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Evaluating the effect of soak time on bottomfish abundance and length data from stereo-video surveys

William F.X.E. Misa [a,*], Benjamin L. Richards [b], Gerard T. DiNardo [b], Christopher D. Kelley [c], Virginia N. Moriwake [d], Jeffrey C. Drazen [d]

[a] Joint Institute for Marine and Atmospheric Research, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, 1000 Pope Rd., Marine Science Bldg. 312, Honolulu, HI 96822, USA
[b] Fisheries Research and Monitoring Division, Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA, 1845 Wasp Blvd., Bldg. 176, Honolulu, HI 96818, USA
[c] Hawaii Undersea Research Laboratory, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, 1000 Pope Rd., Marine Science Bldg. 303, Honolulu, HI 96822, USA
[d] Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, 1000 Pope Rd., Marine Science Bldg. 205, Honolulu, HI 96822, USA

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ABSTRACT

Baited stereo-camera surveys of fish assemblages provide conservative estimates of abundance and length-frequency distributions. While underwater camera systems have numerous advantages over traditional fishing and diver surveys, limitations in sampling capacity, data processing time, and resultant data still exist. Previous studies have shown that shorter camera soak times can increase sampling efficiency and reduce per-sample data processing time without affecting overall data quality. Using data from stereo-video surveys of bottomfish in the main Hawaiian Islands, this study evaluates the effect of camera soak time on relative abundance metrics, fish length data, sampling efficiency, and power to detect differences in relative abundance and fish lengths. A soak time of 15 min was found to be the shortest duration able to capture bottomfish abundance and length metrics while 30 min generated data that did not significantly differ from the standard 40-min soak time. These shorter soak times allow for better survey efficiency and improved cost–benefit through increased levels of field sampling and reductions in video-processing time, while maintaining the power to detect differences in bottomfish relative abundance and lengths. The main drawback to shortening soak time was the concurrent reduction in the number of length measurements collected per species. An increased sample yield can alleviate this effect but only for bottomfish with a higher frequency of occurrence. Species-specific patterns in abundance were apparent in this study suggesting a strong influence of fish behavior on stereo-video abundance metrics. While a soak time of 15 to 30 min was found to be sufficient for effectively sampling bottomfish, the cost–benefit of employing a given soak time in future stereo-video surveys should be assessed based on the target species and survey goals.

1. Introduction

The emergence of underwater video-survey techniques in fisheries science has given researchers the ability to move beyond fishery-dependent data and reduce some of the restrictions of depth, habitat, and fish behavior inherent to diver and fishing surveys (Cappo et al., 2007). By generating standardized species-specific estimates of fish abundance that have been found to positively correlate with fish density (Ellis and DeMartini, 1995; Priede and Merrett, 1996; Willis et al., 2000; Willis and Babcock, 2000; Yau et al., 2001; Cappo et al., 2003; Stoner et al., 2008), baited camera systems have proven to be a valuable tool in spatial (e.g. Westera et al., 2003; Moore et al., 2013), temporal (e.g. Denny et al., 2004; Sackett et al., 2014), and ecological (e.g. Gledhill et al., 2005; Misa et al., 2013) surveys of fish assemblages. Furthermore, underwater camera systems offer a non-extractive alternative to traditional research fishing methods, which make them ideal for studying marine protected areas (e.g. Cappo et al., 2003; Willis et al., 2003; Sackett et al., 2014) and conducting monitoring programs (Murphy and Jenkins, 2010).

While stereo-camera systems offer a number of advantages over fishery-dependent or other extractive sampling techniques (Cappo et al., 2007) and allow for sampling beyond normal diver depths (Langlois et al., 2010), limitations exist in the methodology, data processing, and resultant data. Until advances in automated image processing (Shortis et al., 2013) facilitate its regular use on a broader scale, the time requirement for data processing remains a major consideration. The majority of video data processing is currently done by means of human analysts (Somerton and Gledhill, 2005; Lee et al., 2008), and the increasing volume of image data commonly exceeds analyst capabilities. To be useful in regular stock assessments and fishery studies, a faster turn-around from video data collection to numeric data output

* Corresponding author.
E-mail address: william.misa@noaa.gov (W.F.X.E. Misa).

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is necessary. As data processing time is proportional to video duration (Cappo et al., 2007), shortening video recordings by decreasing camera soak time has been proposed as a straightforward approach to reduce per-sample data processing time. This approach assumes no significant reduction in overall data quality as a result of shortened soak time. Therefore, an evaluation of abundance metrics with respect to camera soak time may reveal avenues for increased efficiency.

Fish relative abundance has been analyzed against soak time in previous baited underwater video studies to look into species accumulation rates (Willis and Babcock, 2000; Stobart et al., 2007; Haratsi et al., 2015) and differences in abundance at various set times (Stobart et al., 2007; Gladstone et al., 2012; Haratsi et al., 2015). From these studies, it can be inferred that a camera soak time between 15 and 30 min is sufficient for collecting relative densities of shallow-water reef fish. Bottomfish species in the families *Lutjanidae*, *Serranidae*, and *Carangidae* are the main focus of this study. While these fish have a broad Indo-Pacific distribution, they are more prominent at mesophotic depths (100–400 m; Kelley and Moriwake, 2012) and exhibit distribution patterns that differ from their shallow-water cogeners. An assessment of how abundance metrics change with camera soak time has yet to be published for bottomfish species.

Accurate and consistent methods to estimate species-specific size-structured abundance are critical for effective fisheries management (Costa et al., 2006; Lee et al., 2008). Stereo-video systems are able to sample a wider range of fish sizes compared to experimental fishing surveys due to the absence of hook selectivity (Langlois et al., 2012) and can be conducted at depths greater than that attainable in diver surveys (Langlois et al., 2010). Stereo-video metrics can also be coupled with habitat data (Moore et al., 2009; Moore et al., 2010) to provide additional information on a fish assemblage that, when paired with more traditional stock assessment metrics (e.g. catch per unit effort [CPUE]), can yield a more accurate representation of the status of a fish stock.

A recent study by Schobernd et al. (2014) suggested that the video abundance metric MeanCount has a linear relationship with true abundance. This type of data could substantially improve the stock assessment of given fish species, however, further evaluation on a species- and region-specific level is necessary. While the more commonly employed stereo-video relative abundance metric, MaxN, is used in the present study, the validity and cost–benefit of the MeanCount method in generating species-specific size-structured abundance of target bottomfish species will be assessed in future work.

The goal of this study is to evaluate differences in relative abundance metrics, fish length data, sampling efficiency, and data-processing costs at three different soak times by using video from bottomfish stereo-video surveys in the main Hawaiian Islands (Fig. 1). Furthermore, this study aims to provide an assessment of the effect of soak time on the statistical power to detect differences in relative abundance and length data.

2. Materials and methods

2.1. BotCam

The bottom camera bait station (BotCam) is a baited stereo-video camera system developed by Merritt (2005) to collect species-specific size-structured abundance information for commercially important Hawaiian deep slope bottomfish populations. This system has proven effective in recording bottomfish species in their habitats across a variety bottom types and slopes at depths of 100–300 m (Merritt et al., 2011). BotCam is outfitted with two ROS Navigator™ ultra-low

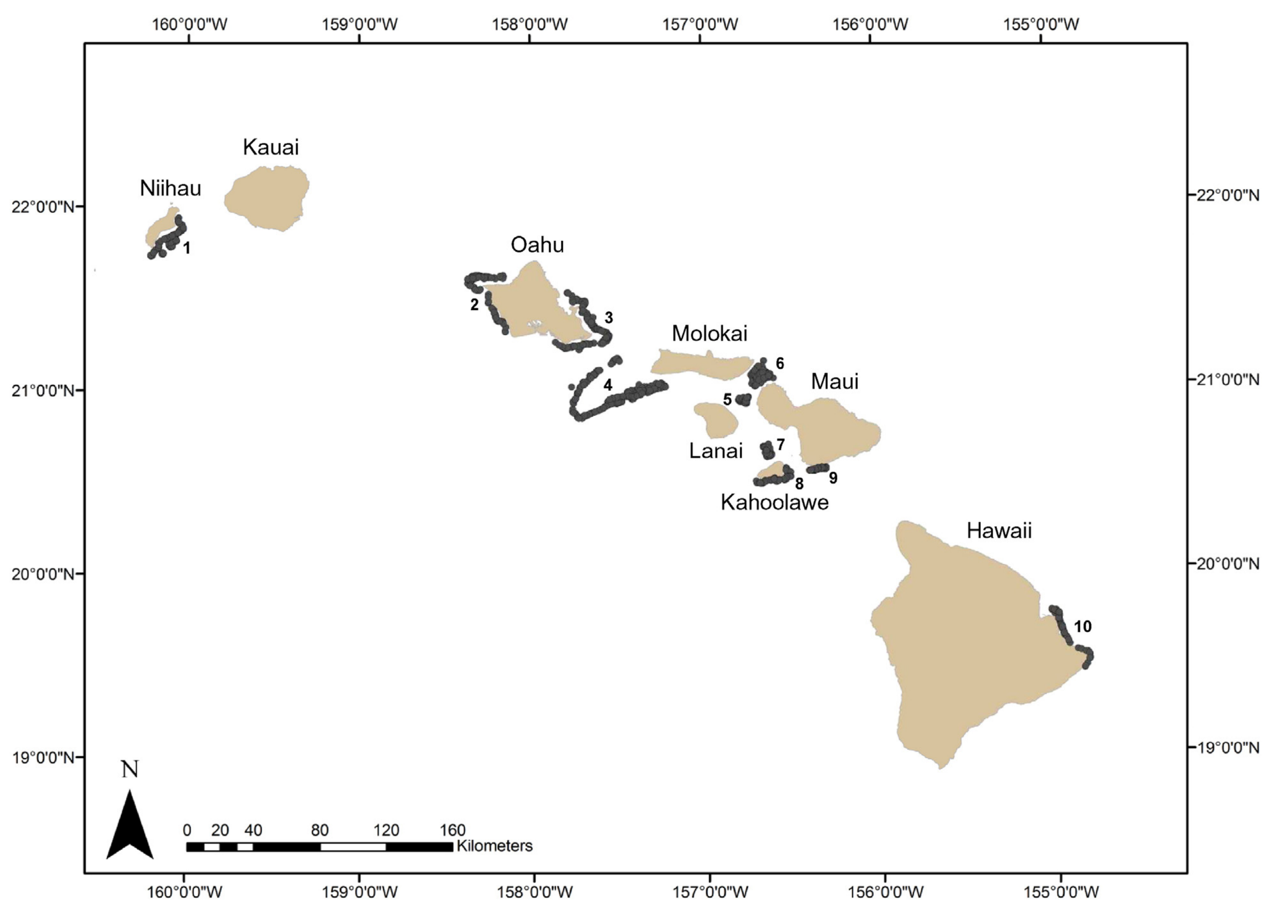


Fig. 1. Map of BotCam sampling regions in the main Hawaiian Islands: Niihau (1), West Oahu (2), East Oahu (3), Penguin Bank (4), Auau Channel (5), Pailolo Channel (6), Kealaikahiki Channel (7), Kahoolawe Island Reserve (8), Alenuihaha Channel (9), Hilo (10).

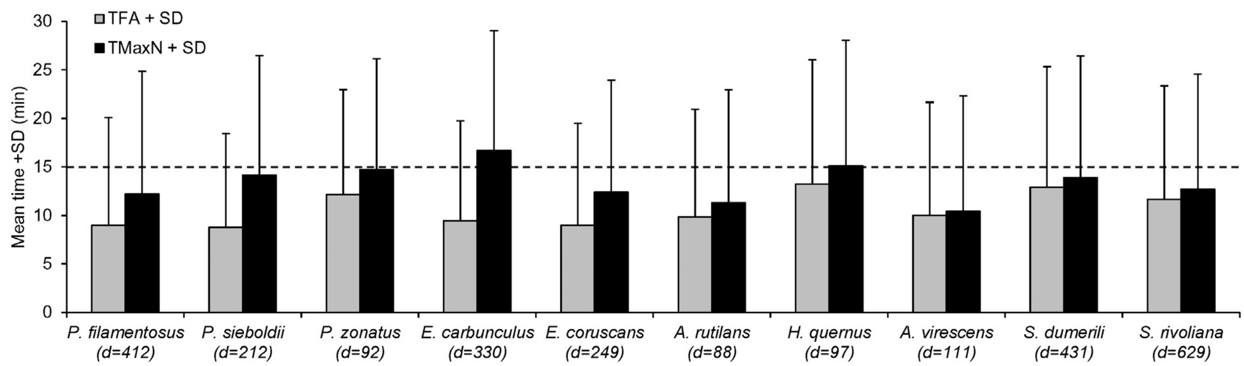


Fig. 2. Mean time of first arrival (TFA) and time to MaxN (TMaxN) for each of the 10 target species recorded from 1504 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2007 to 2013. d = no. of BotCam deployments where a species was present.

light cameras that can detect and record fishes to a depth of 300 m in Hawaiian waters without artificial light sources. An LED device is used to ensure synchronicity between the analog stereo camera pair. Video data are recorded by a dual channel digital video recorder with an average recording time of 45 min resulting in a total soak time of about 40 min (Moore et al., 2013; Misa et al., 2013; Sackett et al., 2014). An 800-g mixture of ground anchovies and squid is used to bait the BotCam as it mimics the traditional bait used by local fishermen (Merritt et al., 2011). Upon deployment, the BotCam floats about three meters above the seafloor, moored to the bottom by anchor weights, and tethered to surface buoys by a surface line. The BotCam is designed to orient itself horizontally down-current with a nominal downward angle of 15° to include the benthic habitat in the field of view (Merritt et al., 2011). Following recovery of the BotCam, video data are downloaded for subsequent analysis.

2.2. Field deployments and target species

A total of 1504 BotCam deployments spanning six years of sampling (2007–2013) in 10 geographic regions around the main Hawaiian Islands (Niihau, West Oahu, East Oahu, Penguin Bank, Auau Channel, Pailolo Channel, Kealaikahiki Channel, Kahoolawe Island Reserve, Alenuihaha Channel, Hilo; Fig. 1) were available for this study. Of the 93 fish species observed, 10 target species were selected on the basis of high commercial value and/or high local abundance. The target list includes the Crimson Jobfish (*Pristipomoides filamentosus*), Lavender Jobfish (*Pristipomoides sieboldii*), Oblique-banded Snapper (Gindai, *Pristipomoides zonatus*), Deep-water Red Snapper (*Etelis carbunculus*), Deep-water Long-tail Red Snapper (*Etelis coruscans*), Rusty Jobfish (*Aphareus rutilans*), Hawaiian Grouper (*Hyporthodus quernus*), Green Jobfish (*Aprion virescens*), Greater Amberjack (*Seriola dumerili*), and Almaco Jack (*Seriola rivoliana*). The Snappers, *P. filamentosus*, *E. coruscans*, and *E. carbunculus* are the top three bottomfish commercially harvested in the main Hawaiian Islands both in terms of total landings and commercial value (WPRFMC, 2011). Along with these three species, *P. sieboldii*, *P. zonatus*, *A. rutilans*, and *H. quernus* make up the commercially harvested Deep 7 bottomfish complex. Despite not being one of the Deep 7, *A. virescens*, is also harvested regularly in the main Hawaiian Islands (WPRFMC, 2011). Although *S. dumerili* and *S. rivoliana* are no longer of high value in Hawaii's bottomfish fishery, they are highly abundant (Moore et al., 2013), are ecologically important predators (Humphreys and Kramer, 1984), and are considered among the more important by-catch species in the fishery (WPRFMC, 1998).

2.3. Video processing

BotCam video was annotated for fish time of first arrival (TFA), relative abundance (MaxN), time to MaxN (TMaxN), and fork lengths (FL). Each fish observed was identified to the most specific taxonomic level (Randall, 2007). As used in this study and previous baited camera work, MaxN (MAXNO [Ellis and DeMartini, 1995], n_{peak} [Priede and Merrett, 1996], MAX [Willis et al., 2000], mincount [Gledhill et al., 2005]) is an estimator of fish abundance generated using the single highest count of a given fish species within the field of view at a single point in a video recording (Cappo et al., 2004). The time (in minutes) from camera touchdown to the time at which a fish species is first detected is TFA (Ellis and DeMartini, 1995) while TMaxN is the time (in minutes) from camera touchdown to the time at which MaxN is recorded. Using one of three stereo-photogrammetric software packages (Vision Measurement System™, Geomsoft, Victoria, Australia; PhotoMeasure™ or EventMeasure™, SeaGIS Pty. Ltd., Victoria, Australia), FL was measured at TMaxN (Willis and Babcock, 2000; Cappo et al., 2007; Merritt et al., 2011) or at another time in a

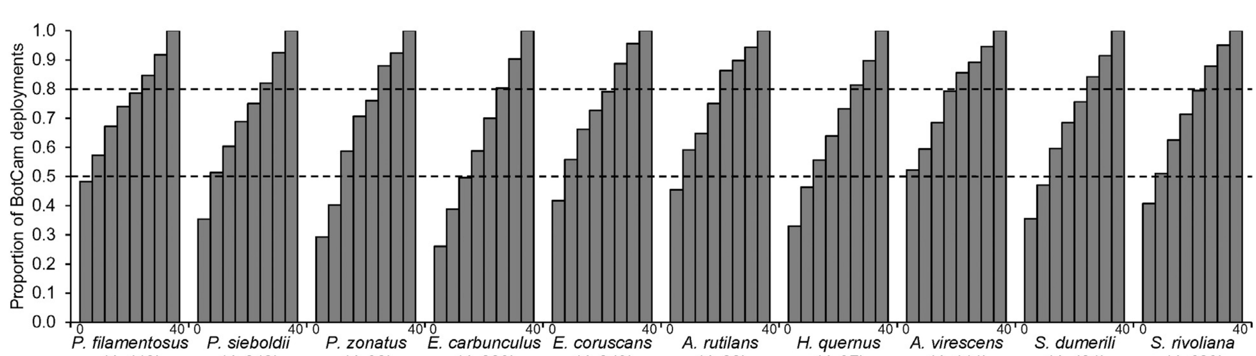


Fig. 3. Cumulative proportion of BotCam deployments where MaxN occurred by 5-min time bins from camera touchdown (minute 0) up to 40 min recorded from 1504 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2007 to 2013. d = no. of BotCam deployments where a species was present.

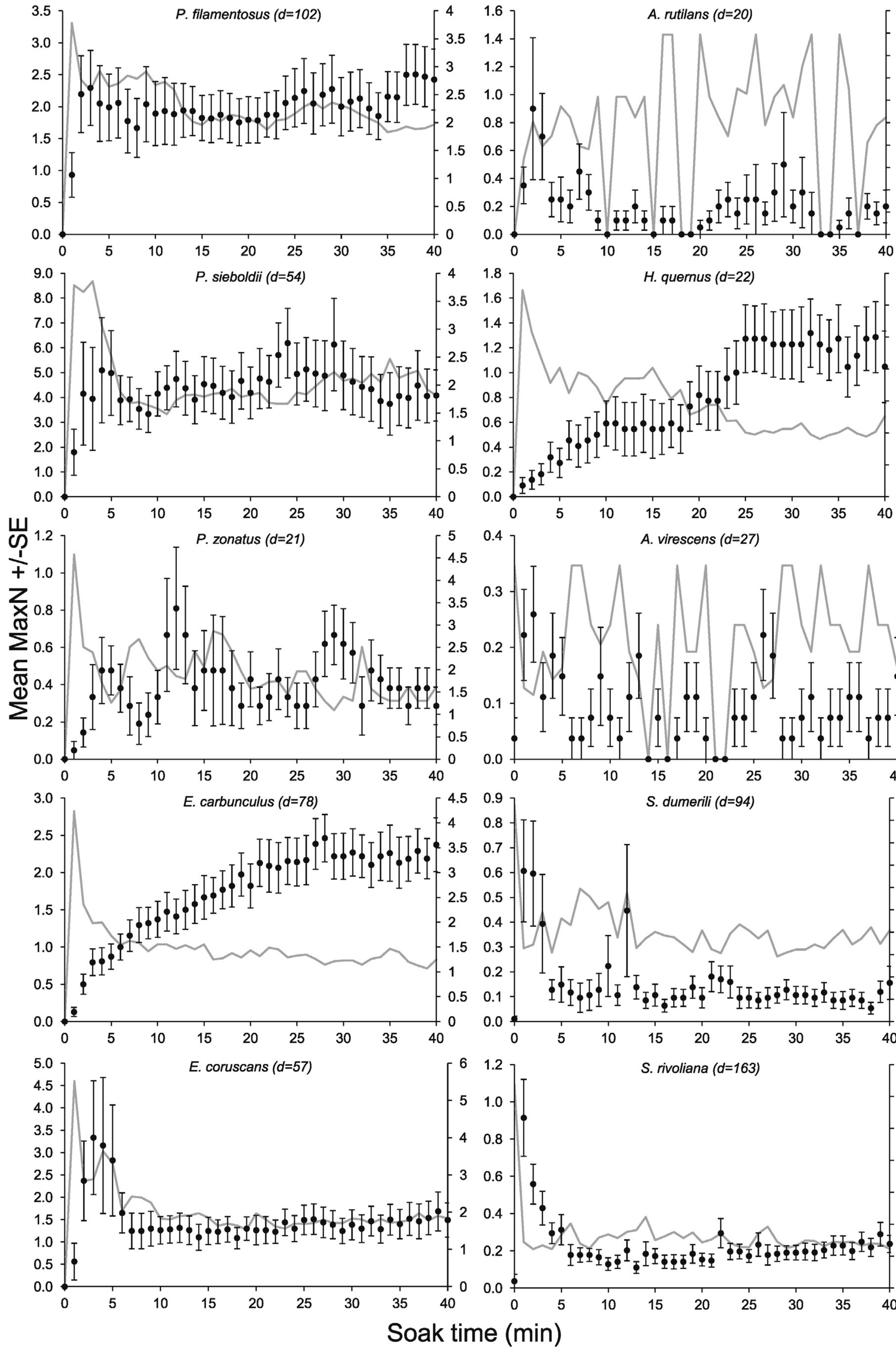


Fig. 4. Mean MaxN and coefficient of variation (CV) for each of the 10 target species by minute from time 0 to time 40. Data set was recorded from 378 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2007 to 2008. d = no. of BotCam deployments where a species was present. Note: MaxN scale varies by species.

video recording when the most fish of a given species were measureable (Moore et al., 2013; Misa et al., 2013; Sackett et al., 2014). To increase accuracy, five replicate measurements were taken per individual, when possible, and the mean was used as the representative length. Measurements with a root mean-square (RMS) error greater than 10 mm and a precision-to-FL ratio greater than 10% were discarded. In tests conducted by Merritt et al. (2011), measurements generated from video taken by the BotCam system were found accurate to within 0.3 to 0.9 cm of actual lengths of test targets. Stereo-camera pairs were calibrated pre-cruise and post-cruise following the calibration procedure in Shortis and Harvey (1998) and Harvey and Shortis (1998). Camera calibrations were processed using the software CAL™ (SeaGIS Pty. Ltd., Victoria, Australia) when either PhotoMeasure™ or EventMeasure™ was used for video annotation while both calibration and annotation were processed in the same software when using Vision Measurement System™.

2.4. Data analysis

For this study, "soak time" is defined as the amount of time, in minutes, from when the camera system touches bottom until the end of a predefined video-analysis duration. Initial evaluations of camera soak time examined TFA, TMaxN, and MaxN. Both TFA and TMaxN data were available for all 1504 BotCam deployments, but for any given species the number of records was considerably less because each has different depth and habitat preferences (Misa et al., 2013). For each of the 10 target species, a mean TFA (±SD) and mean TMaxN (±SD) were calculated for deployments where a target species was present. In using these two metrics, reduced soak times that could encompass both the TFA and TMaxN were identified for the species in question. Thus the cumulative frequency of BotCam deployments at which a species MaxN occurred within 5-min bins from camera touchdown (time 0) to 40 min was observed to determine how often TMaxN had been recorded at the reduced soak times.

To gain a more detailed insight into the influence of species-specific behavior on the MaxN metric, a time series of species-specific MaxN values was generated at 1-min intervals from 0 to 40 min. Given the significant time requirement associated with generating a minute-by-minute MaxN, only 378 BotCam deployments were annotated in this manner. For each 1-min time bin, MaxN values were averaged across all camera deployments where a given species was seen (Willis and Babcock, 2000; Stobart et al., 2007) and the coefficient of variation (CV) was calculated.

From the 1-min MaxN data set, mean MaxN was also calculated within nine time bins, which increased by 5-min increments (i.e., 0–5, 0–10, etc.), to simulate collecting MaxN data from varying set times. MaxN values at each 5-min time bin were again averaged over all camera deployments where a given species was seen. A pairwise permutational analysis of variance (PERMANOVA; Anderson et al., 2008) was used to assess differences in mean MaxN among the simulated soak times. MaxN values were square-root transformed and a Euclidian distance matrix was used with type-III sum of squares.

From the TFA and TMaxN analyses and MaxN indices, two soak times were selected for further testing: 15 and 30 min. MaxN and fish length data from the two reduced time intervals were generated and tested against each other and against count and length data at the original 40-min soak time from the same set of BotCam deployments. Species-specific MaxN values from 618 BotCam deployments and length data from 240 BotCam deployments generated at the three time intervals were compared using a PERMANOVA while differences in species-specific length-frequency distributions were evaluated using either Kolmogorov–Smirnov (KS) or Wilcoxon tests. Lastly, to evaluate the limitation in resulting length data from the current measurement methodology, species-level presence–absence length-frequency comparisons were made using an 84-deployment subset where lengths were also generated for all individuals encountered of a given target species.

2.5. Cost comparison

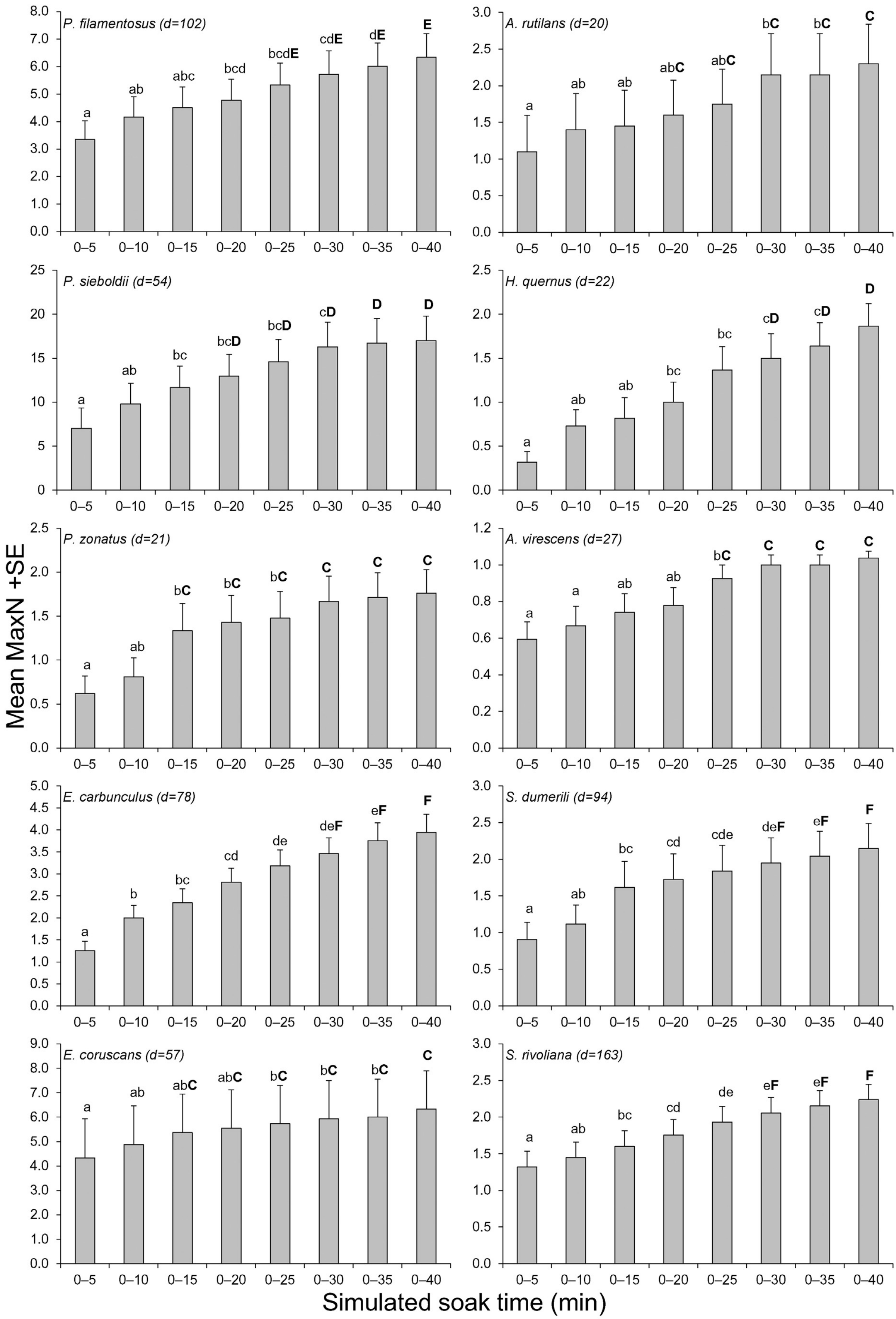
Shortening camera soak time in stereo-video sampling can have major implications on the number of video samples that can be collected during within a finite sampling period, the data-processing time for each sample, and the resulting monetary cost per sample. Comparisons between the per-sample costs associated with 15, 30, and 40-min BotCam soak times were made. Cost-per-sample considered both field deployment and data analysis costs based on a typical 10-day mission. It was expected that the reduction in soak time would result in an increase in video sample yield. Using three BotCam units, deployments with target soak times of 15 and 40 min were tested in three sampling regions (Auau Channel, Kealaikahiki Channel, Alenuihaha Channel) and the daily sample yields and video processing times were recorded. In addition, an estimate of the daily sample yield and video processing time at a soak time of 30 min was made. In calculating a cost per sample, vessel time, pre- and post-cruise mobilization, bait and other equipment, field staff time, daily sample yield, and video processing time were all taken into consideration. The cost of generating fish length measurements was also calculated using the cost per sample or cost per BotCam deployment and the total number of length measurements collected for all 10 target species from 240 BotCam deployments in the three sampling regions.

2.6. Power analysis

Characterizing and comparing fish assemblages inside and outside marine protected areas has been a major focus of stereo-video surveys (Cappo et al., 2003; Willis et al., 2003; Sackett et al., 2014). To determine how different soak times affect the ability to detect differences in fish abundance and lengths (e.g. inside and outside of closed zones), power analyses were carried out for *P. filamentosus*, *E. coruscans*, *E. carbunculus*, and *A. rutilans* using the GPower software package (Faul et al., 2009). Each species selected represents a unique accumulation pattern in the 1-min MaxN indices and the first three are among the most commercially-important harvested species.

From previous stereo-video work done on bottomfish species which included the four bottomfish of interest (Misa et al., 2013; Sackett et al., 2014), the depth range within which 90% of each species' mean relative abundance occurred has been identified. This is referred to as the preferred depth range of each species. Using the mean MaxN and standard deviation generated at 15, 30, and 40-min soak times from camera deployments within each species' preferred depth range out of a total of 618, the probability of detecting a hypothetical 100% difference in relative abundance was calculated in sample size increments of 20 video samples from 20 to 200. For the length power analysis, mean FL and standard deviation generated at 15, 30, and 40-min soak times from 240 camera deployments was used to calculate the probability of detecting a hypothetical 10% difference in fish length at sample size increments of 10 length samples from 10 to 100. The effect size selected for each power analysis was based on results from previous protected area camera studies that found significant differences in abundance and length data at these levels for reef fish (Westera et al., 2003;

Fig. 5. Mean MaxN for each of the 10 target species by 5-min increments of simulated camera soak time from 0 to 40 min. Columns with the same letter are not significantly different (PERMANOVA, $P > 0.05$). Bold type capital letters highlight time bins that do not significantly differ from the highest mean MaxN at '0–40'. Data set was recorded from 378 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2007 to 2008. d = no. of BotCam deployments where a species was present. Note: MaxN scale varies by species.


P. filamentosus (d=102)
A. rutilans (d=20)
P. sieboldii (d=54)
H. quernus (d=22)
P. zonatus (d=21)
A. virescens (d=27)
E. carbunculus (d=78)
S. dumerili (d=94)
E. coruscans (d=57)
S. rivoliana (d=163)
Mean MaxN +SE
0–5
0–10
0–15
0–20
0–25
0–30
0–35
0–40
Simulated soak time (min)

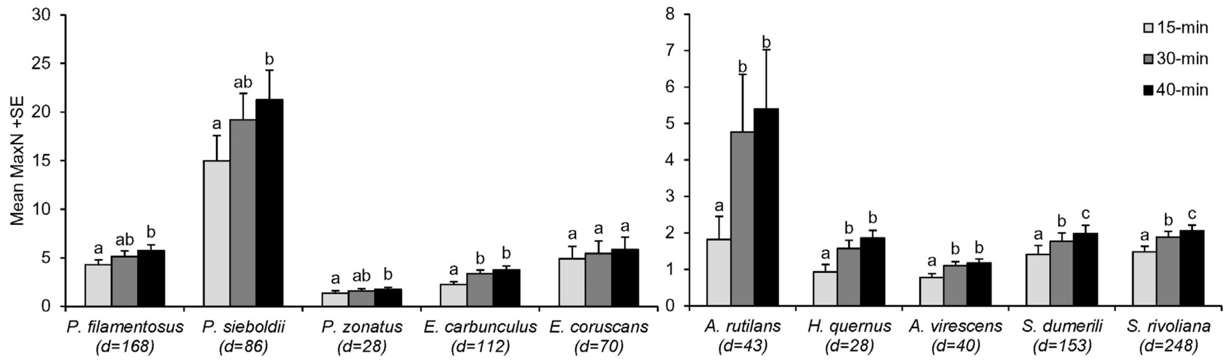


Fig. 6. Mean MaxN comparisons for 15, 30, and 40-min camera soak times for each of the 10 target species. Columns with the same letter are not significantly different (PERMANOVA, $P > 0.05$). Data set was recorded from 618 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2007 to 2008 and 2011 to 2012. d = no. of BotCam deployments where a species was present in at least one soak time analysis duration.

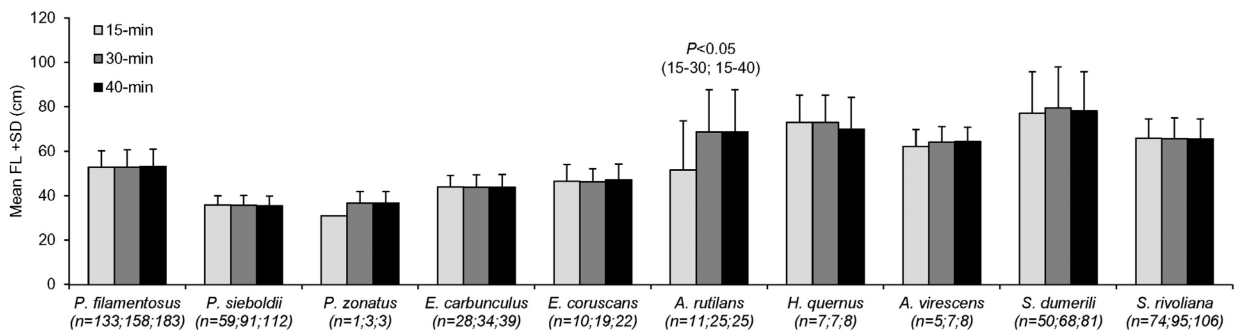


Fig. 7. Mean fork length (FL) generated from 15-min, 30-min, and 40-min camera soak times for each of the 10 target species. No significant differences in mean FL (PERMANOVA, $P > 0.05$) were found between the 15, 30, and 40-min soak times for all target species except *Aphareus rutilans* where mean FL at 15 min of soak time significantly differed (PERMANOVA, $P < 0.05$) from that at 30 and 40 min. Data set was recorded from 240 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2011 to 2012. n = no. of measured fish; d = no. of BotCam deployments where a species was measured in at least one soak time analysis duration.

Watson et al., 2007; Watson et al., 2009) and bottomfish (Sackett et al., 2014).

3. Results

3.1. TFA and TMaxN

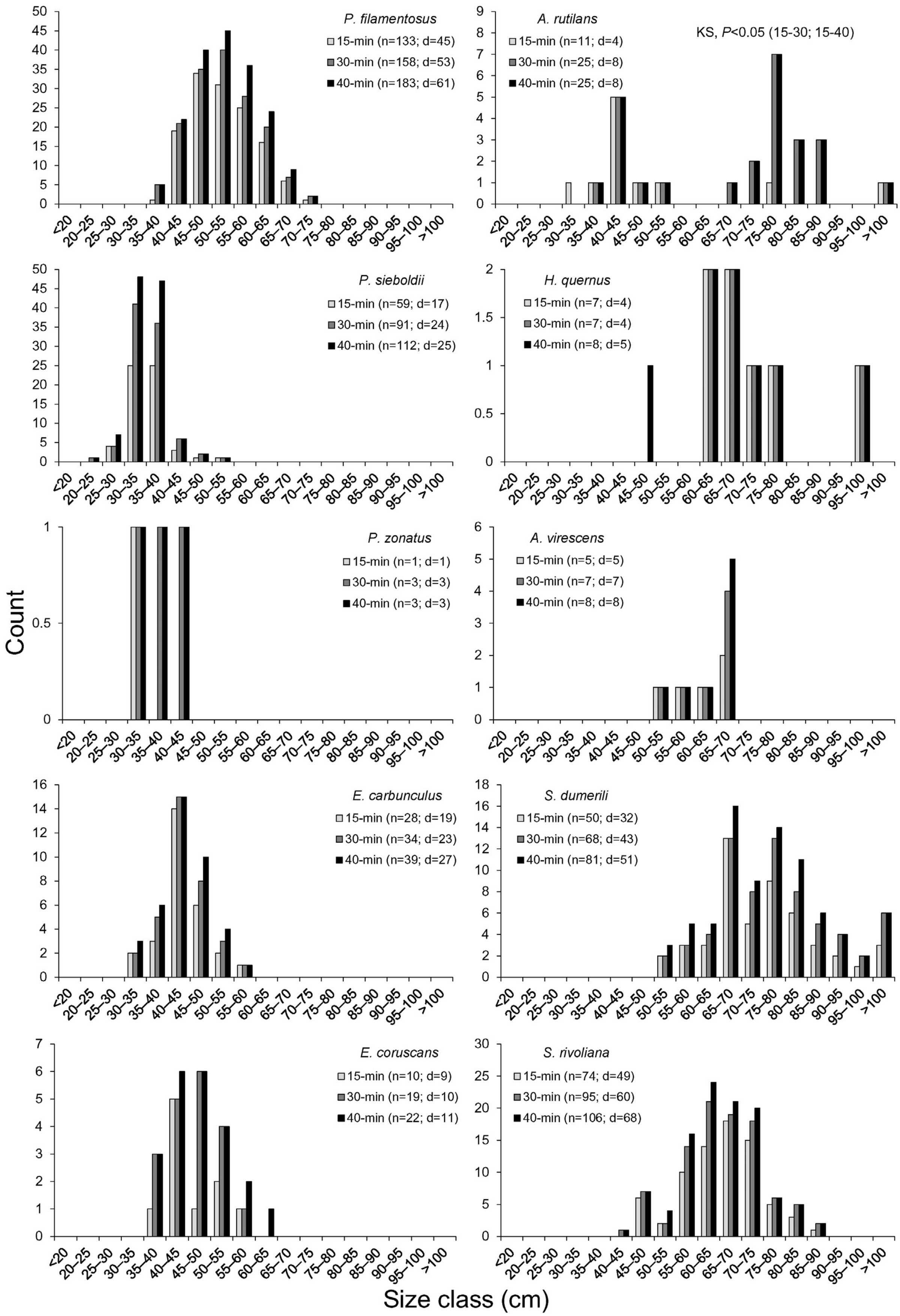
Mean time of first arrival (TFA) occurred within a camera soak time of 15 min for all 10 species studied and 8 of the 10 species had a mean time to MaxN (TMaxN) also within 15 min (Fig. 2). Only two species, *E. carbunculus* and *H. quernus*, had a mean TMaxN greater than 15 min at 16.70 ± 12.34 and 15.13 ± 12.92 min (mean ± SD), respectively. The standard deviations of the TFA and TMaxN means of all species were fully encompassed within the first 30 min after camera touchdown. As expected, the likelihood of detecting MaxN increased with longer soak time though 50% of species-specific MaxNs were already recorded within the first 15 min and 80% were recorded within 30 min (Fig. 3).

3.2. MaxN indices

Four trends were observed in the minute-by-minute MaxN time series (Fig. 4). For *P. filamentosus* and *P. sieboldii*, mean MaxN peaked within the first five minutes of camera soak time followed by an oscillation of MaxN values close to peak levels from minute five to minute 40. Mean MaxN for *E. coruscans*, *S. dumerili*, and *S. rivoliana* also peaked within the first five minutes, but then quickly declined for the remainder of the analysis period. Mean MaxN for *E. carbunculus* and *H. quernus* gradually increased with increasing soak time up to 40 min. Mean MaxN for the remaining species, *P. zonatus*, *A. rutilans*, and *A. virescens*, which were seen the most infrequently, did not exhibit any clear trend and remained variable throughout the 40-min analysis period. The coefficient of variation (CV) for MaxN generally decreased over time for most target species and tracked inversely with mean MaxN (Fig. 4). The largest change in CV occurred within the first 5 to 10 min for species that exhibited clear MaxN trends.

As expected, mean MaxN increased with simulated soak time as the highest mean MaxN values occurred in the 0–40 min soak time bin (Fig. 5). The earliest soak time bin that did not differ significantly (PERMANOVA, $P > 0.05$) from the 0–40 min bin was selected as the asymptote point of mean MaxN for each species. This asymptote in mean MaxN occurred in the 0–15 min bin for *P. zonatus* and *E. coruscans*, the 0–20 min bin for *P. sieboldii* and *A. rutilans*, the 0–25 min bin for *P. filamentosus* and *A. virescens*, and the 0–30 min bin for *E. carbunculus*, *H. quernus*, *S. rivoliana*, and *S. dumerili*.

Fig. 8. Length-frequency distributions generated from 15-min, 30-min, and 40-min camera soak times for each of the 10 target species. No significant differences in length-frequency distributions (KS test, $P > 0.05$; Wilcoxon test, $P > 0.05$) were found between the 15, 30, and 40-min soak times for all target species except *Aphareus rutilans* where length distribution at 15 min of soak time significantly differed (KS test, $P < 0.05$) from that at 30 and 40 min. Data set was recorded from 240 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2011 to 2012. n = no. of measured fish; d = no. of BotCam deployments where a species was measured in at least one soak time analysis duration.


P. filamentosus
15-min (n=133; d=45)
30-min (n=158; d=53)
40-min (n=183; d=61)
A. rutilans
KS, P<0.05 (15-30; 15-40)
15-min (n=11; d=4)
30-min (n=25; d=8)
40-min (n=25; d=8)
P. sieboldii
15-min (n=59; d=17)
30-min (n=91; d=24)
40-min (n=112; d=25)
H. quernus
15-min (n=7; d=4)
30-min (n=7; d=4)
40-min (n=8; d=5)
P. zonatus
15-min (n=1; d=1)
30-min (n=3; d=3)
40-min (n=3; d=3)
A. virescens
15-min (n=5; d=5)
30-min (n=7; d=7)
40-min (n=8; d=8)
E. carbunculus
15-min (n=28; d=19)
30-min (n=34; d=23)
40-min (n=39; d=27)
S. dumerili
15-min (n=50; d=32)
30-min (n=68; d=43)
40-min (n=81; d=51)
E. coruscans
15-min (n=10; d=9)
30-min (n=19; d=10)
40-min (n=22; d=11)
S. rivoliana
15-min (n=74; d=49)
30-min (n=95; d=60)
40-min (n=106; d=68)
<20 20–25 25–30 30–35 35–40 40–45 45–50 50–55 55–60 60–65 65–70 70–75 75–80 80–85 85–90 90–95 95–100 >100
Count
Size class (cm)

3.3. 15-min, 30-min, and 40-min camera soak times

Based on the TFA, TMaxN, and MaxN indices, soak times of 15 and 30 min were selected for further analysis in addition to the original 40-min soak time. Mean TFA for all 10 target species, mean TMaxN for 8 of 10 species, and 50% of MaxN records for all species were found to occur within 15 min. Two of the 10 target species (*P. zonatus* and *E. coruscans*) also had mean MaxN values at a 15-min simulated soak time that were not significantly different from that at 40 min. These results suggest that 15 min is the minimum soak time that can detect some target bottomfish species and estimate their MaxN. A soak time of 30 min encompassed the mean TFA (+1 SD), mean TMaxN (+1 SD), and 80% of MaxN occurrences for all target species. Furthermore, the simulated soak-time analysis showed no significant difference between mean MaxN at 30 or 40 min for all species. These results suggest that a soak time of 30 min can capture MaxN metrics as well as a full 40-min camera deployment.

In evaluating MaxN data generated at soak times of 15, 30, and 40 min from the same BotCam deployments, significant differences (PERMANOVA, $P < 0.05$) were found for mean MaxN in 9 of the 10 target species (Fig. 6). A significantly higher mean MaxN was found at the 40-min camera soak time compared to 15 min for all target species except *E. coruscans*. MaxN values did not significantly differ (PERMANOVA, $P > 0.05$) between the 40-min and 30-min camera soak times for all species except *S. dumerili* and *S. rivoliana*. At 30 min of soak time, *E. carbunculus*, *A. rutilans*, *H. quernus*, *A. virescens*, *S. dumerili*, and *S. rivoliana* all had significantly greater mean MaxN compared to 15 min while *P. filamentosus*, *P. sieboldii*, *P. zonatus*, and *E. coruscans* did not. It is also worth noting that the proportional species composition at 15, 30, and 40-min soak times remained the same.

No significant differences in mean length (PERMANOVA, $P > 0.05$; Fig. 7) and length-frequency distributions (KS test, $P > 0.05$; Wilcoxon test, $P > 0.05$; Fig. 8) were found between the 15, 30, and 40-min soak times for all target species except *A. rutilans*, where both the mean length and length distribution at 15 min significantly differed from that at 30 and 40 min. The low sample sizes (<10 fish measurements) at each of the three soak times for *P. zonatus*, *H. quernus*, and *A. virescens*, however, reduced the ability to reliably test these distributions. For most target species there was an increase in the number of fish measurements in each size bin with an increase soak time.

In assessing the limitation of resulting length data, it was found that certain sizes of fish encountered over the duration of a camera deployment were not detected when using the current measurement methodology (Fig. 9). For *P. filamentosus*, two additional size classes were found to occur above (70–75 and 75–80 cm) and below (30–35 and 35–40 cm) the size range recorded by the current method when measuring all encounters of this species. Three larger size classes (60–65, 65–70, and 70–75 cm) outside the range detected by the current measurement method were recorded for *E. coruscans* while *S. dumerili* had 2 larger size classes (95–100 and >100 cm), *S. rivoliana* had 1 larger size class (85–90 cm), and *E. carbunculus* had 2 smaller size classes (25–30 and 35–40 cm). No difference in size range detection was found for *P. sieboldii* while *P. zonatus*, *A. rutilans*, *H. quernus*, and *A. virescens* had fewer than five records per measurement method reducing the ability to effectively assess these distributions.

3.4. Cost comparison

While field costs were consistent between the three camera soak times, a soak time reduction from 40 to 30 min allowed for a 12.5% increase in samples collected and a 20% decrease in video processing time (Table 1). At a 15-min soak time, 25% more samples were collected and video processing time was 50% less than that of the 40-min soak time. Compared to the 40-min duration and considering both sampling rate and analysis time, the 30-min and 15-min soak times yielded per-sample cost savings of 14 and 28%, respectively. The number of length measurements, however, decreased with shorter soak times (Table 2). There was a 14% reduction in length records at 30 min and 36% fewer records at 15 min compared to the number of lengths collected with a soak time of 40 min. While the cost of generating a fish length within 30 and 40-min were identical, the reduced number of length records at 15 min increased the cost per fish length by 11%.

3.5. Power analysis

The statistical power to detect a hypothetical 100% difference in mean relative abundance and 10% difference in mean fork length both increased with increasing sample size for all species and soak times tested (Fig. 10). The rate of change in statistical power, however, differed between species and soak times with the most evident being that of the *E. coruscans* and *A. rutilans* length power analysis results. Power to detect a significant difference in mean MaxN reached 90% at each soak time for *P. filamentosus* and *E. carbunculus* between 160 and 200 video samples while *E. coruscans* and *A. rutilans* could only achieve about 50 and 20% power, respectively. Power to detect a significant difference in mean FL reached 90% at each soak time for *P. filamentosus*, *E. carbunculus*, and *E. coruscans* between 50 and 70 length samples while *A. rutilans* could only achieve about 50% power at 100 length samples. When power was tested at projected 10-day field sampling yields for each of the three soak times, all four species maintained similar levels of statistical power for mean MaxN but only two species (*P. filamentosus* and *E. carbunculus*) did so in the mean FL test (Table 3). For *E. coruscans* and *A. rutilans*, the power to detect a 10% difference in mean FL at a soak time of 15 min was about half of that at 30 and 40 min. For both power analyses, achieved statistical power was diminished in species with a lower frequency of occurrence.

4. Discussion

Though TFA has been used in previous baited camera work as a metric for determining fish abundance (Priede et al., 1994a; Ellis and DeMartini, 1995), in this study, TFA in tandem with TMaxN provided useful information in identifying reduced soak times still able to detect target species and capture relative abundance metrics. Determining the minimum soak time (15-min) needed for recording the TFA and MaxN of some target species and the reduced soak time (30-min) where arrival and abundance data did not significantly differ from current full length recordings were essential in evaluating the efficiency of BotCam surveys in the main Hawaiian Islands. In comparing baited camera and trawl surveys in the Great Barrier Reef, Cappo et al. (2004) found a mean TFA and mean TMaxN for all reef fish species seen on video at 16.0 ± 14.0 (mean ± SD) minutes and 23.0 ± 16.0 (mean ± SD) minutes of soak time, respectively. Ellis and DeMartini (1995) employed a soak time of 10 min in their baited camera surveys of juvenile *P. filamentosus* as they found that mean TFA occurred at 3.38 ± 2.75 (mean ± SD) minutes and mean TMaxN was achieved at approximately 5.90 ± 2.55 (mean ± SD) minutes after camera touchdown. While the TFA and TMaxN values in these studies differed from those in the present study, the target species in Cappo et al. (2004) and life stage studied in Ellis and DeMartini (1995) were also different. This shows that fish arrival and abundance metrics are both

Fig. 9. Number of BotCam deployments where a target species length record was present across 5-cm size bins from length data generated using the current fish measurement methodology (current method) and from measuring all fish encountered in a camera deployment (measure all). Data set was recorded from 84 BotCam deployments conducted during a single bottomfish survey in the main Hawaiian Islands in 2011. d = no. of BotCam deployments where lengths were generated for a given species in at least one measurement method.

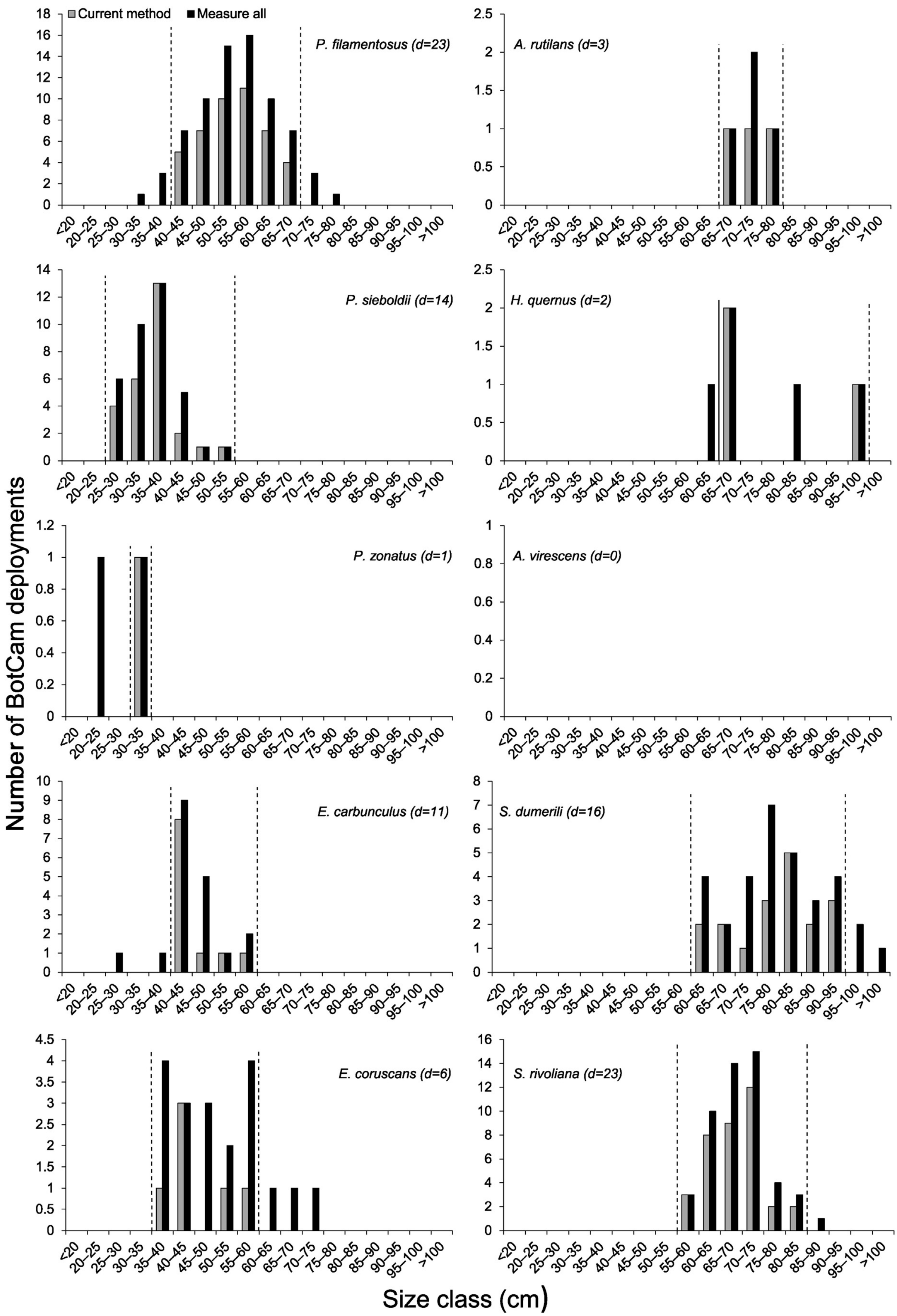

Current method
Measure all
P. filamentosus (d=23)
A. rutilans (d=3)
P. sieboldii (d=14)
H. quernus (d=2)
P. zonatus (d=1)
A. virescens (d=0)
E. carbunculus (d=11)
S. dumerili (d=16)
E. coruscans (d=6)
S. rivoliana (d=23)
Number of BotCam deployments
Size class (cm)

Table 1
Comparison of per-sample costs associated with a 15, 30, and 40-min BotCam soak time based on 2011–2014 sampling efforts for deepwater bottomfish assemblages in the Auau Channel, Kealaikahiki Channel, and Alenuihaha Channel given a 10-day sampling mission (*30-min soak time values are estimates).

Soak time (min)	Maximum samples (day^{-1})	Total samples (10 days)	Processing time per sample (h)	Total processing time (h)	Processing cost	Total cost (field costs + processing costs)	Cost per sample	Cost savings
40	16	160	5	800	$20,300.00	$73,774.00	$461.09	
30*	18	180	4	720	$18,270.00	$71,744.00	$398.58	14%
15	20	200	2.5	500	$12,687.50	$66,161.50	$330.81	28%

species- and size-specific. Habitat, depth, and other environmental factors can also have a strong influence on reef fish (Friedlander and Parrish, 1998; Parrish and Boland, 2004; Moore et al., 2010) and bottomfish (Polovina et al., 1985; Haight et al., 1993a; Kelley et al., 2006; Misa et al., 2013) distributions. The TFA and TMaxN findings specific to the bottomfish species, sampling depths, and sampling regions around the main Hawaiian Islands suggest the possibility of reducing soak time to between 15 and 30 min.

Distinct patterns of fish abundance over time (Stobart et al., 2007) and the importance of fish behavior in relation to observed patterns of relative abundance (Cappo et al., 2004; Harvey et al., 2007) have been noted in previous baited camera work. In this study, four patterns of relative abundance, possibly influenced by fish behavior, were found over the course of a 40-min video analysis period: 1) an early peak in MaxN sustained throughout the analysis period; 2) an early peak in MaxN followed by a rapid decline; 3) a gradual increase in MaxN; and 4) variability in MaxN throughout the analysis period. Pattern 1 was typical for both *P. filamentosus* and *P. sieboldii*. These two species were observed in schools and frequently fed on the bait when present. Schooling behavior would allow for a rapid rise in MaxN as more and more individuals from the immediate area enter the camera's field of view in a short amount of time, while active feeding could extend the residency of these fish in front of the camera. The combination of schooling and feeding behavior may, therefore, be responsible for the observed MaxN trends of *P. filamentosus* and *P. sieboldii*. Pattern 2 was typical for *E. coruscans*, *S. dumerili*, and *S. rivoliana*, which were also observed in schools. These species did not always show interest in the bait and after an initial interest, left the vicinity of camera system as the main body of the school moved away.

Pattern 3, the gradual increase in counts over time, was typical for *E. carbunculus* and *H. quernus*, and may be a result of their strong association with the bottom environment (Kelley and Moriwake, 2012). Since the BotCam is suspended three meters above the seafloor, these two species would have to swim up off the bottom to be detected by the camera system. Both *E. carbunculus* and *H. quernus* also forage primarily on benthic prey (Haight et al., 1993b; Seki, 1984) as opposed to the pelagic food sources of some of the other target species (Haight et al., 1993b). Given these species' instinct to stay close to their bottom habitats for protection as well as their lack of schooling behavior and different feeding pattern as compared to other bottomfish (e.g. *P. filamentosus* and *P. sieboldii*), it is reasonable that they would show an increased reaction time and a different approach pattern. While measurements of bait plume dispersal are complex and beyond the scope of this study, pattern 3 would also be consistent with fish being attracted from greater and greater distances as time progresses. As the goal is to characterize a fish assemblage within a finite sampling area, reducing soak time should, generally, limit the area of attraction. While difficult to assess, the effect of bait plume dispersal is an important area for continued research. For species least encountered by BotCam (*P. zonatus*, *A. rutilans*, and *A. virescens*), their infrequent detection is likely to have caused the variability in relative abundance over the sampling duration (pattern 4). It is still possible, however, that strong behavioral tendencies, when present, may be detected even with a small sample size as evidenced by the results for *H. quernus*.

Species-specific differences in the coefficient of variation (CV) around abundance indices have also been linked to frequency of occurrence on video and fish behavior (Bacheler and Shertzer, 2015). Similar to the results in Bacheler and Shertzer (2015), this study found that schooling species (e.g. *P. sieboldii* and *E. coruscans*) had greater CVs compared to non-schooling species (e.g. *P. zonatus* and *H. quernus*). Although in contrast to Bacheler and Shertzer (2015), species that were infrequently detected (e.g. *A. virescens*) generally had lower CVs than those more often recorded on video (e.g. *P. filamentosus*). The hyperdispersed count data with excess zeros for bottomfish species (Sackett et al., 2014) may account for the difference in CV for frequency of detection as schooling species typically had greater counts compared to non-schooling species in the instances when they were recorded on video whereas the reef fish targets in Bacheler and Shertzer (2015) may have a more consistent rate of detection. The largest change in CV for all target species in this study, which occurred in the first 5–10 min, is not directly comparable to the rapid decline in CV when reading counts from 1 to 50 frames in Bacheler and Shertzer (2015) as the method for counting fish (MaxN vs MeanCount) and the interval for taking counts (continuous vs random frames) are different. With a longer duration for counting fish whether by time or number of frames, however, a reduction in CV is likely. Aggregative behavior (Cappo et al., 2004), diet (Harvey et al., 2007), and differential attraction to baited camera systems (Cappo et al., 2004; Harvey et al., 2007) have been found to affect species-specific differences in fish abundance. With the extensive array of behaviors exhibited by demersal fishes (Armstrong et al., 1992), however, the dynamics behind fish arrivals and attractions observed during surveys still remains relatively unknown (Sainte-Marie and Hargrave, 1987; Armstrong et al., 1992).

In simulating multiple soak times using MaxN time indices, MaxN was found to increase with longer soak times. This is consistent with the findings of Willis and Babcock (2000) and Haratsi et al. (2015) in their respective baited camera surveys of reef fish in Australia and New Zealand. Despite using the same data set as the minute-by-minute MaxN time series, the simulated soak time indices were cumulative resulting in an increase in MaxN with increasing soak time as opposed to the minute-by-minute patterns of MaxN observed in a continuous time analysis. It is noteworthy, however, that for all 10 target species in this study, an asymptote in mean MaxN was achieved between soak times of 15 and 30 min. Willis and Babcock (2000) found that the highest mean rate of fish accumulation at their baited camera systems occurred between 25 and 30 min. They also found that a 30-min camera soak time provided consistent estimates of MaxN between their study sites and longer video sequences did not substantially improve data quality. While beyond the scope of this study, site-specific environmental factors such as depth, temperature, and nutrient dynamics should also be considered when looking into fish arrival and accumulation rates as these factors are likely to influence foraging behavior in fish species and subsequent attraction to baited camera systems (Armstrong et al., 1991; Armstrong et al., 1992; Priede et al., 1994b).

While changes in relative abundance with soak time varied by species, mean MaxN for target bottomfish was more consistently captured at a reduced soak time of 30 min (8 species) compared to 15 min (1 species) in testing species MaxN differences at 15, 30, and 40 min. This is consistent with the finding that only two species (*P. zonatus* and *E. coruscans*) had an asymptote in mean MaxN that occurred within 15 min in the simulated soak time analysis. Evaluating camera soak time

Table 2
Comparison of cost associated with generating fish lengths at 15, 30, and 40-min soak times for all 10 target species from 240 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2011 to 2012.

Soak time (min)	Cost per deployment	Total no. of fish lengths generated	No. of fish lengths per deployment	Cost per fish length	Cost savings
40	$461.09	587	2.45	$188.52	
30	$398.58	507	2.11	$188.68	−0.1%
15	$330.81	378	1.58	$210.04	−11%

in relation to known abundances of fish in a closed tank experiment (Schobernd et al., 2014) may better elucidate how MaxN at reduced soak times compare to absolute abundance and the sensitivity of these estimates to varying degrees of fish density. Though closed tank experiments with large deep water fish will be very challenging, this information might allow for the development of more accurate species-specific soak time-abundance indices and accumulation curves as the total number of fish in a predefined area is known.

Despite finding differences in mean MaxN between soak times, the power analysis showed that similar levels of statistical power can be achieved at 15, 30, and 40 min given the respective increases in sampling intensity associated with each soak time. While a 100% effect size was used to simulate abundance differences inside and outside of closed zones, further evaluation on an appropriate effect size for long-lived deep water species such as those in this study remains necessary. The ability to detect differences in abundance inside and outside of restricted fishing areas remains a high priority for many camera surveys

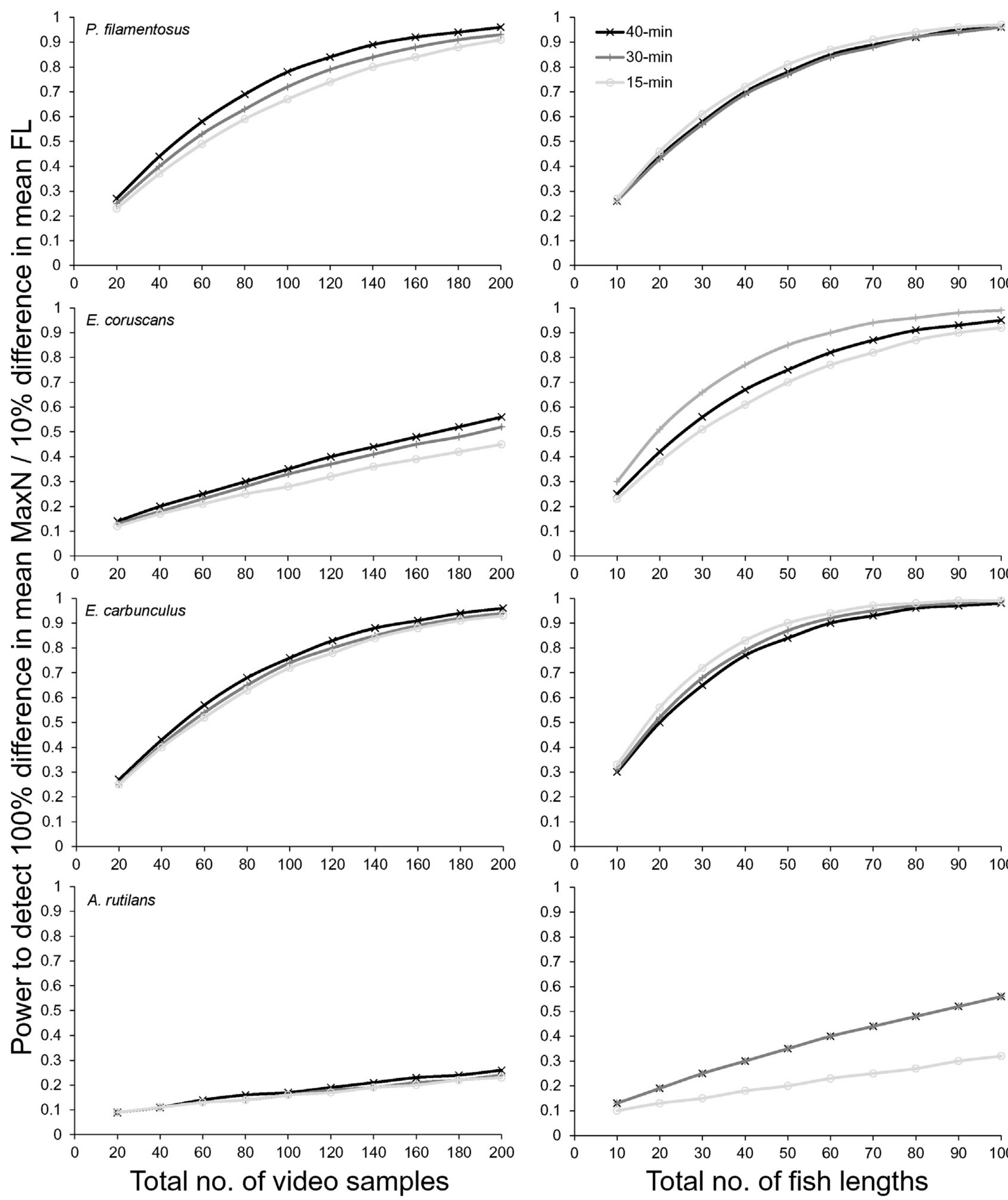


Fig. 10. Achieved statistical power for detecting a hypothetical 100% difference in mean relative abundance by number of video samples and 10% difference in mean fork length by number of length samples based on means and standard deviations generated at 40, 30, and 15-min camera soak times for *Pristipomoides filamentosus*, *Etelis coruscans*, *E. carbunculus*, and *Aphareus rutilans* at each species' preferred depth range. Relative abundance data was recorded from 618 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2007 to 2008 and 2011 to 2012 while fork length data was recorded from 240 BotCam deployments conducted during bottomfish surveys in the main Hawaiian Islands from 2011 to 2012. Note that 40 and 30-min lines overlap in the *A. rutilans* length-power plot due to equal values.

Table 3
Achieved statistical power for detecting a hypothetical 100% difference in mean relative abundance and 10% difference in mean fork length based on the number of video and length samples attainable in a 10-day field effort at 40, 30, and 15-min camera soak times for *Pristipomoides filamentosus*, *Etelis coruscans*, *Etelis carbunculus*, and *Aphareus rutilans*. Frequency of occurrence is the percentage of camera deployments that recorded a given species out of the total number of deployments within each species preferred depth range. The number of video samples attainable in a 10-day field effort was calculated in the cost comparison section (Table 1). The number of length samples attainable in a 10-day field effort was estimated based on the proportion of length samples collected from camera deployments within each species preferred depth range out of a total of 240 and the number of video samples attainable at each soak time.

	Preferred depth range	Freq. of occur.	Soak time (min)	Mean MaxN	SD	n	Video samples (10-day)	Power to detect 100% diff.	Mean FL (cm)	SD	n	Length samples (10-day)	Power to detect 10% diff.
P. filamentosus	90–210 m	0.52	40	2.99	6.17	323	160	0.92	53.24	7.65	183	206	1.00
			30	2.67	5.96	323	180	0.91	52.86	7.71	158	200	1.00
			15	2.23	5.30	323	200	0.91	52.90	7.36	133	187	1.00
E. coruscans	210–310 m	0.26	40	1.53	6.04	268	160	0.48	47.16	7.05	22	50	0.75
			30	1.43	5.95	268	180	0.48	46.20	5.99	19	48	0.84
			15	1.28	5.91	268	200	0.45	46.51	7.49	10	28	0.48
E. carbunculus	210–310 m	0.42	40	1.57	3.30	268	160	0.91	43.76	5.73	39	88	0.97
			30	1.41	3.08	268	180	0.92	43.80	5.53	34	86	0.98
			15	0.95	2.13	268	200	0.93	43.93	5.25	28	79	0.98
A. rutilans	90–240 m	0.10	40	0.52	3.66	442	160	0.23	68.69	19.05	25	21	0.20
			30	0.46	3.50	442	180	0.22	68.69	19.05	25	23	0.22
			15	0.18	1.39	442	200	0.23	51.63	21.95	11	11	0.10

as these types of comparisons provide useful information for stock assessment, life history studies, and management strategies for commercially exploited fish species. Furthermore, camera systems provide a non-extractive means for surveying fish populations inside areas closed to fishing making them an ideal tool for such work. Maintaining the ability to detect these types of differences in fish abundance using shorter soak times is an added benefit to being able to increase sampling intensity and spatial coverage, which should improve the ability to characterize fish assemblages over larger areas regardless of protection.

The lack of significant differences in mean length and length frequency distributions at soak times of 15, 30, and 40 min may be due to the method of measuring fish at TMaxN or where the most fish are measurable. Measuring fish in stereo-video requires a reasonable view of the head and tail of a target individual in both cameras, which was not always attainable. Together with the amount of movement during swimming or feeding exhibited by fish species within a close enough proximity to the camera system for measurement, the number of fish that could be measured was much less than the number of individuals that made up a species' MaxN. In evaluating the current measurement method, a threshold for size detection was evident as the smallest and largest sizes for some species were not captured. Furthermore, the standard deviations of lengths for target species known to school were found to be less than 100 mm suggesting that these schools may be comprised of similarly sized fish. Taking lengths at a single time point may, therefore, subsample the full size range of each species, missing some individuals of larger or smaller sizes that were occasionally observed swimming through the camera's field of view. This was apparent in Willis et al. (2003) where small sparid snappers had more length records compared to larger individuals when taking fish measurements at TMaxN using their downward-facing camera system. Willis et al. (2003) also took fish measurements outside of TMaxN when fish could be clearly distinguished as different individuals based on size (>100 mm). Measuring significantly smaller or larger individuals outside of TMaxN may not be a viable option for forward-facing camera systems, such as BotCam, since the absence of a fixed depth of field makes quick estimation of fish lengths by eye difficult.

While the fish measurement limitations found to occur with the current survey methodology may not affect fish species that occur at lower counts (e.g. *P. zonatus*, *H. quernus*, *A. virescens*), schooling species (e.g. *P. filamentosus*, *P. sieboldii*, *E. coruscans*) will have limits to the number of fish that can be measured when fish densities at the camera system are high. For the schooling species, there is a greater potential for measuring smaller species and smaller individuals within species as a greater number of these individuals are able to saturate the camera's field of view compared to larger fish. This apparent autocorrelation and potential bias in length data collected at the time of MaxN or when the highest number of measureable fish occurs could be overcome by making measurements of fish across a range of still frames or from a random selection of points within the video sequence. Schobernd et al. (2014) described an approach for recording fish abundance using the mean number of fish observed in a series of intervals (MeanCount). Generating fish lengths in a similar manner may be an alternative method for fish measurement that warrants further investigation.

To attain significant results in spatial and temporal analyses of bottomfish length data, Sackett et al. (2014) suggested a sample size of greater than 100 fish measurements per species. This magnitude in fish length data was generated for three species at a soak time of 40 min and only one species at either reduced soak time in the analysis of 240 BotCam deployments. Using shorter soak times to collect more video samples potentially increases the length-data sample size and allows for similar levels of statistical power for species with a higher frequency of occurrence such as *P. filamentosus* and *E. carbunculus*. Fewer deployments with longer soak times, however, provide much greater statistical power for species with a lower frequency of occurrence such as *E. coruscans* and *A. rutilans*. Having more time per camera recording to encounter these species, thereby increasing the number of opportunities to take length measurements, becomes more advantageous. As *E. coruscans* is one of the main targets of the fishery, increased statistical power to detect differences in lengths would be highly desired. Based on these results, it is apparent that the number of fish measurements generated by the current sampling methodology is influenced by fish behavior (schooling vs. non-schooling), species-specific response rates, and camera soak time.

Recent stereo-video-camera studies of bottomfish in the main Hawaiian Islands (Moore et al., 2013; Misa et al., 2013; Sackett et al., 2014) have utilized a soak time of 40 min to maximize the number of fish observations over the duration of a video recording (Harvey and Cappo, 2001). Video recordings of this length, however, can limit the number of independent samples collected in a field day given the sampling design and number of camera units used in these studies. At a target soak time of 40 min, a maximum of 16 BotCam deployments were collected in a single 8-h day of field work by a single vessel. The greatest increase in sample yield and cost savings was found at the identified minimum required bottomfish sampling soak time of 15 min. At this soak time, the maximum daily deployment count was 20, a 25% increase from the 40-min soak time BotCam deployment yield. Assuming that between-site variation is greater than within-site variation, a larger number of independent samples is desirable as it is more likely to capture the variability in the population when using baited camera systems (Willis et al., 2000). While daily sample yield was found to increase with reduced soak times in this study, other factors such as sampling design, distance between deployment locations, site-specific weather conditions, experience level of field crew, and project logistics should also be taken into account in similar research endeavors as they are likely to influence field sampling efficiency.

With a 40-min soak time, per-sample video processing was time intensive, often exceeding the capabilities of a small pool of human analysts for rapid turn-around. Using current video annotation protocols, it took an average of 5 h to process 40-min of video whereas it took only 2.5 h to process 15 min. Taking field sampling and data processing costs into account, shortening camera soak time from 40 to 15 min resulted in a 28% per-sample cost savings, which is likely significant for most field research programs. With 25% more samples and a video processing time half that of 40-min soak times, a faster turn-around of more video samples can be achieved using a soak time of 15 min which, in turn, increases the ability to report fishery data in a timely manner at a lower cost per sample. This is consistent with the findings of Gladstone et al. (2012) and Haratsi et al. (2015) that longer camera soak times incurred greater sampling costs.

While an 11% increase in cost per fish length at a 15-min soak time compared to 30 and 40 min may not be of major concern, the reduced number of length measurements (36%) may be an issue. Certain criteria must be met to retain a length measurement using the current methodology (e.g. head and tail of fish in view in both cameras, fish body should be straight and oriented parallel to the camera system, RMS error <10 mm, precision-to-FL ratio < 10%). With longer soak times, the number of opportunities to measure a given fish increases thus leading to a greater number of length records. For bottomfish with a higher frequency of occurrence (e.g. *P. filamentosus*, *E. carbunculus*), the deficit in number of length records collected at 15 min can be overcome with an increase in sampling intensity as seen in the power analysis results. For bottomfish with a lower frequency of occurrence (e.g. *E. coruscans*, *A. rutilans*), however, an increase in sampling intensity at the 15-min soak time was still unable to alleviate the discrepancy in length data. For these species, a 30-min soak time or shorter camera deployments targeted at preferred depths and habitats would be necessary to produce sufficient quantities of length data. As the ability to generate fish lengths is highly dependent on fish behavior, further evaluations on length data should be conducted on a species-by-species basis.

5. Conclusions

The 40-min camera soak time used in stereo-video surveys of bottomfish in the main Hawaiian Islands likely can be reduced without meaningfully sacrificing overall data quality. This presents the possibility for increased survey efficiency and improved cost–benefit through increased levels of field sampling and reductions in video-processing time while maintaining the power to detect differences in bottomfish relative abundance and length data. A soak time of 15 min was found to be the shortest duration able to capture bottomfish abundance and length metrics while 30 min generated data that did not significantly differ from the standard 40-min soak time. Species-specific attraction patterns to the baited camera system in this study suggest that abundance trends are highly influenced by fish behavior and species-specific accumulation rates. While the number of fish length records decreased with shorter soak times, an increased sampling capacity can still provide the necessary sample size for obtaining significant results in length-related analyses of species with a higher frequency of occurrence. Longer soak times or alternative measurement methods, however, will be required to detect differences in lengths of species with a lower frequency of occurrence. If the goal of a survey is to capture a snap-shot of abundance at a given place and time as needed in stock assessment surveys, the 15-min soak time will provide consistent abundance estimates with little loss in statistical power compared to 30 or 40 min. If the goal of a survey is to capture ecological dynamics of fish assemblages, detect changes in size structure, and further understand inter- and intra-species behavior as they relate to relative abundance, a soak time of at least 30 min would be necessary. The influence of species-specific behavior on fish abundance indices and alternative methods for increasing fish measurement samples while maintaining independence between samples should continue to be investigated.

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