal target species of this commercial fishery (Northern Demersal Scalefish Fishery, NDSF), with their stock status periodically determined from age-based assessment models to provide advice on appropriate management strategies for the entire retained suite of species (Newman et al., 2012). Given that traps are designed to fish selectively for larger individuals (Newman and Williams, 1995), we hypothesised that for each species, stereo-BRUV methods would produce length distributions with significantly smaller mean lengths (location) and skewed (shape) towards smaller fishes relative to length distributions from standard commercial fish traps. We also hypothesised that the KDE method would produce the same statistical significance to the established KS method (after Langlois et al., 2012a).

2. Materials and methods

2.1. Sampling plan

All sampling was conducted in the Northern Demersal Scalefish Fishery (NDSF) north of Broome off the coast of north western Australia (Fig. 1) in depths of 60–110 m across a range of habitats (sand, rubble areas, sponges and soft corals). Samples were collected using commercial fish traps and stereo-BRUV from commercial fishing vessels in June of 2007, 2008 and 2009. Data were collected from 356 trap and 275 stereo-BRUV deployments.

Given the relative low abundance of fisheries species obtained by these sampling methods per annual survey (Harvey et al., 2012b), the length data for each species, either collected by traps or stereo-BRUV, were pooled across years to produce length-frequency distributions. All species were pooled across the same number of years for each method.

2.2. Sampling technique

2.2.1. Traps

Sampling was undertaken using galvanised steel, commercial fish traps of the type used by the commercial fishers in the NDSF. Traps were rectangular with rounded corners measuring approximately 60 cm in height, 150 cm in length and 120 cm in width; and were covered by 5 cm square steel mesh (Fig. 2). The width of the vertical funnelled entrance to the trap was 60 × 20 cm, tapering to 60 × 10 cm internally. The traps were baited using ~1 kg of crushed Australian sardines *Sardinops sagax* placed in a mesh box. Traps were set on the sea bed and left for up to 3 h. Bait was still present in all traps when retrieved at the end of sampling. All fish caught were identified to species using the descriptions given in Carpenter and Niem (2001) and their total or fork lengths were measured to

Table 1
Known and suspected biases of commercial fish traps and stereo baited remote underwater video (stereo-BRUV) for sampling fish assemblages. Biases are grouped into 'Type' based on the likely mechanism. References of studies that first documented biases are given along with the suggested influence.

Type	Bias	Commercial fish trap	Stereo-BRUV	Suggested influence on:
'Trap'	Territoriality	High and Ellis (1973)	–	Species; length
	Ambush predation	Munro (1974)	Current study ^{FW}	Species; length
	Frame dimensions	Bohnsack et al. (1989)	–	Species; length
	Mesh size	Moran and Jenke (1990)	–	Species; length
	Entrance size	Ward (1988)	–	Species; length
	Orientation to current	Sainsbury et al. (1990)	?	Species; abundance; length
	Saturation	Whitelaw et al. (1991)	–	Species; abundance; length
	Density dependent loss of small fish	Gobert (1998)	–	Species; length
	Family specific length selection	Current study	Current study	Length
'Video'	Length at MaxN misses small fish	–	Cappo et al. (2009) ^{FW}	Length
	Error in length estimation	–	Harvey et al. (2010)	Length
	Visibility	–	Stoner et al. (2008)	Species; abundance
	Saturation of field of view	–	Current study ^{FW}	Species; length
'Bait'	Burley effect	Sainsbury et al. (1990)	?	?
	Type	Ward (1988)	Dorman et al. (2012)	Species; abundance
	Amount	Ward (1988)	Hardinge et al. (2013)	Species; abundance
	Soak time	Ward (1988)	Watson (2006) ^{FW}	Species;
	Bait depletion	Cappo and Brown (1996)	?	?
	Learnt behaviour	High and Ellis (1973)	Birt et al. (2012) ^{FW}	Species; abundance
	Diurnal	?	Birt et al. (2012) ^{FW}	Species; abundance
	Day vs night	Newman and Williams (1995)	Harvey et al. (2012a)	Species
	Moon phase	Ward (1988)	?	?
	Effective area fished	Collins (1990)	Taylor et al. (2013) ^{FW}	Species; abundance

"–", indicates where biases are not likely to occur, "?", indicates where more knowledge is required and "^{FW}", indicates where further work is suggested.

the nearest 1 mm. We followed the nomenclature of Craig et al. (2011) for the family Epinephelidae.

2.2.2. Stereo-BRUV

Six stereo-BRUV systems were used with their design based on that described in Langlois et al. (2010) and Watson et al. (2010). Each stereo-BRUV used two Sony video cameras (models HC 15E in 2007 and 2008 and HDR-CX7 in 2009) mounted inside underwater housings fixed 70 cm apart on a base bar, with fields of view inwardly converged at an angle of 8° to gain an optimised field of view (Fig. 2). The quantity of bait used per deployment was identical to that for the fish traps, i.e. ~1 kg of crushed *S. sagax*, placed in a mesh bait bag fixed on a pole 140 cm in front of the cameras to attract fish into the field of view of the stereo-BRUV. In shallow depths (<80 m) illumination of the field of view was

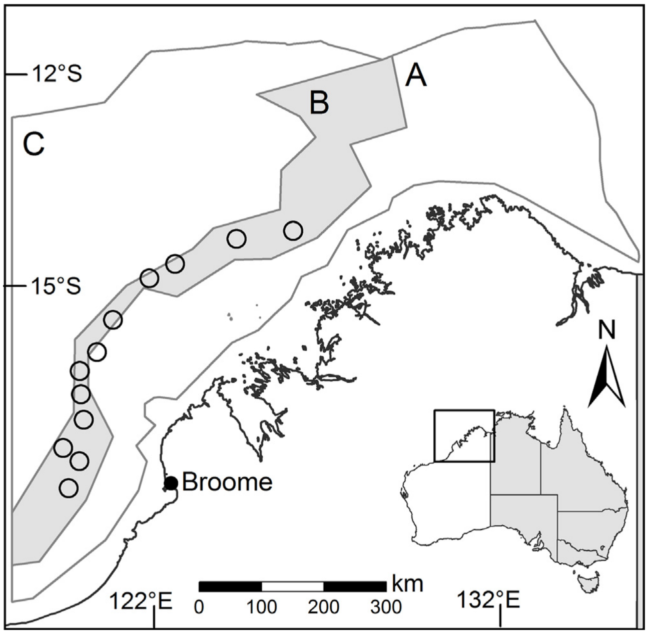


Fig. 1. Location of the study area where stereo-BRUV and fish traps were set in the Northern Demersal Scalefish Fishery off the Kimberley coast of north-western Australia. Circles indicate sampling sites for both stereo-BRUV and traps. A, B, and C represent zones of the fishery with fishing activity concentrated in Zone B.

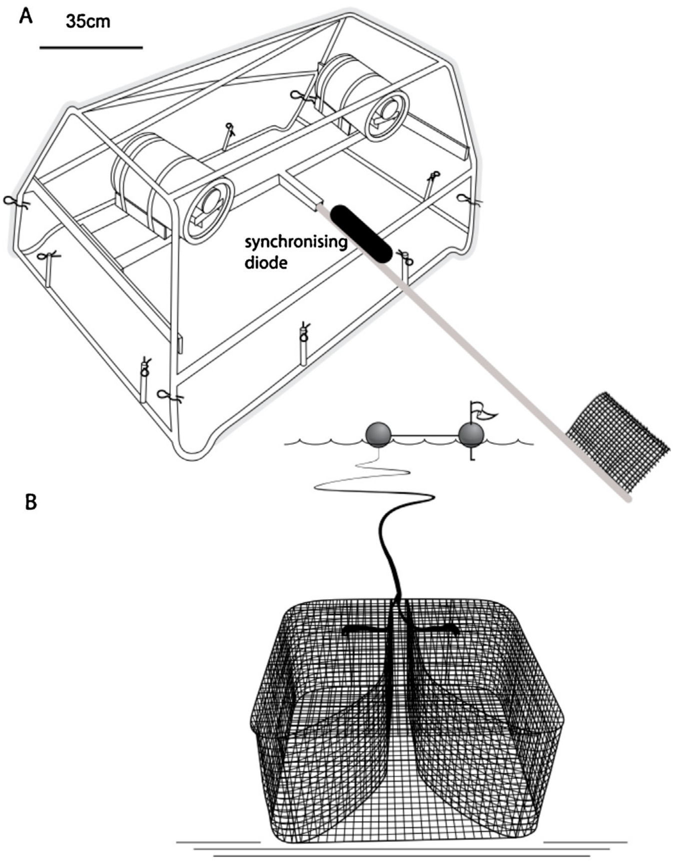


Fig. 2. (a) Baited remote underwater stereo-video (stereo-BRUV) and (b) standard commercial fish traps used in the Northern Demersal Scalefish Fishery.

adequate from natural light, but at the deeper sites illumination was achieved from artificial light, which delivered a radiant flux of 350–425 mW at wavelengths ranging from 450 to 465 nm (a bank of 7 Royal Blue Cree XLamps XP-E LEDs™). This wavelength was chosen as a compromise between minimising fish repulsion, back scatter and reflection, whilst still illuminating a large enough field of view to facilitate counts and measurements of fish. When lights were used, the cameras were switched to night shot mode, which improved the clarity of recorded imagery. Stereo-BRUV were set on the sea bed and recorded for 3 h.

2.3. Video analysis

2.3.1. Image calibration, capture and conversion

At the beginning and completion of the field surveys, the stereo BRUV were calibrated following procedures outlined in Harvey and Shortis (1998) using Cal™ software (v1.32; www.seagis.com.au). Video samples taken in 2007 and 2008 were recorded on Mini DV tapes. The video images were captured and converted to an Audio Video Interleaved (avi) format using Adobe Premier V6. Sampling in 2009 used Sony CX7 camcorders which recorded video imagery in a MPEG Transport Stream format (MTS). This format was converted from MTS to a high-definition MPEG format using the Elecard™ converter studio (www.elecard.com) following Harvey et al. (2010).

2.3.2. Image analysis

Video samples collected in 2007, were analysed using the "BRUVS2.1.mdb" interface developed by the Australian Institute of Marine Science, whereas samples from 2008 and 2009 we analysed using the software EventMeasure™ (www.seagis.com.au). Both software programmes annotated the time and maximum number of individuals (*MaxN*) for each fish species within the field of view within a single video frame. This overcame repeated counts of individual fish that continually left and re-entered the field throughout the duration of the video. Thus, *MaxN* was considered a conservative estimate of the number of fish seen of any one species on each stereo BRUV deployment (Cappo et al., 2003). Measurements of the length of each fish (fork length; FL or total length; TL) and the distance away from the camera (range) were made at the time of *MaxN* again using EventMeasur™ software. The R language for statistical computing (R Development Core Team, 2013) was used to check all *MaxN* and length data with a likely species list for the region, including minimum and maximum sizes for each species, using the following packages; XLConnect (GmbH, 2014), reshape2 (Wickham, 2007), plyr (Wickham, 2011), ggplot2 (Wickham, 2009). Computer code for implementing these methods and example datasets are provided (see Appendix A). Observations and measurements of fish from videos with blue LEDs were restricted to 5 m from the camera system. All stereo-BRUV samples were standardised to the same range resulting in a sampling area of 25.5 m^2 and volume of 158 m^3.

2.4. Statistical analyses

2.4.1. Kernel density estimates

Length distributions for each species, that had a sample size of at least 45 individuals in either method, were compared using kernel density estimates (KDEs, Sheather and Jones, 1991). The KDE method is sensitive to differences in both the shape and location of length distributions. Therefore, to investigate differences due to shape alone, length distributions were first standardised by median and variance ($y = x$-median/st.dev.), as suggested by Bowman and Azzalini (1997). As all tests for shape were found to be insignificant (Table 2, $P > 0.05$), all subsequent tests on raw data provided a test between locations of length distributions only. Separate KDEs were constructed for the length distributions of each species derived from either trap or stereo-BRUV (Fig. 2). Bandwidths were selected via a 'plug-in' style data-driven bandwidth selection process (Sheather and Jones, 1991), which is well-suited to univariate analyses where assumptions are not made about the nature of the distribution being estimated. To check for over parameterisation, the procedure of Liao et al. (2010) was used, but in each case the bandwidth selected by the Sheather-Jones selection procedure was retained. Sheather-Jones bandwidths were estimated with the 'dpik' function in the package 'KernSmooth' (Wand, 2012) using the R language for statistical computing (R Development Core Team, 2013).

The statistical test between the pairs of length distributions collected by each sampling method, for each species, was based on a null model of no difference and a permutation test. To construct the test, the geometric mean between the bandwidths for trap fishing and stereo-BRUV data were calculated for each species. This avoids the effect of differences in sample size adding more weight to the data from one method (Bowman and Azzalini, 1997). The mean bandwidths for each species were then used to construct KDEs for both the trap and stereo-BRUV data. If trap and stereo-BRUV data represented the same distribution, the KDEs should only differ in minor ways due to within population variance and sampling effects. The statistical test compared the area between the pair of KDEs, for trap and stereo-BRUV data, to that resulting from permutations of the data into random pairs using the function 'sm.density.compare' (10,000 permutations) in the package 'sm' (Bowman and Azzalini, 2010).

The 'sm.density.compare' function produces a plot to accompany each test with a grey band, representing the null model of no difference between the pair of KDEs. This grey band is centred on the mean KDE and extends one standard error above and below, thereby indicating which regions of the length distribution is likely to be causing any significant differences (Bowman and Azzalini, 1997). The computational code for implementing these methods and example datasets are provided by Langlois et al. (2012a).

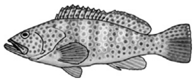
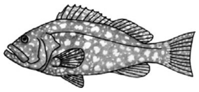
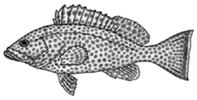
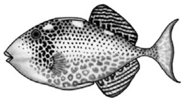
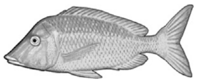
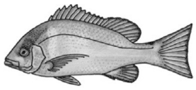
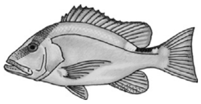
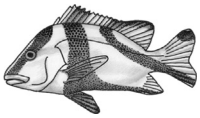
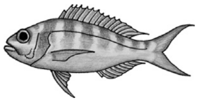
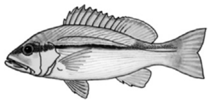
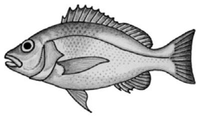
2.4.2. Kolmogorov–Smirnov test

The Kolmogorov–Smirnov (KS) two-sample test was used to compare the two length frequency samples for each species from trap fishing and stereo-BRUV via a non-parametric test of the significance of the greatest difference in their respective cumulative distributions (Zar, 1999). As with the KDE analyses, to investigate differences due to shape alone, length distributions were first standardised by median and variance ($y = x$-median/st.dev). As all tests for shape were found to be insignificant (Table 2, $P > 0.05$), all subsequent tests on raw data provided a test between locations only. We used Monte Carlo simulations to overcome uncertainty regarding the asymptotic distributions of KS test statistics under the null hypothesis (Abadie, 2002), which also enabled the test to be conducted with data containing ties, which were present in the trap data. This procedure was implemented using the 'ks.boot' function (10,000 simulations) in the package 'Matching' (Sekhon, 2011).

3. Results

Across the three annual sampling trips involving the two methods, 12 species were collected in adequate numbers for comparison of length distributions (Tables 2 and 3). Using KDE's, no significant differences were found between the shape of the length distributions sampled with stereo-BRUV and standard commercial fish traps for any of the 11 target and one bycatch species (Table 2; Figs. 3–6). The implication of this result is that all of the subsequent tests for both shape and location were essentially tests of location (mean length) only. In particular, comparisons of the shape of the length distributions for the highly targeted indicator species *L. sebae*

Table 2
Eleven target and two bycatch^{BC} species sampled by commercial fish traps and stereo-BRUV, including two indicator* species used for stock assessment. Results of kernel density estimate (KDE) and Kolmogorov-Smirnov (KS) tests for shape and location are given. Due to a lack of any significant differences in test of Shape, all tests of untransformed length data represent a test of Location (mean size) only. Bold values indicate significant test results. Species have been ordered from larger mean length in traps to larger on stereo-BRUV.

	Family	Species		KDE		KS	
				Shape	Location	Shape	Location
Larger in traps	Epinephelidae	*Epinephelus bleekeri*		0.75	**<0.01**	0.94	**<0.01**
	Epinephelidae	*Epinephelus multinotatus*		0.82	**<0.05**	0.39	**<0.05**
	Epinephelidae	*Epinephelus areolatus*		0.47	**<0.01**	0.79	**<0.01**
	Balistidae	*Abalistes stellatus*^{BC}		0.85	**<0.05**	0.89	0.06
	Lethrinidae	*Lethrinus nebulosus*		0.99	0.86	0.77	0.50
	Lutjanidae	*Lutjanus erythropterus*		0.58	0.30	0.53	0.08
	Lutjanidae	*Lutjanus malabaricus*		0.09	0.12	0.06	0.60
	Lutjanidae	*Lutjanus sebae**		0.08	**<0.01**	0.17	0.10
	Lutjanidae	*Pristipomoides typus*		0.63	0.70	0.35	0.35
	Lutjanidae	*Lutjanus vitta*		0.15	**<0.01**	0.17	**<0.01**
	Lutjanidae	*Pristipomoides multidens**		0.44	**<0.01**	0.67	**<0.01**
Larger on stereo-BRUV	Lutjanidae	*Lutjanus bitaeniatus*		0.1	**<0.01**	0.17	**<0.01**

and *P. multidens* demonstrated a very similar declining slope from the modal (length with the highest frequency) to the maximum lengths.

Comparisons of the location of the length distributions for the 11 target species found four to have no significant difference between stereo-BRUV and fish trap samples (Table 2; Figs. 3–6). Of the seven target species that exhibited significant differences in location, three had larger mean lengths sampled by traps (*Epinephelus multinotatus*; *Epinephelus bleekeri* and *Epinephelus areolatus*), whilst the remaining four had larger mean lengths sampled by stereo-BRUV (*L. sebae*; *Lutjanus bitaeniatus*; *Lutjanus vitta* and *P. multidens*). The location of the length-frequencies of the bycatch species *Abalistes stellatus* was also found to be significantly different, with a greater mean length sampled by fish traps. Stereo-BRUV

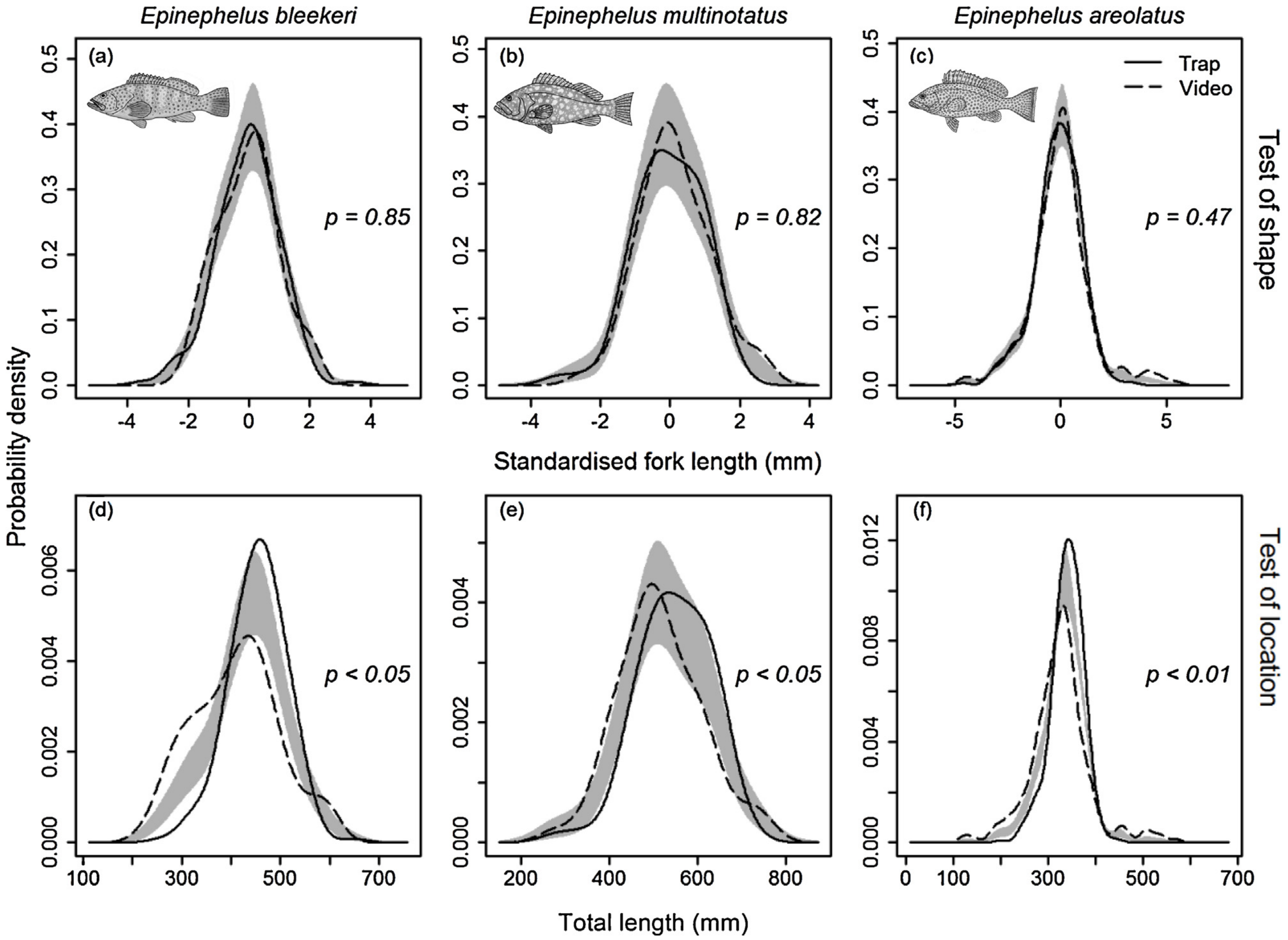


Fig. 3. Comparison of kernel density estimate (KDE) probability density functions, using mean bandwidths, for *Epinephelus bleekeri*, *Epinephelus multinotatus* and *Epinephelus areolatus* sampled using either trap fishing (Trap) or stereo-BRUV (Video). Solid and dashed lines represent the KDE probability density functions that approximate the trap and stereo-BRUV length-frequency data, respectively. Grey bands represent one standard error either side of the null model of no difference between the KDEs for each method.

sampled a greater range of lengths for the one bycatch species and 10 of the target species, with the exception being *L. bitaeniatus* (Table 3). Length samples of *L. bitaeniatus* were more abundant from traps ($n = 189$) than were recorded from stereo-BRUV ($n = 48$).

Concomitant tests using the KS method found identical levels of significance for the tests between shapes (Table 2), but less frequent significant results for the tests between locations. However, there were two cases, where for the location of the length distributions, the level of significance of the KDE and KS test did not match; the bycatch species *A. stellatus* was found to be significant ($P < 0.05$) with the KDE but only approach significance ($P = 0.06$) with the KS, whereas, the indicator species *L. sebae* had a P value of 0.1 using the KS test compared to <0.01 using the KDE method.

4. Discussion

This study did not find any significant differences in the shape of the length distributions of 11 target and one bycatch species sampled by both standard commercial fish traps and stereo-BRUV. Langlois et al. (2012a) found a similar pattern in the shapes of the length distributions sampled by stereo-BRUV and line fishing in two temperate/subtropical target species, indicating no relative bias or skew towards a particular size class between fishery dependent and independent methods. Conversely, Wells et al. (2008) found large differences in the abundance and length composition of fish assemblages sampled from trawl, trap and baited video in the Gulf of Mexico. However, this was likely due to very low levels of replication and large differences in sample unit area between sampling methods compared by Wells et al. (2008); combined with the difficulty of using paired lasers to obtain length measurements with mono-baited video, which relies on individual fish being aligned exactly parallel to the camera (Harvey et al., 2002). The stereo-BRUV used in the current study enable length estimates to be made whenever the snout and caudal fork of the fish could be defined, thereby increasing the sample size of the length distributions produced.

Stock assessments for lutjanids and epinephelids in the Caribbean have recognised species specific differences in behaviour and catchability that can influence life history parameters derived from fisheries dependent data (Barans, 1982). For example, Goodyear (1995) derived two significantly different growth schedules for *Epinephelus morio* when using samples from either commercial hook and line or recreational hook and line fisheries. However, the current study suggests standard commercial traps do not have a particular skew or bias towards a particular size class of fish, relative to the length distributions sampled by stereo-BRUV. Although length-age relationships are highly variable for these species after maturity and between sexes (Newman and Dunk, 2002), the very similar shape of the length distributions from the modal to maximum length suggest that if age structures were estimated for the fish sampled by each method they would produce highly comparable life history parameters.

Despite the overall similarities in the shapes of the length compositions between the two methods, the locations (mean length) within these distributions for seven of the target and the sole

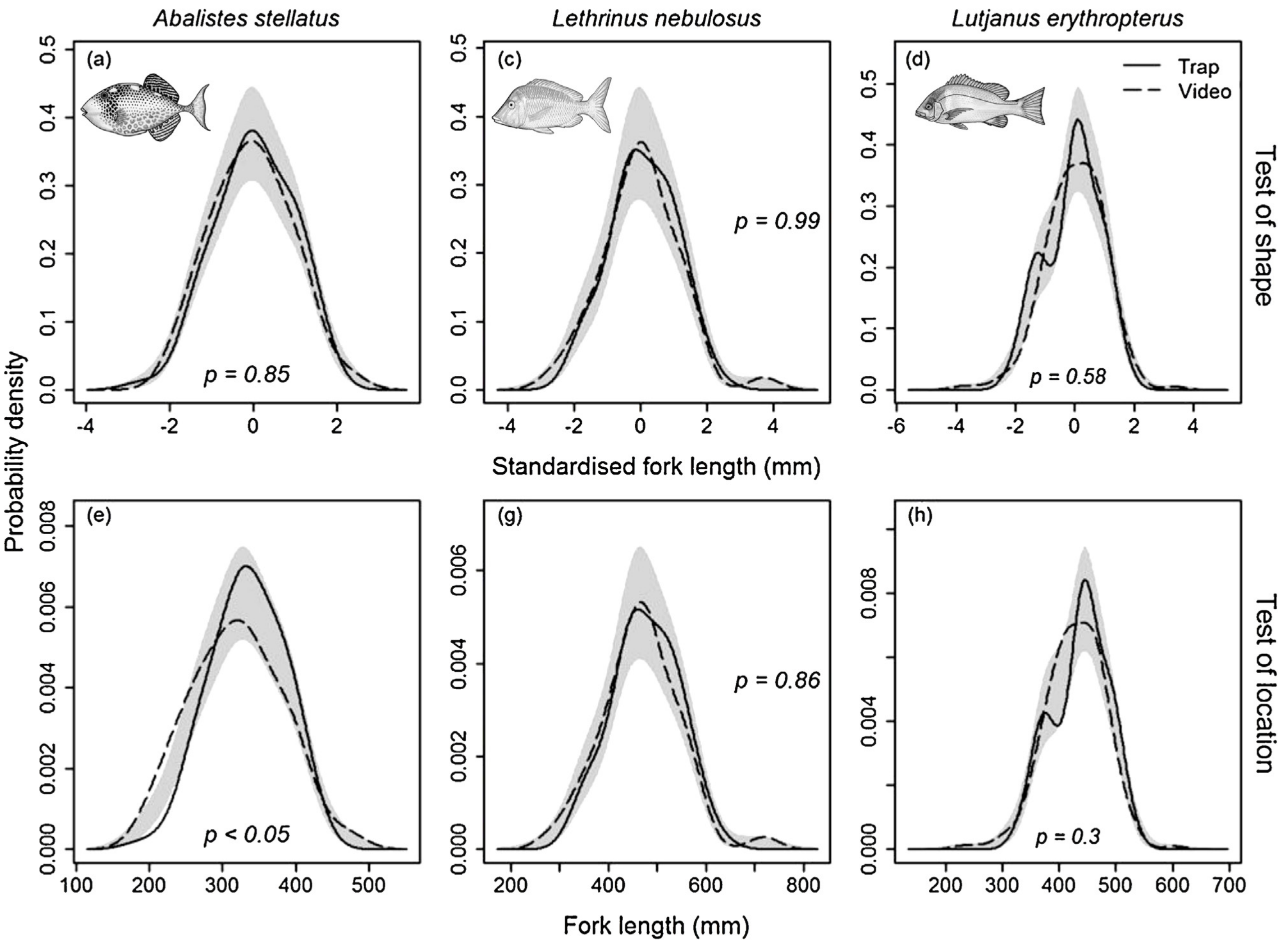


Fig. 4. Comparison of kernel density estimate (KDE) probability density functions for *Abalistes stellatus*, *Lethrinus nebulosus* and *Lutjanus erythropterus* sampled using either trap fishing (Trap) or stereo-BRUV (Video). See Fig. 3 for details.

Table 3
Eleven target and two bycatch^{BC} species sampled by commercial fish traps and stereo-BRUV, including two indicator* species used for stock assessment. Results of kernel density estimate (KDE) and Kolmogorov-Smirnov (KS) tests for shape and location are given. Due to a lack of any significant differences in test of Shape, all tests of untransformed length data represent a test of Location (mean size) only. Bold values indicate significant test results. Species have been ordered from larger mean length in traps to larger on stereo-BRUV.

	Species	Method	N	Mean length	Difference	sd	Min	Max	Range
Larger in traps	*Epinephelus bleekeri*	Trap	196	**453**	43	57	260	**650**	390
		BRUV	91	410		88	**219**	613	**393**
	Epinephelus multinotatus	Trap	126	**548**	33	82	**270**	725	455
		BRUV	58	515		96	274	**753**	**479**
	Epinephelus areolatus	Trap	417	**340**	15	34	201	451	250
		BRUV	239	326		64	**121**	**569**	**448**
	Abalistes stellatus^{BC}	Trap	90	**334**	15	49	190	427	237
		BRUV	107	319		63	**187**	**479**	**292**
	Lethrinus nebulosus	Trap	80	**476**	10	67	336	633	297
		BRUV	48	466		79	**281**	**719**	**438**
	Lutjanus erythropterus	Trap	50	**437**	9	49	329	531	202
		BRUV	213	428		52	**228**	**603**	**376**
	Lutjanus malabaricus	Trap	161	479	-4	83	242	661	419
		BRUV	100	**484**		85	**235**	**684**	**449**
	*Lutjanus sebae**	Trap	518	466	-8	68	**265**	682	417
		BRUV	186	**474**		85	288	**734**	**446**
	Pristipomoides typus	Trap	78	435	-9	67	268	579	311
		BRUV	192	**444**		85	**109**	**707**	**598**
	Lutjanus vitta	Trap	115	266	-14	38	152	400	248
		BRUV	59	**280**		39	**109**	**426**	**317**
	*Pristipomoides multidens**	Trap	624	472	-15	74	**241**	658	417
		BRUV	347	**488**		89	265	**847**	**582**
Larger on stereo-BRUV	*Lutjanus bitaeniatus*	Trap	189	303	-43	43	**224**	**650**	**426**
		BRUV	48	**346**		59	265	546	281

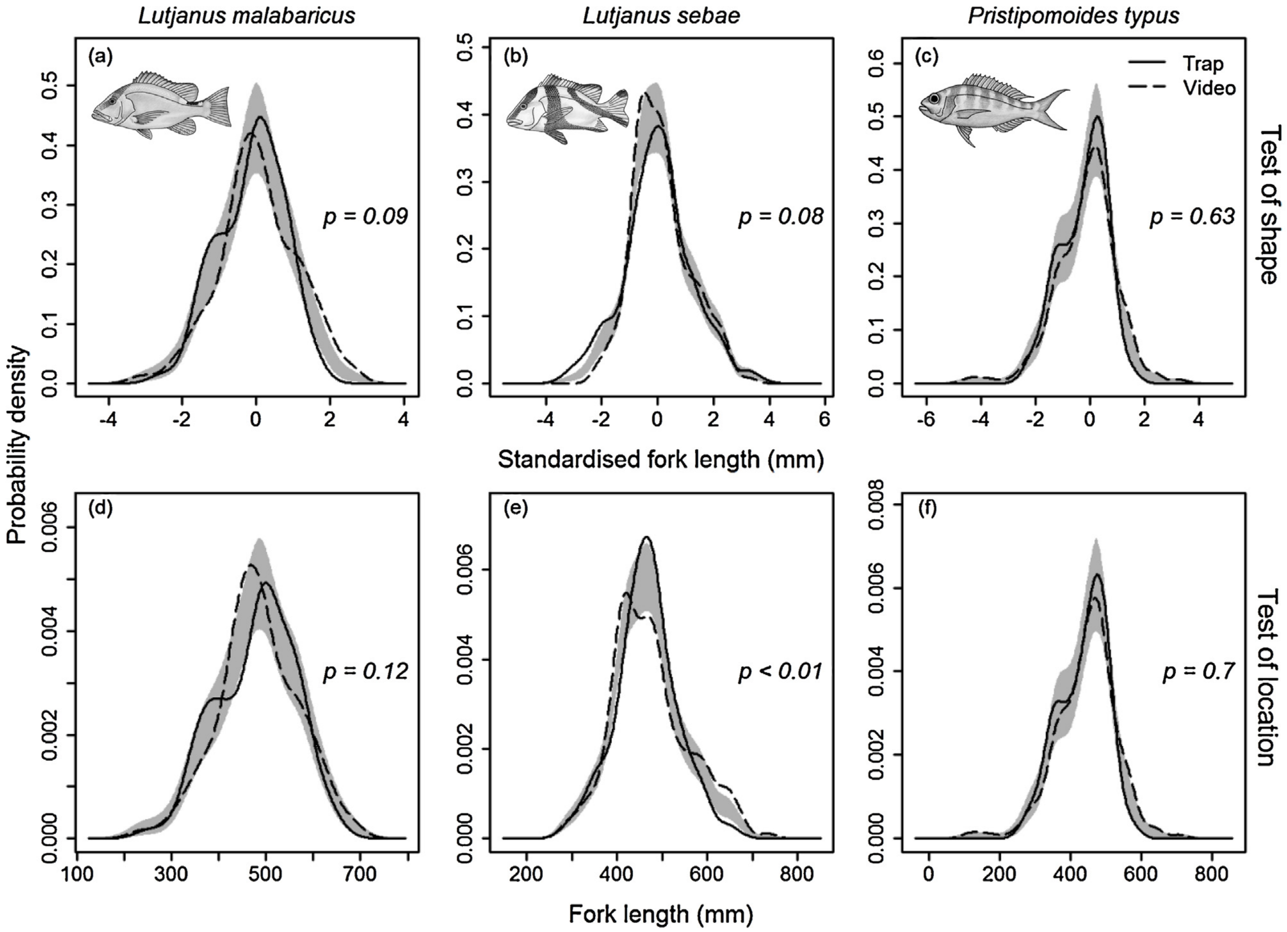


Fig. 5. Comparison of kernel density estimate (KDE) probability density functions for *Lutjanus malabaricus*, *Lutjanus sebae* and *Pristipomoides typus* sampled using either trap fishing (Trap) or stereo-BRUV (Video). See Fig. 3 for details.

bycatch species differed significantly. These differences in locations were consistent within families, with all of the epinephelids having larger mean lengths sampled by traps and four lutjanids having the converse (Tables 2 and 3). Previous studies have documented a positive 'trap bias' for large epinephelids in the Caribbean, which was thought to be due to territorial and ambush predatory behaviour exhibited in and around baited traps (High and Ellis, 1973; Munro, 1974). This concurred with a pilot study in northwestern Australia that used direct camera observations from inside and outside of traps to record fish behaviour, entries and exits during fishing (Harvey et al., 2012b). For the lutjanids, although significant differences occurred in only four out of eight species, seven of these had a larger mean length from the stereo-BRUV samples. However, the magnitude of these differences in mean length were very small compared to the maximum lengths of these species observed (Table 3) and are not likely to have any biological significance given the life history characteristics of comparable species in the region (Newman and Dunk, 2002).

In the Great Barrier Reef Marine Park, Cappo et al. (2009) demonstrated a potential for stereo-BRUV methods to overestimate the mean length of *L. sebae* and *Plectropomus leopardus* throughout the 60 min deployment. Measurements made at the *MaxN* during the last 15 min of the deployment produced larger length estimates than when measurements were made at an identical *MaxN* from the first 15 min, where smaller fish were visiting the stereo-BRUV earlier in the deployment (Table 1). The current study found a family specific length selection between length distributions sampled by standard commercial baited traps and stereo-BRUV, likely associated with family specific behaviour and the possible limitations of video observations (Table 1). To meet these knowledge gaps, we suggest that further studies be undertaken using cameras to assess family specific behaviour inside and outside of traps (Harvey et al., 2012b), as these behaviours and interactions are important in understanding the selectivity parameters of trap fishing gears. To validate and possibly improve the abundance and length distribution estimates from stereo-BRUV we also recommend that studies of fish behaviour around baited video be conducted to investigate methodological biases described by Cappo et al. (2009).

The major limitation of the current study was the unequal numbers of length measurements obtained between trap and stereo-BRUV samples for each species. Although, the KDE is robust to differences in sample size (Sheather and Jones, 1991), very small sample sizes (<50) will have reduced sensitivity to differences in the shape of length distributions (Bowman and Azzalini, 1997). Therefore, the test of shape results for *L. bitaeniatus* should be interpreted cautiously given the three-fold disparity in sample size and with a probability value that approaches significance ($P = 0.1$).

The major assumption used in this study was that stereo-BRUV would representatively sample the length distribution of the fish assemblage attracted to bait, without the possible size-selective 'trap' biases associated with standard commercial fish traps (Table 1). Nonetheless, stereo-BRUV have been found to have their own specific 'video' biases where fish lengths measured earlier in the deployment are smaller than those measured later in the deployment (Cappo et al., 2009). Potentially stereo-BRUV may also be useful for estimating the relative abundance and recruitment strength of juveniles, if these smaller bodied individuals that appear earlier in deployments, can be accurately quantified.

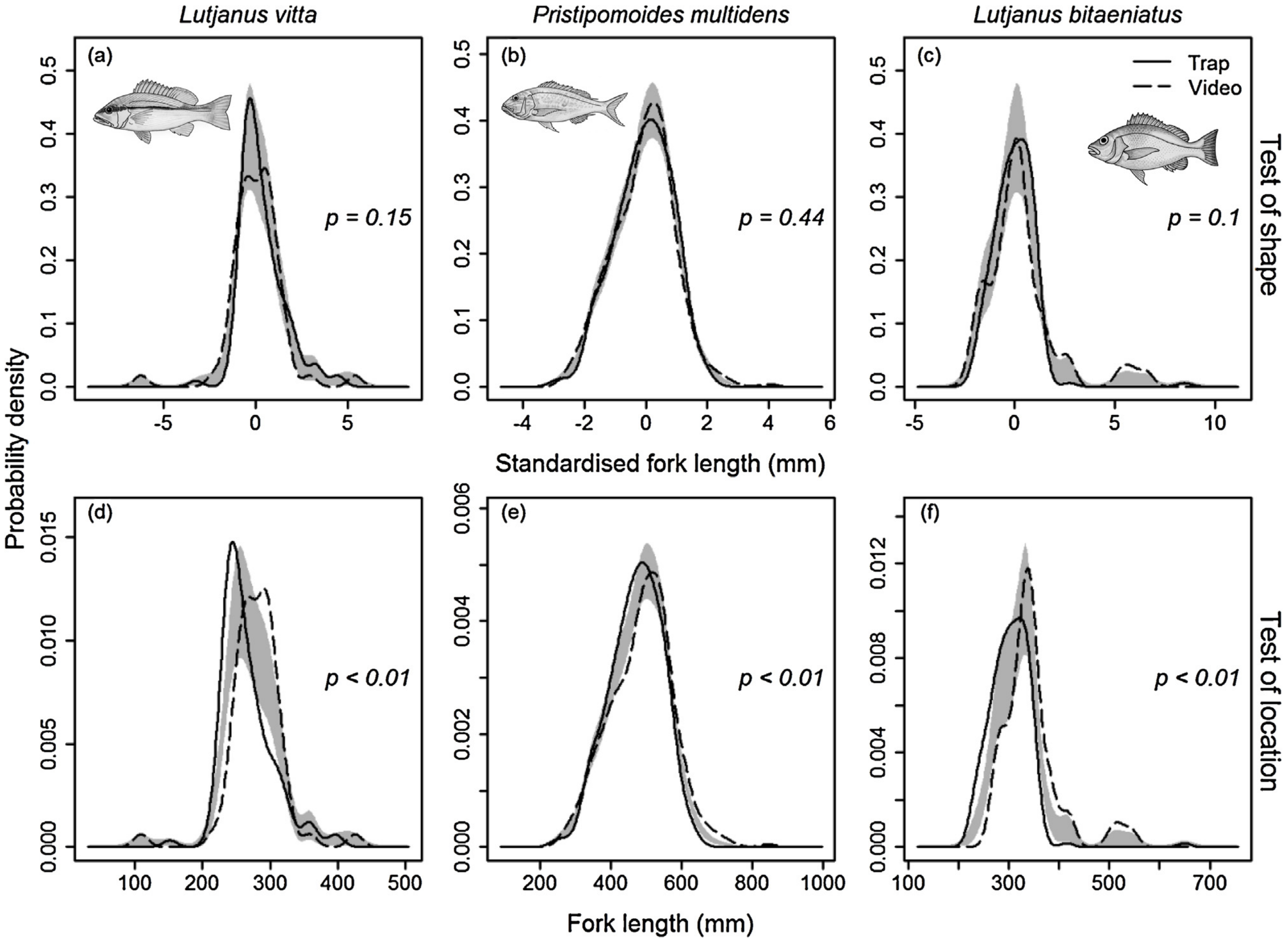


Fig. 6. Comparison of kernel density estimate (KDE) probability density functions for *Lutjanus vitta*, *Pristipomoides multidens* and *Lutjanus bitaeniatus* sampled using either trap fishing (Trap) or stereo-BRUV (Video). See Fig. 3 for details.

In conclusion, the key findings of this study revealed that the shapes of the length distributions for each species sampled by each method were not significantly different. This indicates that samples of target species, in particular the indicator species (*L. sebae* and *P. multidens*) from commercial trap catches in the NDSF are likely to provide a representative and robust sample for estimating age structure and life history parameters of the populations within this northwestern Australian demersal scalefish trap fishery. However, the behaviour of fish and their interspecific and intraspecific interactions in and around standard commercial baited traps in association with limitations of sampling with stereo video systems can result in subtle family-specific biases.

Acknowledgements

The authors gratefully acknowledge funding from the Commonwealth Government's Fish Corporation (FRDC) for this project. This work was undertaken as part of FRDC Project No. 2006/031. Logistical support was provided by the Department of Fisheries; Government of Western Australia (DoFWA) and The University of Western Australia (UWA). We would like to thank all the research staff from DoFWA and UWA; in particular A. Grochowski; J. Goetze; A. Payne; D. Walker; L. Fullwood and S. McMillan for both their assistance in the field and in the laboratory analysing many hours of stereo-BRUV footage. The project could not have been undertaken without the assistance and co-operation of a number of commercial operators from the NDSF. In particular we would like to thank; D. Gibson; G. Barker; the skipper and crew of the Ashburton Road; the skipper and crew of the *Carolina M* and the skipper and crew of the *Exodus*. A special thank you to I. Lightbody (DoFWA); and the manager of the FNAS combined workshop at UWA; R. Scott who assisted with the construction of research equipment and provided technical support throughout the project. Thanks also to James Seager for continual support in refining the SeaGIS software. We also thank T. Simmonds (AIMS) for trap and stereo-BRUV drawings and J. Corley for fish illustrations.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2014.06.008.

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