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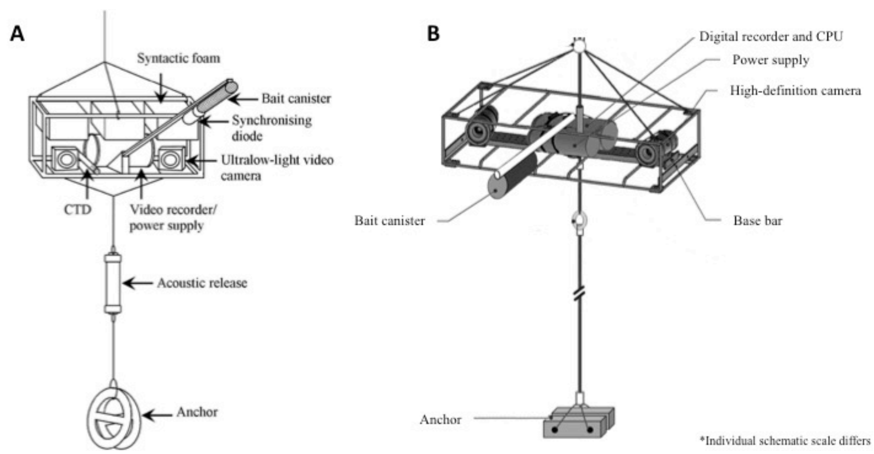

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Cover: Photo courtesy of Moore et al. (2013) for BotCam schematic and Amin et al. (2017) for MOUSS schematic.

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Executive Summary

Stereo-camera systems have become integral tools in surveys of bottomfish species in the main Hawaiian Islands. At the Pacific Islands Fisheries Science Center, camera sampling technology has transitioned from an analog system (Bottom Camera Bait Station—BotCam) to a high-definition digital system (Modular Optical Underwater Survey System—MOUSS) to increase sampling efficiency and data yield. To ensure continuity of data streams between camera systems, comparative tests on species richness, relative abundance (MaxN), and length measurements were undertaken. No significant differences were found between BotCam and MOUSS in their ability to detect bottomfish species and in the relative abundance and length data generated by both systems thus allowing for continuity of videographic data streams. Of the two camera systems, MOUSS generally produced better quality imagery leading to some more precise fish identifications and better measurement accuracy. BotCam, on the other hand, had greater light sensitivity at deeper sampling depths, allowing it to detect some species missed by MOUSS in light-limited conditions. While the MOUSS has shown to be an upgrade over the BotCam given the quality of imagery produced along with the benefits of a smaller overall form-factor and modularity, further fine-tuning of the low-light settings of the MOUSS would still be required for it to match the performance of BotCam in low-light environments.

Introduction

Underwater camera technologies have had a wide variety of applications in fisheries research, such as the development of fishery-independent indices of species-specific abundance, community structure analyses, and studies on the effect of marine protected areas on target fish species (Cappo et al. 2007). These systems provide a non-destructive alternative to sampling target fish species in their habitat without the depth and time limitations of traditional survey methods (Cappo et al. 2007; Langlois et al. 2010). Through increased survey capabilities, underwater camera systems can aid in the improvement of abundance estimates of target fish stocks that is critical to fisheries management, providing fish abundance and length-frequency data streams, spatial and temporal trends, fish distribution and behavior, and information on habitat.

At the National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center (PIFSC), underwater stereo-camera systems have been used to generate species-specific, size-structured abundance estimates of commercially-important bottomfish in Hawaii (Richards et al. 2016). These bottomfish species have been found to be susceptible to overfishing (Haight et al. 1993) thus making non-extractive sampling methodologies ideal. Bottomfish data collected from underwater stereo-camera systems have also been used in marine protected area surveys (Moore et al. 2013; Sackett et al. 2014; Sackett et al. 2017), habitat-association studies (Misa et al. 2013), and species distribution modeling (Moore et al. 2016).

Early sampling was carried out using a low-light, analog stereo-camera system called the Bottom Camera Bait Station—BotCam (Merritt et al. 2005; Merritt et al. 2011). While BotCam provided imagery adequate to generate species-specific fish counts and lengths, improvements in image quality, measurement accuracy, and a reduction of overall gear footprint were deemed necessary to increase sampling efficiency and data output. Current bottomfish surveys at PIFSC now make use of the Modular Optical Underwater Survey System—MOUSS (Amin et al. 2017), a smaller, low-light, high-definition digital stereo-camera system, which is also used at (least) two other NOAA Fisheries Science Centers, serving as the nominal gear choice for NOAA Fisheries research to investigate sampling capabilities in untrawlable habitats in the Gulf of Mexico and coastal California.

With the continued modernization of optics and other sampling technologies, it remains necessary to establish data quality benchmarks when transitioning to new underwater videographic systems. These benchmarks ensure continuity between gear data streams, setting the parameters for evaluating succeeding technologies. In order to verify that comparable or improved stereo-camera fish data are generated by new camera systems, differences in relative abundance, species richness, measurement accuracy, and image quality are evaluated in this study between BotCam and MOUSS in the main Hawaiian Islands.

Methods

Camera Systems and Sampling

BotCam, developed by Merritt (2005), has been an efficient tool in bottomfish surveys at PIFSC since 2005. MOUSS was developed in 2012 with the goal of enhancing the sampling capabilities of BotCam by improving image quality for better fish identification and measurement, reducing the overall form-factor and gear footprint to allow for camera deployments off small boats, and enabling multi-platform usage through modular components (Amin et al. 2017). For better image quality, the MOUSS makes use of two Allied Vision Prosilica cameras that capture photos at a resolution of 1936 × 1456 as opposed to the BotCam's ROS NavigatorTM low light cameras that record video at a 720 × 480 resolution (Table 1). Both systems record imagery using only ambient light and are deployed to a maximum depth of 300 m. Merritt et al. (2011) determined that 300 m was the maximum camera deployment depth for accurate species identification and sizing under ambient light conditions in Hawaii. By using high definition photographs as the mode of raw image capture prior to conversion to video, the MOUSS can also provide more detailed video still frames compared to those of the BotCam's analog interlaced video. The MOUSS has an overall gear footprint of 46.99 cm × 21.59 cm × 102.49 cm and a weight of 29.43 kg, significantly smaller compared to the BotCam's 55.88 cm × 45.72 cm × 121.91 cm, 48.99 kg size (Table 1). However, MOUSS is only rated to 500 m compared to the BotCam's maximum operating depth of 1000 m. The 300 m sampling depth constraint under ambient light conditions was factored into the target depth rating of MOUSS housing components during the system's development.

Comparative deployments of the BotCam and MOUSS were carried out in the main Hawaiian Islands as part of the Deep-7 bottomfish survey (SE1701) from October 14 to November 3, 2016. Components/cameras from both the BotCam and MOUSS were tandem mounted within a single BotCam frame (Figure 1) to ensure that both systems maintained a near identical field of view. This tandem system was deployed from the NOAA Ship *Oscar Elton Sette* at 23 sites between 0800 and 1400 HST, with depths ranging from 86 m to 250 m in known Hawaiian bottomfish habitat. Prior to deployment, a bait mix of ground anchovies and squid was loaded into canisters fronting the camera systems to attract fish targets into the field of view. Once deployed, the tandem system stayed 3 m off the seafloor and oriented horizontally down-current with a vertical downward angle of 15 degrees (Merritt et al. 2011). Video (BotCam) and image (MOUSS) recordings from each camera system were downloaded at the end of each sampling day and stored on hard drives for subsequent processing and analysis in the laboratory. For reference, camera deployments were labeled according to precise deployment dates and times in UTC date_time format (i.e., yyyymmdd_hhmmss).

Data Analysis

BotCam and MOUSS video footage were processed using the stereo-photogrammetric software—EventMeasureTM (SeaGIS Pty. Ltd., Victoria, Australia). Relative abundance (MaxN) and the total number of fish species encountered (species richness) were taken for all fish species seen within a 15-minute observation period. MaxN is the single highest count of a given fish species recorded in a single video frame within a set observation period and is widely used as a conservative estimate of abundance in underwater camera studies (Ellis and DeMartini 1995; Willis et al. 2000; Cappo et al. 2003; Merritt et al. 2011). A 15-minute observation period was used, based on work by Misa et al. (2016), that showed a general detectability of bottomfish species in Hawaii within this duration of camera bottom time. Taxonomic identifications were made to the most specific level possible as allowed by each system's recorded imagery.

In order to assess comparability and detectability between methods, the differences in paired relative abundance and species counts were examined. Specifically, for each count pair (MaxNs for a species in a deployment from MOUSS and BotCam), the absolute difference between methods was calculated. To test for systematic bias between methods, the mean and 95% confidence interval (CI) of the standardized differences (i.e., the difference between counts divided by mean of counts) were assessed considering a 95% CI not overlapping zero as being equivalent to a significant difference at alpha = 0.05. Showing comparisons in this manner (i.e., as mean and confidence intervals of difference) provided substantial additional information compared with simply reporting a significance test result (Cumming and Finch, 2005).

Fork length, measurement precision, and range values of selected fish individuals visible in the field of view of both BotCam and MOUSS cameras were recorded using EventMeasure. System-specific camera calibration procedures following Shortis and Harvey (1998) were carried out using the software CALTM (SeaGIS Pty. Ltd., Victoria, Australia) to enable sizing of fish targets in EventMeasure. Precision values are mathematically derived estimates calculated by the EventMeasure software using physical camera properties, three-dimensional intersection geometry, and a 1-pixel image measurement precision. Range is the distance between the target fish individual being measured and the camera system. In this study, measurement precision was used as an indicator of measurement quality while the combination of precision and range values was used to assess each system's ability to accurately measure fish targets when factoring in distance. Measurement targets were limited to those individuals with good visibility of head and tail in both stereo-camera pairs, straight body, and central position in the field of view. To ensure proper pairing of target individuals in BotCam and MOUSS footage, the time (in minutes) from camera touchdown to the measurement time were matched. Position, orientation, and movement were used to decipher selected individuals from others of the same species when multiple individuals were present in the field of view.

Notched box plots generated in R (R Core Team 2016) provided indications of differences between length measurements collected by each method, with median notch widths being proportional to interquartile range and inversely proportional to sample size (McGill et al. 1978). While not strictly a formal test, cases where notches did not overlap were indicative of significant differences in median length, independent of assumptions of data normality of distributions or equivalence of variances (Chambers et al. 1983). Non-parametric kernel density estimates (KDEs) were further used to approximate pair-wise comparisons in length frequency distributions between methods in shallow-water strata, based on a null model of no difference between groups and a permutation test (n = 100,000) following the approach used by Langlois et al. (2012). KDE tests were constrained to species recording a minimum of 10 length measurements for BotCam and MOUSS. KDE bandwidths were selected using Sheather-Jones assignment protocol (Sheather and Jones 1991) via the function 'dpik' in the package Kernsmooth in the R statistical program version 3.3.0 (Wand and Ripley 2011; Langlois et al. 2012). Given the sensitivity of length-distribution tests to differences in shape and location, data were also standardized by median and variance to assess shape-only effects (Bowman and Azzalini 1997; Langlois et al. 2012).

Table 1. Comparison of BotCam and MOUSS specifications (MOUSS specifications taken from Amin et al., 2017).

	BotCam	**MOUSS**
Stereo-Cameras		
Camera Model	ROS Navigator	ST-CAM-1920HD (Allied Vision Prosilica GT 1920)
Resolution	570 TV Lines-EIA RS-170, 560 TV Lines-CCIR, 720 × 480 at 30p	1936 × 1456 (2.82 MP)
Field of view (in water)	80º diagonal (15º horizontal)	82° diagonal (15° horizontal)
Color/Mono	Mono	Color or Mono
Interface	Composite, 1.0V peak to peak into 75 ohm	Ethernet IEEE 802.3 1000base-T
Image Sensor	1.27-cm Interline Transfer CCD	Sony ICX674
Sensor Type (Size)	1.27-cm	Progressive CCD (2/3)
Cell Size	N/A	4.54 µm
Iris	Automatic, f/0.8 - f/360	Fixed
Focus	Auto	Fixed
Exposure Control	Auto	10 µs to 60 µs; 1µs increments
Frame Rate	30 FPS	0–40 FPS
Bit Depth	0.5 Mbps to 16.0 Mbps	8/14 bits
Binning	N/A	1–8 pixels/rows
Gain	>50 dB	0–30 dB
Power Requirement	12–30 VDC, 250 mA (max)	7–25 VDC (5 W)
Lens	3.8 mm, f/0.8	Schneider 21017528 4.8 mm, f/1.8
Housing Dimensions	8.89 × 24.13 cm long	8.89 × 20.32 cm long
Weight Including Housing	2.58 kg/camera	2.36 kg/camera
Data Recorder		
Model	DataToys XM-DVR	ST-DVR-2HD Custom build
Operation System	Linux	Linux

	BotCam	MOUSS
Data Storage	2 × 32 GB SD cards, 1 × 64 GB CF card	2 × 512 GB Solid State Drives
Output	MPEG, Power Stream	DNG, JPEG, PGM, PNG TIFF, SGI
Power Requirement	5 VDC	9-36 VDC (16)
Housing Dimensions	36.83 × 21.59 cm	33.02 × 15.87 cm
Weight Including Housing	17.24 kg (including batteries)	8.16 kg
Power Supply		
Type	NiMH	NiMH
Duration	6-8 h	6+ h
Housing Dimensions	36.83 × 21.59 cm (same housing as data recorder)	33.02 × 15.87 cm
Weight Including Housing	Included in data recorder weight	7.48 kg
Complete System Overview		
Depth Rating	1000 m	500 m
Total Weight	48.99 kg	29.43 kg
Overall Dimensions (excluding rigging)	55.88 × 45.72 × 121.92 cm	46.99 × 21.59 × 102.49 cm

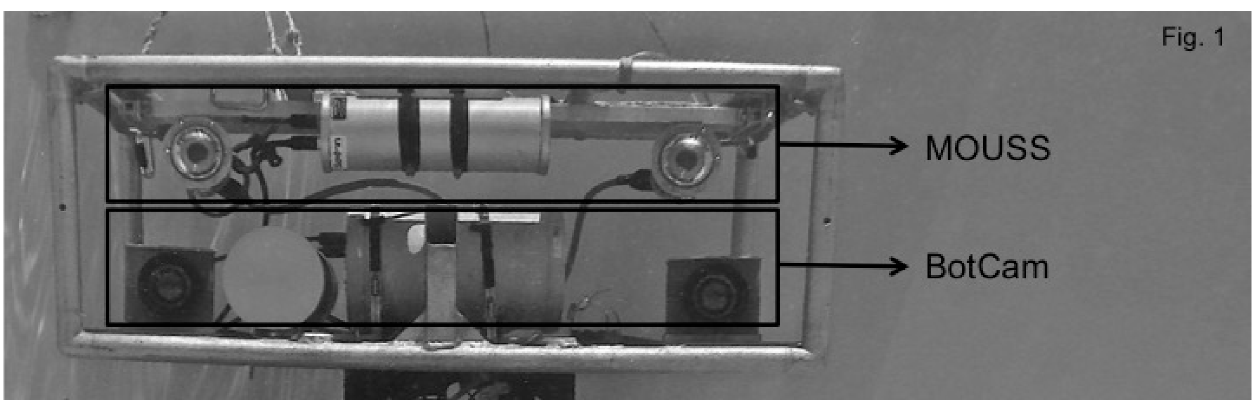

Figure 1. The BotCam-MOUSS tandem camera system configuration as used during the 2017 Deep-7 bottomfish survey of the main Hawaiian Islands from October 14 to November 3, 2016.

Results

Fish were observed in 14 of the 23 comparative BotCam-MOUSS tandem system deployments. Locations and ancillary data for these 14 deployments are provided in Table 2. There were no differences in the number of fish species recorded from both camera systems in 12 of the 14 camera drops in which fish were observed (Table 3). The first of the two differences in species counts was a result of a more specific taxonomic identification in the MOUSS footage that led to an added species (20161030_181404; 175 m). The second occurred in a 250-m deployment (20161101_215424) where BotCam recorded two species (*Antigonia* sp. and *Etelis carbunculus*), but MOUSS footage was too dark to identify any fish (Table 3). In general, MOUSS footage yielded more specific fish identifications for some reef fish compared to BotCam (e.g., BotCam—*Naso* sp.; MOUSS—*Naso hexacanthus*).

Over a combined 48 paired observations, human analysts were able to resolve a mean abundance (mean MaxN) of 12.6 ± 6.2 (SE) from BotCam video footage compared to 13.5 ± 6.9 from MOUSS imagery. Two notable outliers included a school of *Lutjanus kasmira*, where analysts recorded 210 from BotCam vs. 220 from MOUSS (4.5% greater abundance), and a group of *Symphysanodon* sp., where analysts recorded a MaxN of 220 from BotCam vs. 260 from MOUSS (15% greater abundance). With these outliers removed, mean MaxN dropped to 3.8 ± 0.6 (BotCam) and 3.6 ± 0.6 (MOUSS), respectively. Of the 48 BotCam-MOUSS paired abundance comparisons, 42 were identical, i.e., zero difference in counts between the two methods. Absolute differences, with the inclusion of schooling outliers, were |1.2| ± 5.9 (SD), and when schooling outliers were removed, the mean difference was further reduced to |0.2| ± 0.6, with 91% of paired BotCam-MOUSS deployments recording the same number of fishes. There was no indication of bias between methods as the standardized difference (MOUSS-BotCam/average of counts) was −4% ± 14% (95% CI), which strongly overlaps zero. Species detection using MOUSS and BotCam had a 93.8% similarity, with the mean difference in species encounters recorded at 0.06 ± 0.07. This difference was a result of the four *Etelis carbunculus* and one *Antigonia* sp. that were detected in one BotCam deployment and not observed within MOUSS imagery, and the single *Pristipomoides filamentosus* that was observed in MOUSS imagery but was not observed within paired BotCam footage.

A total of 54 fish individuals with an ideal measurement orientation (head and tail visible with straight body) were measured in both BotCam and MOUSS recordings (Table 4). These included six Lutjanid species (*Pristipomoides filamentosus*, *P. sieboldii*, *Aphareus rutilans*, *A. furca*, *Etelis carbunculus*, *Lutjanus kasmira*), five Carangids (*Seriola dumerili*, *S. rivoliana*, *Caranx ignobilis*, *C. melampygus*, *Carangoides orthogrammus*), a single wrasse species (*Bodianus albotaeniatus*), and one Serranid (*Odontanthias fuscipinnis*). Differences in length measurements ranged from 0.02 mm to 113.32 mm, with a mean length discrepancy of 19.86 mm. On average, length measurements from BotCam were higher (+ 6.25 mm) than those from MOUSS. Differences in precision ranged from 0.01 mm to 30.31 mm, with a mean precision discrepancy of 2.26 mm. On average, MOUSS allowed for greater measurement precision (by 1.56 mm) compared to BotCam. For both BotCam and MOUSS, measurement precision decreased as the distance to fish target increased (Table 4; Figure 2).

While close measurement alignments between BotCam (mean 525.3 ± 30.8 SE) and MOUSS (519.3 ± 30.0) were found across the 54 lengths measurements generated, only *S. rivoliana* (n =

21) and *L. kasmira* (n = 10) recorded the minimum number required for direct comparisons, with *S. rivoliana* (BotCam: 706.5 ± 15.0; MOUSS: 692.9 ± 13.3) and *L. kasmira* (BotCam: 242.5 ± 5.6; MOUSS: 243.9 ± 6.7) being generally similar. There were no significant differences in standardized length distributions between BotCam and MOUSS, i.e., no indication of skewing or kurtosis biases between methods (Langlois et al. 2012), and thus it was appropriate to compare mean lengths. As such, KDE comparisons remained non-significant ($P > 0.05$) for all shape and location tests.

Table 2. BotCam-MOUSS tandem system deployment locations and ancillary data for 14 deployments in which fish were observed from camera deployments around the main Hawaiian Islands between October and November 2016.

Deployment ID (yyyymmdd_hhmmss)	Latitude	Longitude	Depth (m)
20161014_192048	20° 41.711	156° 43.645	150
20161025_220505	21° 47.127	160° 10.023	165
20161026_225548	21° 52.867	159° 36.537	117
20161027_195244	20° 57.526	157° 30.638	86
20161027_221058	20° 56.247	157° 32.149	222
20161028_233052	19° 47.768	156° 06.223	147
20161029_235715	19° 29.758	155° 58.727	210
20161030_181404	19° 11.035	155° 55.000	175
20161030_194035	19° 10.148	155° 55.243	226
20161101_215424	19° 38.613	154° 56.754	250
20161101_231656	19° 39.379	154° 57.037	230
20161102_231017	20° 45.542	155° 57.199	227
20161103_181851	21° 01.569	157° 01.260	180
20161103_202523	20° 59.635	157° 01.577	206

Table 3. Relative abundance (MaxN) of all fish species observed within a 15-min camera bottom time from BotCam-MOUSS tandem system deployments around the main Hawaiian Islands between October and November 2016.

Deployment ID	Species ID	BotCam MaxN	MOUSS MaxN
20161014_192048	*Pristipomoides filamentosus*	8	8
20161014_192048	*Seriola rivoliana*	2	2
20161025_220505	*Hyporthodus quernus*	1	1
20161025_220505	*Seriola rivoliana*	1	1
20161025_220505	*Lutjanus kasmira*	210	220
20161025_220505	*Bodianus albotaeniatus*	2	2
20161025_220505	*Naso* sp. / *Naso hexacanthus*	13	13
20161025_220505	*Naso brevirostris*	1	1
20161025_220505	*Chaetodon* sp.	2	2
20161025_220505	*Forcipiger* sp.	2	2
20161025_220505	*Chromis verater*	12	12
20161025_220505	*Symphysanodon* sp.	15	15
20161025_220505	*Xanthichthys caeruleolineatus*	2	2
20161025_220505	*Zanclus cornutus*	3	3
20161025_220505	*Caranx melampygus*	3	3
20161025_220505	*Caranx ignobilis*	1	1
20161025_220505	*Aprion virescens*	1	1
20161026_225548	*Aphareus rutilans*	1	1
20161026_225548	*Seriola rivoliana*	6	6
20161026_225548	*Symphysanodon* sp.	220	260
20161027_195244	*Carangoides orthogrammus*	2	2
20161027_195244	*Seriola rivoliana*	1	1
20161027_221058	*Seriola dumerili*	1	1
20161028_233052	*Pristipomoides filamentosus*	2	2
20161029_235715	*Seriola rivoliana*	2	2
20161029_235715	*Odontanthias elizabethae*	4	4
20161029_235715	*Symphysanodon* sp.	15	15
20161030_181404	*Etelis carbunculus*	2	2

Deployment ID	Species ID	BotCam MaxN	MOUSS MaxN
20161030_181404	*Pristipomoides sieboldii*	13	12
20161030_181404	*Pristipomoides filamentosus*	0	1
20161030_181404	*Odontanthias fuscipinnis*	3	3
20161030_181404	Anguilliform / *Gymnothorax* sp.	1	1
20161030_194035	*Pristipomoides sieboldii*	8	8
20161030_194035	*Pristipomoides zonatus*	1	1
20161030_194035	*Seriola rivoliana*	1	1
20161030_194035	*Mulloidichthys pfluegeri*	4	4
20161030_194035	*Roa* sp.	1	1
20161030_194035	*Odontanthias elizabethae*	12	12
20161101_215424	*Etelis carbunculus*	4	0
20161101_215424	*Antigonia* sp.	1	0
20161101_231656	*Etelis carbunculus*	1	1
20161101_231656	*Seriola rivoliana*	1	1
20161101_231656	*Chromis* sp.	2	2
20161101_231656	*Symphysanodon* sp.	8	8
20161102_231017	*Pristipomoides filamentosus*	3	3
20161102_231017	*Seriola rivoliana*	2	2
20161103_181851	Shark	2	2
20161103_202523	Shark	1	1

Table 4. Fork length, measurement precision, and range values of 54 fish individuals generated from BotCam and MOUSS imagery. Mean range is the average distance to a fish target derived from both systems. Negative (−) ∆ length values indicate lower length measurements in BotCam while negative (−) ∆ precision values indicate better measurement precision in BotCam.

			BotCam		MOUSS		∆	
Deployment ID	Species ID	Mean range	Length (mm)	Precision (mm)	Length (mm)	Precision (mm)	Length (mm)	Precision (mm)
20161014_192048	*P. filamentosus* 1	968.86	531.49	2.57	535.82	2.51	−4.33	0.06
20161014_192048	*P. filamentosus* 2	1306.92	511.31	3.48	500.17	3.08	11.13	0.41
20161014_192048	*P. filamentosus* 3	1205.48	482.06	3.36	475.24	2.75	6.81	0.61
20161014_192048	*P. filamentosus* 4	996.34	540.54	2.58	538.58	2.28	1.96	0.30
20161014_192048	*P. filamentosus* 5	710.83	430.94	1.87	445.84	1.58	−14.90	0.29
20161014_192048	*P. filamentosus* 6	718.64	532.86	1.87	514.87	1.71	17.99	0.15
20161014_192048	*S. rivoliana* 1	4666.10	786.16	42.55	757.11	26.10	29.05	16.46
20161025_220505	*A. virescens* 1	4474.67	716.43	21.89	603.11	18.47	113.32	3.42
20161025_220505	*B. albotaeniatus* 1	3159.39	399.43	21.29	404.95	22.03	−5.52	−0.74
20161025_220505	*C. ignobilis* 1	3704.91	1061.19	48.30	999.56	46.35	61.63	1.95
20161025_220505	*C. melampygus* 1	2878.83	554.54	17.32	575.93	19.29	−21.39	−1.97
20161025_220505	*L. kasmira* 1	918.75	206.17	2.82	205.11	2.14	1.05	0.68
20161025_220505	*L. kasmira* 2	1419.18	246.98	4.25	249.04	3.17	−2.06	1.08
20161025_220505	*L. kasmira* 3	1072.78	241.24	4.41	223.66	3.35	17.58	1.07
20161025_220505	*L. kasmira* 4	1401.95	232.10	6.18	243.25	5.71	−11.15	0.47
20161025_220505	*L. kasmira* 5	1112.95	261.59	5.07	285.66	5.06	−24.07	0.01
20161025_220505	*L. kasmira* 6	1171.50	247.39	3.60	244.27	3.24	3.12	0.36
20161025_220505	*L. kasmira* 7	1146.33	225.91	3.93	233.83	3.64	−7.92	0.29
20161025_220505	*L. kasmira* 8	871.15	240.49	2.45	242.13	2.08	−1.64	0.37
20161025_220505	*L. kasmira* 9	919.89	257.53	2.63	253.90	2.45	3.62	0.18
20161025_220505	*L. kasmira* 10	1365.68	265.36	4.80	257.72	3.54	7.64	1.27
20161025_220505	*S. dumerili* 1	2293.56	996.93	20.09	1016.94	19.42	−20.00	0.67

Deployment ID	Species ID	Mean range	BotCam Length (mm)	BotCam Precision (mm)	MOUSS Length (mm)	MOUSS Precision (mm)	Δ Length (mm)	Δ Precision (mm)
20161025_220505	*S. rivoliana* 1	3109.69	806.96	14.45	796.57	10.70	10.40	3.75
20161026_225548	*A. rutilans* 1	2649.45	854.67	17.82	815.79	14.82	38.88	3.00
20161026_225548	*S. rivoliana* 1	3072.92	632.58	30.45	632.61	30.47	−0.02	−0.02
20161026_225548	*S. rivoliana* 2	2815.36	691.49	23.13	703.96	25.59	−12.46	−2.46
20161026_225548	*S. rivoliana* 3	2467.37	665.50	16.49	689.60	12.20	−24.09	4.29
20161026_225548	*S. rivoliana* 4	2577.07	619.41	14.04	627.23	18.04	−7.82	−4.00
20161026_225548	*S. rivoliana* 5	3095.54	731.82	29.89	711.10	30.83	20.72	−0.94
20161026_225548	*S. rivoliana* 6	2913.29	612.81	28.60	668.51	31.56	−55.70	−2.96
20161026_225548	*S. rivoliana* 7	3660.92	738.77	51.34	661.07	41.92	77.70	9.42
20161026_225548	*S. rivoliana* 8	3500.81	701.54	63.85	700.79	33.54	0.75	30.31
20161026_225548	*S. rivoliana* 9	3036.75	692.27	30.41	601.86	31.63	90.41	−1.21
20161026_225548	*S. rivoliana* 10	3177.48	697.86	38.21	727.95	39.44	−30.09	−1.23
20161026_225548	*S. rivoliana* 11	2786.72	667.26	25.61	660.14	25.74	7.12	−0.13
20161026_225548	*S. rivoliana* 12	2583.27	655.22	16.92	633.58	15.10	21.64	1.82
20161026_225548	*S. rivoliana* 13	2062.87	609.06	6.53	620.62	7.33	−11.55	−0.80
20161027_195244	*C. orthogrammus* 1	1802.90	421.44	11.24	414.53	10.81	6.91	0.43
20161027_195244	*S. rivoliana* 1	1741.45	812.36	7.33	810.62	6.87	1.74	0.46
20161028_233052	*P. filamentosus* 1	3490.71	685.12	23.28	687.72	14.81	−2.60	8.47
20161029_235715	*S. rivoliana* 1	2003.79	697.57	15.20	636.99	10.66	60.58	4.54
20161029_235715	*S. rivoliana* 2	1940.97	696.36	9.24	735.11	9.40	−38.75	−0.16
20161030_181404	*A. furca* 1	2886.18	542.19	14.90	539.21	14.58	2.98	0.32
20161030_181404	*E. carbunculus* 1	2286.34	300.15	19.92	341.03	17.65	−40.88	2.27
20161030_181404	*O. fuscipinnis* 1	1232.75	159.63	3.43	164.55	2.96	−4.91	0.48
20161030_181404	*O. fuscipinnis* 2	1270.12	161.98	4.17	167.80	3.14	−5.83	1.03
20161030_181404	*P. filamentosus* 1	799.22	377.49	2.01	363.86	3.60	13.63	−1.60

Deployment ID	Species ID	Mean range	BotCam Length (mm)	BotCam Precision (mm)	MOUSS Length (mm)	MOUSS Precision (mm)	Δ Length (mm)	Δ Precision (mm)
20161030_181404	*P. sieboldii* 1	1510.46	395.63	4.36	380.43	3.55	15.20	0.81
20161030_181404	*P. sieboldii* 2	980.73	333.23	3.00	289.36	3.79	43.87	−0.79
20161030_181404	*P. sieboldii* 3	1634.71	343.27	4.68	347.70	4.65	−4.43	0.03
20161030_194035	*P. sieboldii* 1	1930.99	343.90	9.64	334.62	9.58	9.28	0.06
20161030_194035	*P. sieboldii* 2	1830.53	295.24	8.42	287.17	8.09	8.08	0.33
20161030_194035	*S. rivoliana 1*	1158.97	691.74	4.42	706.12	3.27	−14.38	1.15
20161102_231017	*S. rivoliana* 1	1128.49	775.58	3.33	776.62	3.12	−1.04	0.22
						Mean:	**6.25**	**1.56**

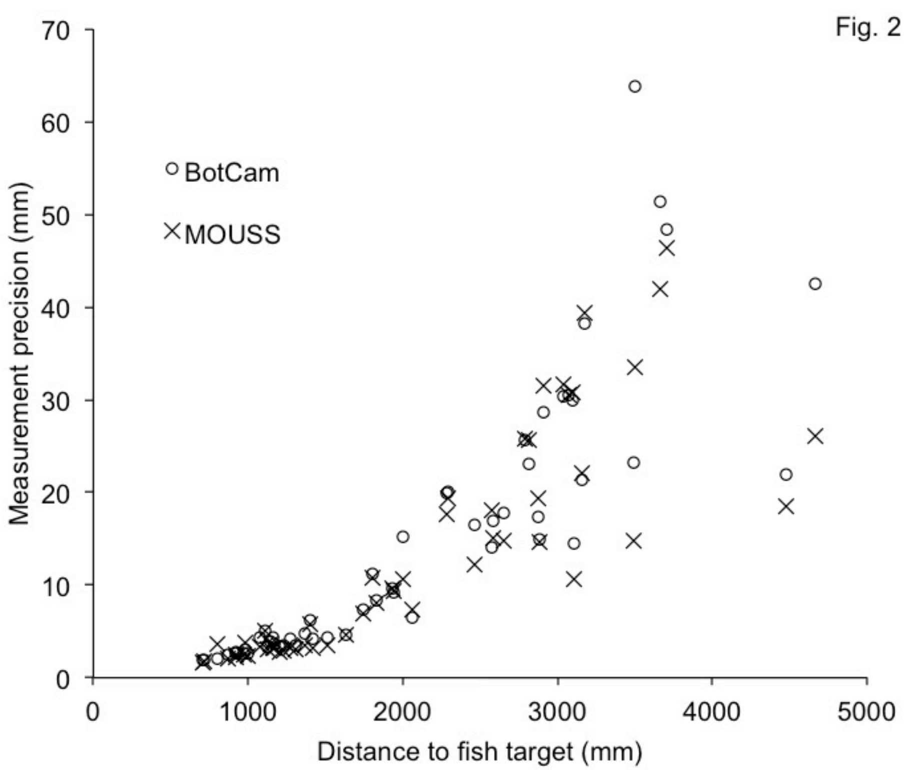

Figure 2. BotCam and MOUSS measurement precision values relative to distance of 54 fish targets collected during the 2017 Deep-7 bottomfish survey of the main Hawaiian Islands from October 14 to November 3, 2016.

Discussion

Continuity of bottomfish species richness, relative abundance, and length measurement data streams between BotCam and MOUSS are achievable given the lack of significant differences amongst these stereo-camera metrics when comparing camera systems. This result shows that, at minimum, the MOUSS is able to match the bottomfish data benchmark set by BotCam. However, coupled with its potential for higher sampling yield given a smaller overall form-factor and more precise data from superior imagery, the MOUSS can surpass BotCam outputs using the same sampling methodologies. With the BotCam's prior history of use at PIFSC in gathering bottomfish assemblage data, a continuity of data streams with the upgraded MOUSS is ideal in that analyses involving historical bottomfish data sets.

Better clarity and object definition in MOUSS imagery were among the strengths of this system (Figure 3). They allowed for more specific taxonomic identifications of some of the fish encountered, as morphological characteristics were discernable in the MOUSS imagery (e.g., from camera deployment 20161030_181404, distinct dark margins of the *Pristipomoides filamentosus* dorsal and caudal fins that were visible in MOUSS imagery allowed for this individual to be identified amongst a school of *Pristipomoides sieboldii*, but the same individual could not be identified using BotCam footage). Furthermore, the well-defined outlines of fish targets allowed for more accurate point placement during the measurement process that led to better measurement precision values compared to BotCam. Given the greater image resolution of MOUSS (1936 × 1456) compared to BotCam (720 × 480), these results were anticipated with the move from an analog to digital camera system.

The auto-adjustability of the BotCam's Navigator cameras was its main advantage over MOUSS (Amin 2017). Capturing footage of target species towards the deeper end of the sampling range (200 m to 300 m) is crucial in bottomfish research as species, such as *Etelis carbunculus* and *Etelis coruscans,* have been found to primarily occupy these depths (Misa et al. 2013). Adjustments to camera exposure settings and post-collection image enhancement are options applicable to the MOUSS that may alleviate its current light limitation at greater depths. However, further tests on camera light sensitivity relative to field conditions should also be investigated, as time of day, turbidity, and atmospheric conditions tend to affect the ability to capture camera imagery at depth. Furthermore, since MOUSS camera settings are fixed and not auto-adjusting, different camera settings for shallow and deep deployments should be looked into and utilized as a single camera setting for MOUSS may not allow for efficient sampling of the entire target bottomfish depth range.

As both BotCam and MOUSS are reliant on ambient light, sampling at depths in excess of 300 m or sampling at night using these systems is currently not feasible. The use of acoustic imaging systems (e.g., BlueView; Didson) is a possible means to overcome the light limitation when using optics. However, the effective survey range and the ability to accurately identify and size fish targets in multi-species assemblages have yet to be determined. With some target bottomfish species residing at depths beyond stereo-camera ambient light limits in Hawaii (300 m to 400 m; Kelley and Moriwake 2012) and a good portion of commercial bottomfishing operations occurring at night, the use of artificial lighting that does not alter fish behavior in low-light environments as well as other alternatives to optics for sampling fish assemblages should be studied further.

Technological advancements provide avenues for upgrading underwater camera systems such as those used in surveys of bottomfish in Hawaii. In this study, the move from the analog BotCam system to the digital MOUSS improved species identification capabilities and measurement precision through better image quality while maintaining the same level of species detection and relative abundance estimates. However, further fine-tuning of the low-light settings of the MOUSS are still necessary to match the performance of BotCam in low-light conditions and enable sampling at greater depths (250 m to 300 m) provided that environmental conditions are favorable. With its ability to generate more accurate data on bottomfish assemblages, the MOUSS can enhance camera survey capabilities and improve on the previous data quality benchmark set by BotCam.

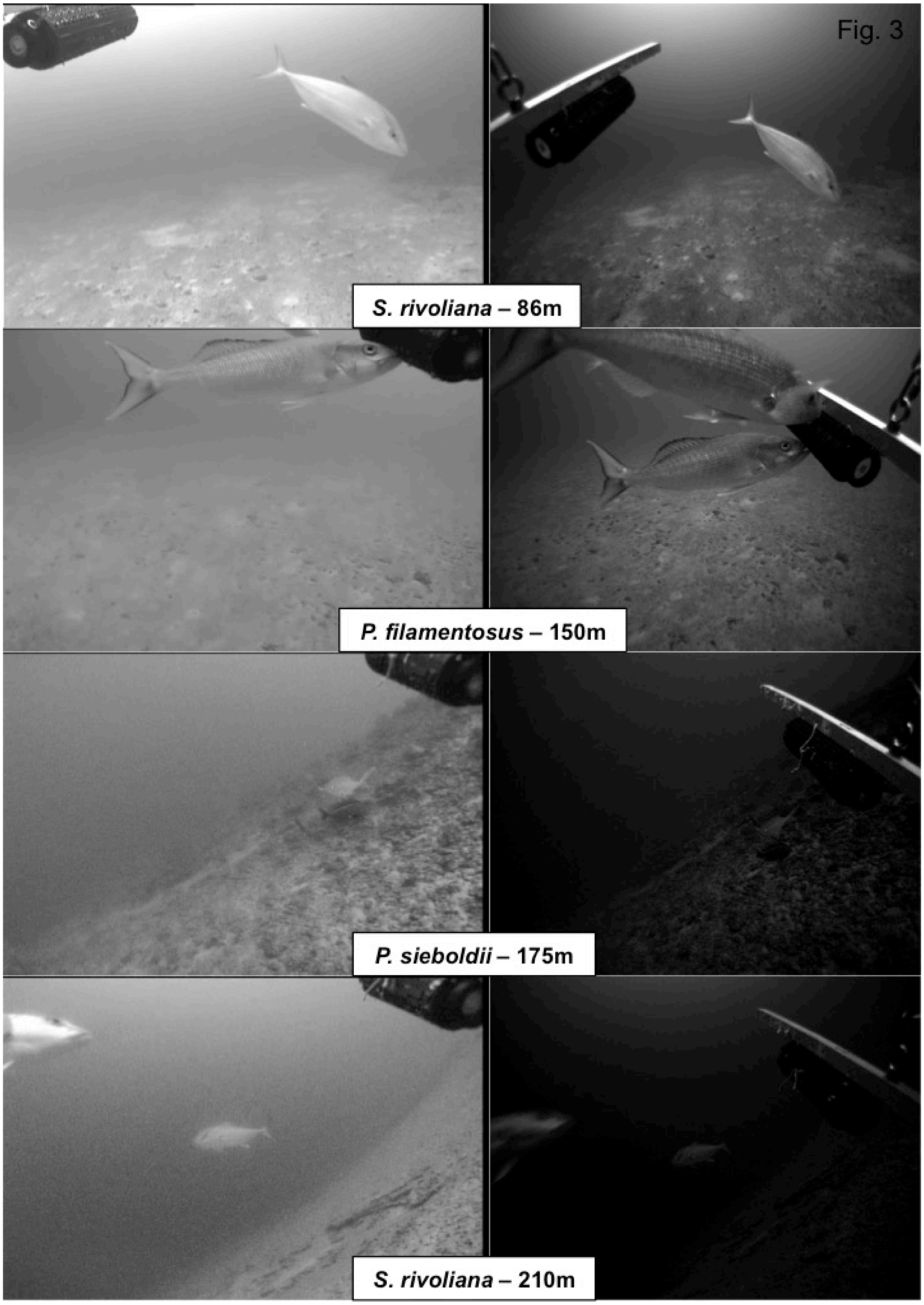

Figure 3. Sample image comparisons of bottomfish recorded on BotCam (left) and MOUSS (right) at different sampling depths during the 2017 Deep-7 bottomfish survey of the main Hawaiian Islands from October 14 to November 3, 2016. Bottomfish species presented include *Seriola rivoliana*, *Pristipomoides filamentosus*, and *Pristipomoides sieboldii*.

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