Evaluating Soak Time and Measurement Methodology for Stereo-Video Surveys of Commercially Important Bottomfish in the Main Hawaiian Islands

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Abstract

Fishery-independent surveys of main Hawaiian Island bottomfish make use of a baited stereo-video camera system (BotCam) to estimate species-specific size-structured abundance. While current BotCam sampling methodologies provide conservative estimates of bottomfish abundance and length-frequency distributions, limitations exist in the data processing and resultant data. These limitations include an immense video-processing time requirement, an unknown area of bait influence, and a subsampling of fish lengths. Using BotCam relative abundance (MaxN) and length data for 10 bottomfish species from 10 locations in the main Hawaiian Islands, this study evaluated the effects of reducing camera soak time, estimated the effective range of fish attraction to baited systems, and assessed potential biases in estimates of fish-length distributions. A reduction in BotCam soak time from the current 40-minute target was deemed possible without sacrificing data quality. An optimal BotCam bottomfish sampling soak time range of 15 to 30 minutes was identified. At 30 minutes MaxN and length-frequency trends comparable to 40-minute soak time values were successfully captured for most target species while 15 minutes was the minimum amount of soak time needed to record bottomfish stereo-video metrics. At a camera soak time of 15 minutes significant increases in daily sample yield and reductions in video processing time and overall cost per sample were also found. Estimates on the effective range of fish attraction showed that the BotCam may possibly be attracting fish beyond its target sampling area and that shorter soak times may provide a better coupling of stereo-video data and the scale of habitat classification. A subsampling of fish lengths from a truncation effect was found in current measurement methodologies in that a bias towards measuring smaller schooling species and an exclusion of size classes with the lowest frequency

of occurrence was taking place. The effects of fish behavior on relative abundance, the dynamics of bait dispersal, and alternative measurement methodologies in stereo-video surveys should be investigated further.

1. Introduction

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). 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., 2006). In Hawaii, baited video camera systems have been used to identify and survey juvenile deepwater snapper habitats (Parrish et al., 1997), compare fish relative abundance to CPUE (Ellis and DeMartini, 1995), study deepwater bottomfish and their habitat (Merritt et al., 2011; Moore et al., 2013; Misa et al., 2013; Sackett et al., 2014), and assess the effectiveness of deepwater marine protected areas (Moore et al., 2013; Sackett et al., 2014).

Baited camera systems have been used to produce a variety of standardized species-specific size-structured estimates of fish abundance (MAXNO [Ellis and DeMartini, 1995], n_{peak} [Priede and Merrett, 1996], MAX [Willis et al., 2000], MaxN [Cappo et al., 2004], mincount [Gledhill et al., 2005]). By taking the single highest fish count observed at any point in a video recording and, in doing so, avoiding multiple counts of the same fish as it re-enters the camera's field of view, these homologous metrics produce conservative fish abundance estimates. Ongoing non-extractive fishery-independent studies of Hawaiian deep-slope bottomfish also use baited stereo-video camera systems (BotCam; Fig. 1; Merritt et al., 2011) to generate consistent metrics of size-structured abundance (MaxN). Many studies have found a positive correlation between MaxN and 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) enabling the use of MaxN 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.

While stereo-camera systems offer a number of advantages over fishery-dependent or other extractive sampling techniques (Cappo et al., 2006) and allow for sampling beyond normal diver depths, 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 (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 is necessary. As data processing time is proportional to video duration (Cappo et al., 2006), shortening video recordings by decreasing camera soak time has been proposed as a straightforward approach to reduce per-sample data processing time. However, this assumes no significant reduction in overall data quality as a result of shortened soak time. Therefore, an evaluation of abundance metrics (MaxN) with respect to camera soak time may reveal avenues for increased efficiency.

The unknown area of bait influence when using baited camera systems raises additional questions on the actual size of a sampling area induced by the bait plume (Cappo et al., 2006). Previous studies have provided estimates on the effective range of fish attraction to baited systems (e.g. Ellis and DeMartini, 1995; Cappo et al., 2004), but the dynamics of bait plume dispersal and its effect on resident fishes remains largely unknown (Cappo et al., 2006). Location, current velocity and direction, depth, fish behavior and soak time are among the factors that influence the area of fish attraction to bait. In this study, we aim to provide location-specific estimates of the effective range of fish attraction to our baited camera system in relation to soak time.

In addition to abundance estimates, fish length data can be generated from stationary stereo-video cameras (e.g., BotCam, Merritt et al., 2011) by measuring fish at the time of MaxN or at another time in the video recording where the most fish are measurable in a single frame of view. We refer to this method of fish measurement as *Max lengths*. The *Max lengths* approach ensures that the same fish is not measured twice maximizing the number of independent length measurements. In comparison to traditional transect surveys, the *Max lengths* method likely restricts fish length data to a subset of the overall fish population present. However, to our knowledge, the extent and effect of this limitation has not been quantified.

The goal of this study is to compare stereo-video abundance and length metrics, sampling and data-processing costs, and the effective range of fish attraction at three different soak times by using video from bottomfish sampling efforts in the main Hawaiian Islands. For this study, we define "soak time" as the amount of time, in minutes, from when the camera system touches bottom until the end of a predefined video-analysis duration. Secondly, this study aims to quantify differences between measuring fish at a single time point and measuring all fish present throughout a camera deployment.

2. Materials and methods

2.1. BotCam

BotCam (Fig. 1) 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 meters (Merritt et al., 2011). BotCam is outfitted with two ROS Navigator^{TM} ultra-low light cameras that can detect and record fishes to a depth of 300 meters in Hawaiian waters without artificial light sources. An LED device is used to ensure synchronicity between the analogue stereo camera pair. Video data are recorded by a dual channel digital video recorder with an average recording time of 45 minutes resulting in a total soak time of about 40 minutes (Moore et al., 2013; Misa et al., 2013; Sackett et al., 2014). Following recovery of the BotCam, video data are downloaded for subsequent analysis. BotCam is baited with an 800-g mixture of ground anchovies and squid, which mimics the traditional bait used by local fishermen (Merritt et al., 2011).

2.2. Field deployments and target species

A total of 1504 BotCam deployments spanning 7 years of sampling in 10 geographic locations 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. 2) were available for this study. Of the 93 fish species observed, 10 target species (Fig. 3) were selected on the basis of high commercial value and/or high local abundance. The target list includes the Crimson Jobfish (Opakapaka, *Pristipomoides filamentosus*), Lavender Jobfish (Kalekale, *Pristipomoides sieboldii*), Oblique-banded Snapper (Gindai, *Pristipomoides zonatus*), Deep-water Red Snapper (Ehu, *Etelis carbunculus*), Deep-water Long-tail Red Snapper (Onaga, *Etelis coruscans*), Rusty Jobfish (Lehi, *Aphareus rutilans*), Hawaiian Grouper (Hapuupuu, *Hyporthodus quernus*), Green Jobfish (Uku, *Aprion virescens*), Greater Amberjack (*Seriola dumerili*), and Almaco Jack (*Seriola rivoliana*). Opakapaka, Onaga, and Ehu 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, Kalekale, Gindai, Lehi, and Hapuupuu make up the commercially harvested Deep 7 bottomfish complex. Uku, despite not being one of the Deep 7, is harvested regularly in the main Hawaiian Islands (WPRFMC, 2011). Although the Greater Amberjack and Almaco Jack 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 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). TFA is the time (in minutes) from camera touchdown to the time at which a fish species is first detected (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 (Visual Measurement System^{TM}, Geomsoft, Victoria, Australia; PhotoMeasure^{TM} or EventMeasure^{TM}, SeaGIS Pty. Ltd., Victoria, Australia), FL was measured at TMaxN or at another time in a video recording when the most fish of a given species were measureable. To increase accuracy, 5 replicate measurements were taken per individual and the mean was used as the representative length. Measurements with a root mean-square (RMS) error >10 mm and a precision-to-FL ratio >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.

2.4. Data analysis

In an initial evaluation of camera soak time in relation to fish stereo-video metrics, a series of analyses 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, we hypothesize that an ideal camera soak time for detecting a species and recording MaxN should be the shortest amount of time needed to encompass both the TFA and TMaxN. Thus we observed the cumulative frequency of BotCam deployments at which a species MaxN occurred in 5-minute bins from camera touchdown (time 0) to 40 minutes.

To gain a more detailed insight into the species-specific behavior of the MaxN metric, we created a time series of values at one-minute intervals from 0 to 40 minutes of camera soak time. Given the significant time requirement associated with generating a minute-by-minute MaxN, only 378 BotCam deployments were annotated in this manner. Using the same data set to evaluate varying soak times, mean MaxN was calculated within 9 time bins, which increased by 5-minute increments (i.e, 0–5, 0–10, etc.). For each time bin (1-min or 5-min), MaxN values were averaged across all camera deployments where a given species was seen (Willis and Babcock, 2000). 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 first 3 metrics analyzed (TFA, TMaxN, MaxN indices), two 2 soak times were selected. We then generated and tested MaxN and fish length data from the reduced time intervals against each other and against count and length data from the same BotCam deployments at the original 40-minute soak time. For all target species, species-specific MaxN values for the 3 time intervals from 618 BotCam deployments were compared using a PERMANOVA while differences in species-specific length-frequency distributions from 240 deployments were evaluated using either Kolmogorov-Smirnov (KS) or Wilcoxon tests.

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 a research cruise, the data-processing time for each sample, and the resulting monetary cost per sample. With a reduction in soak time, an increase in the number of video samples was expected. Using 3 BotCam units, deployments with target soak times of 40 and 15 minutes were tested in three sites within the Maui triangle area (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 minutes 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. These cost items along with the final cost per sample were compared for BotCam deployments using camera soak times of 15, 30, and 40 minutes.

2.6. Effective range of attraction

Using current velocities (V_c, ms^{-1}) recorded by a current meter attached to the BotCam system and fish swimming speeds (V_f, ms^{-1}) derived from mean fork lengths (3 body lengths per second; Ellis and DeMartini, 1995), the effective range of attraction (*AR*) was calculated with respect to a 15, 30, and 40-minute camera soak time (S_t, min) for all target species at each of the 10 BotCam sampling locations using the equation, $AR = 60 \times (S_t) \times ((V_f \times V_c) - V_c^2)/V_f$, from Cappo et al. (2004). The resulting *AR* from the minimum and maximum recorded current velocities at each location and the slowest and fastest fish swimming speeds are presented by soak time.

2.7. Fish measurement methodology

Differences between measuring fish at a single time-point (*Max lengths*) and measuring all fish present throughout a camera deployment (*All lengths*) were also quantified. While fish measurements are typically made at the time of MaxN (Willis and Babcock, 2000; Willis et al., 2003; Denny et al., 2004; Merritt et al., 2011) or where the most fish are measurable in the field of view (Moore et al., 2013; Misa et al., 2013; Sackett et al., 2014), we also measured all individuals of a given target species present at any point throughout a camera deployment from the same BotCam video sets in a manner similar to that used in a typical transect survey. Comparisons were made between the two methods on a species-level presence-absence basis with a 5-cm increment for size classes. Presence-absence comparisons were deemed appropriate as measuring the same individual multiple times could not be avoided in the *All lengths* method.

Given the extensive time required to count and measure each and every fish in a video recording, annotation time was restricted to the first 15 minutes of video and only 84 BotCam deployments were analyzed. The resulting length-frequency distributions were evaluated using either Kolmogorov-Smirnov (KS) or Wilcoxon tests.

3. Results

3.1. TFA and TMaxN

Mean time of first arrival (TFA) occurred in less than 15 minutes of camera soak time for all 10 species studied and 8 of the 10 species had a mean time to MaxN (TMaxN) within 15 minutes (Fig. 4A). Ehu and Hapuupuu were the only two species that had a mean TMaxN greater than 15 minutes at 16.70 ± 12.34 and 15.13 ± 12.92 minutes (mean ± SD), respectively. The standard deviations of the TFA and TMaxN means of all species were fully encompassed within the first 30 minutes after camera touchdown. As expected, the likelihood of detecting MaxN increased with longer soak time. However, 50 percent of species-specific MaxNs were already recorded within the first 15 minutes after camera soak time and 80 percent were recorded within 30 minutes (Fig. 4B).

3.2. MaxN indices

Four trends were observed in the minute-by-minute MaxN time series (Fig. 5). For Opakapaka and Kalekale, 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 Onaga, Greater Amberjack, and Almaco Jack also peaked within the first five minutes of soak time, but then quickly declined for the remainder of the analysis period. Mean MaxN for Ehu and Hapuupuu gradually increased with increasing soak time up to 40 minutes. Mean MaxN for the remaining species, Gindai, Lehi, and Uku – which were seen infrequently – did not exhibit any clear trend and remained variable throughout the 40-minute analysis period.

As expected, mean MaxN increased with simulated soak time as the highest mean MaxN values occurred in the 0–40 minute soak time bin (Fig. 6). The earliest soak time bin that did not differ significantly (PERMANOVA, $P>0.05$) from the 0–40 minute bin was selected as the asymptote point of mean MaxN for each species. This asymptote in mean MaxN occurred in the 0–15 minute bin for Gindai and Onaga, the 0–20 minute bin for Kalekale and Lehi, the 0–25 minute bin for Opakapaka and Uku, and the 0–30 minute bin for Ehu, Hapuupuu, Almaco Jack, and Greater Amberjack.

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

Based on the TFA, TMaxN, and MaxN indices, soak times of 15 and 30 minutes were selected for further analysis in addition to the original 40-minute soak time. Mean TFA for all 10 target species, mean TMaxN for 9 of 10 species, and 50 percent of TMaxN records for all species were found to occur within 15 minutes of camera soak time. Two of the 10 target species (Gindai and

Onaga) also had mean MaxN values at a 15-minute simulated soak time that were not significantly different from 40-minute soak times. These results suggest that 15 minutes is the minimum amount of soak time needed to detect some target species and estimate their MaxN. A soak time of 30 minutes encompassed the mean TFA (+1 SD), mean TMaxN (+1 SD), and 80 percent of TMaxN occurrences for all target species. Furthermore, the simulated soak-time analysis showed no significant differences between mean MaxN at 30 and 40 minutes of soak time for all species. These results suggest that a soak time of 30 minutes is still able to generate the same TFA and MaxN metrics as a full BotCam deployment.

In evaluating MaxN and fish length data generated at 15, 30, and 40 minutes of soak time, significant differences were found for MaxN in all target species but no differences were identified in their length-frequency distributions. A significantly higher mean MaxN (PERMANOVA, $P < 0.05$) was found at the 40-minute camera soak time compared to 15 minutes for all target species except Onaga (Fig. 7). MaxN values did not significantly differ (PERMANOVA, $P > 0.05$) between the 40-minute and 30-minute camera soak times for all species except Greater Amberjack and Almaco Jack (Fig. 7). Ehu, Lehi, Hapuupuu, Uku, Greater Amberjack, and Almaco Jack all had significantly greater mean MaxN at 30 minutes of soak time compared to 15 minutes while Opakapaka, Kalekale, Gindai, and Onaga did not (Fig. 7). It is also worth noting that the proportional species composition at 15, 30, and 40 minutes of soak time remained the same. 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-minute soak times for all target species except Lehi where the length distribution at 15 minutes of soak time significantly differed (KS test, $P<0.05$) from that at 30 and 40 minutes (Fig. 8). However, the low sample sizes (< 10 fish measurements) at each of the three soak times for Gindai, Hapuupuu, and Uku reduced our 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 (Fig. 8).

3.4. Cost comparison

As part of our cost-benefit analysis, we compared the per-sample cost associated with 15, 30, and 40-minute BotCam soak times (Table 1). Cost-per-sample considered both field deployment and data analysis costs based on a typical 10-day mission. While field costs were consistent between the 3 camera soak times, a soak time reduction from 40 to 30 minutes allowed for a 12.5-percent increase in samples collected and a 20-percent decrease in video processing time. At a 15-minute soak time, 25 percent more samples were collected and video processing time was 50 percent less than that of the 40-minute soak time. Considering both sampling rate and analysis time, the 30-minute and 15-minute soak times yielded per-sample cost savings of 14 and 28 percent, respectively, compared to the 40-minute duration.

3.5. Effective range of attraction

Fish swimming speed (V_f) ranged from 0.98 ms^{-1} for Kalekale (mean FL = 32.79 cm) to 2.24 ms^{-1} for Greater Amberjack (mean FL = 74.53 cm) (Table 2). Recorded current velocities ranged from 0.020 ms^{-1} at Hilo to 0.455 ms^{-1} in the Kealaikahiki Channel. The resulting effective range of attraction (*AR*) increased proportionally with current velocity and soak time (Table 3). At a camera soak time of 15 minutes, *AR* was calculated to be between 18 and 326 meters. At 30 and 40 minutes of soak time, *AR* ranged from 36 to 652 meters and 48 to 869 meters, respectively.

3.6. Max lengths vs. All lengths

The *All lengths* measurement method generated a wider range of lengths and resulted in 30 to 200 percent more length records for each species compared to the *Max lengths* method (Fig. 9). For all species, however, no significant differences were found in the length-frequency distributions of both methods (KS test, $P > 0.05$; Wilcoxon test, $P > 0.05$). For Opakapaka, the *All lengths* method detected two size classes above (70–75 and 75–80 cm) and below (30–35 and 35–40 cm) the range recorded by *Max lengths*. The *All lengths* data for Greater Amberjack and Almaco Jack contained records for 2 size classes above (95–100 and > 100 cm), Onaga had 3 size classes above (60–65, 65–70, and 70–75 cm), and Ehu had 2 size classes below (25–30 and 35–40 cm) those recorded by the *Max lengths* method. For Kalekale, both measurement methods produced the same range of size classes though counts remained higher when measuring all fish. Gindai, Lehi, and Hapuupuu had 5 or fewer length records per measurement method reducing our ability to test these distributions while Uku had no records altogether.

4. Discussion

Though TFA has been used in previous baited camera work as a metric for determining fish abundance (Priede et al., 1994; 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 abundances. 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 minutes in their baited camera surveys of juvenile Opakapaka 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 ours, 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 species-specific and size-specific. However, habitat and depth, among 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. Our TFA and TMaxN findings specific to our bottomfish target species, sampling depths, and sampling locations around the main Hawaiian Islands showed possibilities for reducing soak time to between 15 and 30 minutes, justifying further analyses at these times.

The importance of fish behavior in relation to observed patterns of relative abundance has been acknowledged in baited camera studies (Cappo et al., 2004; Harvey et al., 2007). Four patterns of relative abundance possibly influenced by fish behavior were observed in this study over the course of a 40-minute 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 Opakapaka and Kalekale. These two species were observed in schools and actively fed on the bait when present. A 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 Opakapaka and Kalekale. Onaga, Greater Amberjack, and Almaco Jack, which were also observed in schools primarily exhibited pattern 2. 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. The gradual increase in Ehu and Hapuupuu counts over time (pattern 3) may be a result of their strong association with the bottom environment (Kelley and Moriwake, 2012). Since the BotCam sits 3 meters off the seafloor, these two species would have to swim up off the bottom to be detected by the camera system. Ehu and Hapuupuu 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. Opakapaka and Kalekale), it is reasonable that they would show an increased reaction time and a differential approach pattern. Gindai, Lehi, and Uku were infrequently encountered by BotCam. This infrequent detection is likely to have resulted in the variability of their relative abundance over the sampling duration.

However, with Hapuupuu observations being within the same range as Gindai, Lehi, and Uku, it is possible that strong behavioral tendencies, when present, may still be detected even with a small sample size. Species-specific differences in fish abundance have previously been reported in relation to 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). However, with the extensive array of behaviors exhibited by demersal fishes (Armstrong et al., 1992), 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 with our MaxN time indices, MaxN was found to increase with longer camera soak times. This is consistent with Willis and Babcock (2000) who found similar patterns in their baited camera study of the Australasian Snapper (*Pagrus auratus*) and Blue Cod (*Parapercis colias*) in northern New Zealand. Despite using the same data set as our 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 our study, an asymptote in mean MaxN was achieved between 15 and 30 minutes of soak time. Willis and Babcock (2000) also found that the highest mean rate of fish accumulation at their baited camera systems occurred between 25 and 30 minutes of soak time. They also found that a 30-minute camera soak time provided consistent estimates of MaxN between their study sites and longer video sequences did not substantially improve data quality. While changes in relative abundance with soak time varied by species, by identifying the minimum soak time necessary for capturing MaxN in at least one target species and the soak time within which an asymptote in MaxN could be achieved for all target bottomfish species, we were able to determine the optimal soak time range (15–30 minutes) for sampling bottomfish in the main Hawaiian Islands.

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 an average recording time of 45 minutes (40-min soak time) to maximize the number of fish observations over the duration of a video recording (Harvey and Cappo, 2001). However, video recordings of this length can limit the number of independent samples collected in a field day. At a target soak time of 40 minutes, a maximum of 16 BotCam deployments were collected in a single 8-hour 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 minutes. At this soak time, the maximum daily deployment count was 20, a 25-percent increase from the 40-minute 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). With a 40-minute soak time, per-sample video processing was also 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 hours to process 40-minutes of video whereas it took only 2.5 hours to process 15 minutes. Lastly, shortening camera soak time from 40 to 15 minutes resulted in a 28% per-sample cost savings, which is likely significant for most field research programs. With 25 percent more samples and a video processing time double that of 40-minute soak times, a faster turn-around of more video samples can be achieved using a soak time of 15 minutes which, in turn, increases our ability to report fishery data in a timely manner at a lower cost per sample. Hence, a reduced soak time would be of great benefit as long as the data from shorter camera deployments retain similar levels of accuracy and precision.

Mean MaxN for our target bottomfish species was more consistently captured at a reduced soak time of 30 minutes (8 species) compared to 15 minutes (1 species) in testing species' MaxN differences at 15, 30, and 40 minutes of soak time. This result was, somewhat , expected as only two species (Gindai and Onaga) had an asymptote in mean MaxN that occurred within 15 minutes in our simulated soak time analysis. As these tests used the 40-minute relative abundance as a basis for comparisons, evaluating camera soak time in relation to known abundances of fish in a closed tank experiment similar to Schobernd et al. (2014) may better examine how reduced soak time MaxN estimates compare to absolute abundance and the sensitivity of these estimates to varying degrees of fish density. This information would allow for the development of more accurate species-specific soak time-abundance indices and species accumulation curves as the total number of fish in a predefined area is known.

The lack of significant differences between length-frequency distributions at 15, 30, and 40 minutes of camera soak time may be due to the method of measuring fish at TMaxN or where the most fish are measurable (*Max lengths*). Our comparison of length measurements from the *Max lengths* and *All lengths* methods suggest that *Max lengths* tends to subsample the full size range of each species. While larger or smaller individuals were occasionally observed swimming through the camera's field of view, they were rarely present in the *Max lengths* measurement frame. Furthermore, measuring fish on 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 by our current methodology was much less than the number of individuals that made up species' MaxN. With these limitations, an increase in the number of video samples and more fish measurements would be desirable in future fish-length analyses. While shorter soak times were shown to increase video sample yield, fewer fish measurements were also obtained at reduced soak times. Longer video durations may allow for more opportunities for fish measurement within the parameters of the *Max lengths* method increasing the number of length records for a given species. Sackett et al. (2014) found that significant results in spatial and temporal analyses of bottomfish length data were attainable with a sample size greater than 100. This magnitude in fish length data was generated for 3 species at a soak time of 40 minutes and only 1 species at either reduced soak time in our analysis of 240 BotCam deployments. Using shorter soak times (i.e., 15 minutes) to collect more video samples may increase the length-data sample size for early arriving species such as Opakapaka, Kalekale, Onaga, Greater Amberjack, and Almaco Jack but longer video recordings may be more suited to Ehu and Hapuupuu whose counts gradually increased with soak time. Based on our results, it is apparent that the number of fish measurements generated by our sampling methodology is influenced by fish behavior (schooling vs. non-schooling), species-specific attraction responses to bait, and camera soak time. The BotCam deployment count and camera soak time necessary for increasing statistical power when testing species-specific bottomfish length data should be looked into further.

In comparing length records generated by the *Max lengths* and *All lengths* measurement methodologies, a subsampling of the full size range of five of the target species was apparent when using the *Max lengths* method. This subsampling of fish lengths could be a result of a “truncation” effect. There is a limit to the number of fish visible in a camera’s field of view at any given time (Willis and Babcock, 2000), and the number of individuals of a species at an ideal measurement distance from the camera system is also limited. While this truncation effect may not affect fish species that occur at lower counts (e.g., Gindai, Uku), schooling species (e.g., Opakapaka, Kalekale, Onaga) 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, because *Max lengths* maximizes independent measurements by taking lengths where the most fish are measureable, smaller species and smaller individuals within species are more likely to be measured as a greater number of these individuals are able to saturate the camera’s field of view compared to larger fish. This is consistent with the results of Willis et al. (2003) where small sparid snappers had more length records compared to larger individuals when taking fish measurements at TMaxN in their survey of the marine reserves of Northern New Zealand using a downward-facing baited camera system. While the truncation effect described earlier may be responsible for missing some of the larger individuals of Opakapaka, Onaga, Greater Amberjack, and Almaco Jack, length records that fell below the range of size classes detected by the *Max lengths* measurement method were also found for Opakapaka and Ehu when using the *All lengths* method. In addition to the truncation effect that may skew measurements towards smaller fish, smaller or larger size classes with the lowest frequency of occurrence may also be missed by the *Max lengths* method. Further investigation into these possible measurement biases would be necessary as they may have major implications in analyses that generate lengths using the *Max* *lengths* methodology. It is possible that, while MaxN may be an appropriate and conservative measure of relative abundance, gathering fish lengths at select intervals throughout a video recording or another measurement methodology may yield a more accurate representation of the length-frequency distribution of the population. Willis et al. (2003) 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 or the time where *Max lengths* was taken 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 difficult. Schobernd et al. (2014) describe 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 another alternative method for fish measurement but further analyses on the resulting length data would be necessary.

Standard BotCam sampling methodologies in the main Hawaiian Islands have made use of either a 200 × 200-meter or 500 × 500-meter habitat sampling grid. Based on our estimates of the effective range of attraction (*AR*), it is possible that fish are being drawn from distances that extend outside the boundaries of these habitat sampling grids at all soak times tested using the maximum recorded current velocity (0.455 ms^{-1}, Kealaikahiki Channel) and maximum calculated fish swimming speed (2.24 ms^{-1}, Greater Amberjack). In this case, a further reduction of camera soak time to 11.5 minutes would be necessary for *AR* to fall within the 250-meter linear distance from the center of a 500-meter grid to its boundary. As *AR* increases proportionally with soak time, a reduction in camera soak time may represent a means to more closely match actual sampling areas with the targeted sampling grid sizes, therefore allowing for better pairing of stereo-video data and the scale of habitat classification. However, the variability in current velocities, habitat heterogeneity, and the presence of small-scale bathymetric features at our mesophotic sampling depths (100–300 m) in the main Hawaiian Islands makes difficult any determination of the area of bait influence (Misa et al., 2013) as bait odor plume dispersion will be driven by site-specific advection and turbulent diffusion (Sainte-Marie and Hargrave, 1987).

5. Conclusions

Our results suggest that the 40-minute camera soak time used in current BotCam surveys of main Hawaiian Island bottomfish can likely be reduced without meaningfully sacrificing overall stereo-video 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. However, the variability in the effective range of attraction (*AR*) presents a significant concern if the goal is to capture a snap-shot of size-structured abundance at a given place and time as needed in stock assessment surveys. In this instance, the 15-minute soak time may provide more accurate abundance estimates of fish within the immediate vicinity of the baited camera system by allowing for higher number of “snap-shot” estimates and may also guard against the inclusion of individuals recruiting from outside the assumed sampling area. The differential bottomfish attraction trends to our baited camera system suggest the presence of behavioral differences and species-specific response rates to bait. If the goal of a survey is to capture ecological dynamics of fish assemblages and further understand inter- and intra-species behavior as they relate to relative abundance, a soak time of at least 30 minutes would be necessary as MaxN trends were successfully captured for all our target species at this soak time. Future work should focus on quantifying bait odor plume dispersal areas and the incorporation of fish behavior into baited camera studies, as these have shown to be major factors that influence relative abundance (Cappo et al., 2004; Harvey et al., 2007). The current use of the *Max lengths* fish measurement methodology may have a bias towards smaller schooling species or smaller individuals within species and also fails to detect size classes of fish with the lowest frequency of occurrence. Possible avenues for increasing fish measurement samples while maintaining independence between samples should continue to be investigated. MaxN and *Max lengths* data provide conservative estimates of fish abundance and length-frequency distributions by avoiding double counts and measurements of fish seen on underwater video systems. The MaxN metric guards against over-estimation of population sizes while the *Max lengths* measurement method ensures independence of length samples. However, it is also important to understand the limitations inherent to these methods and the effect it may have on fishery surveys.

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Figure captions

Fig. 1. BotCam with labeled parts.

Fig. 2. Map of BotCam sampling locations 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. 3. Target species as seen on BotCam: Opakapaka (A), Kalekale (B), Gindai (C), Ehu (D), Onaga (E), Lehi (F), Hapuupuu (G), Uku (H), Greater Amberjack (I), Almaco Jack (J). Note: fish not to scale.

Fig. 4. (A) Mean time of first arrival (TFA) and time to MaxN (TMaxN) for each of the 10 target species; (B) Cumulative proportion of BotCam deployments where MaxN occurred by 5-minute time bins from camera touchdown (minute 0) up to 40 minutes. Both data sets were 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. 5. Mean MaxN 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.

Fig. 6. Mean MaxN for each of the 10 target species by 5-minute increments of simulated camera soak time from 0 to 40 minutes. Columns with the same letter are not significantly different (PERMANOVA, $P>0.05$). Bold type, capital letters highlight time bins not significantly different 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.

Fig. 7. Mean MaxN comparisons for 15, 30, and 40-minute 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 1 soak time analysis duration.

Fig. 8. Length-frequency distributions generated from 15-min, 30-min, and 40-min camera soak times with Kolmogorov-Smirnov (KS) test 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-minute soak times for all target species except Lehi where length distribution at 15 minutes of soak time significantly differed (KS test, $P<0.05$) from that at 30 and 40 minutes. 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 1 soak time analysis duration.

Fig. 9. Number of BotCam deployments where each of the 10 target species was recorded by 5-cm size classes in a 15-minute analysis period using the *Max lengths* and *All lengths* measurement methods. No significant differences in length-frequency distributions (KS test, P>0.05; Wilcoxon test, P>0.05) were found between the *Max lengths* and *All lengths* measurement methods for all target species. Data set was recorded from 84 BotCam deployments conducted during a single bottomfish survey in the main Hawaiian Islands in 2011 using a 15-min analysis period. d = no. of BotCam deployments where lengths were generated for a given species in at least 1 measurement method.

Tables

Table 1

Comparison of per-sample costs associated with a 15, 30, and 40-minute 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-minute soak time values are estimates).

Soak time (min)	Maximum samples (day^{-1})	Total Samples (10 days)	Processing time per sample (hr)	Total processing time (hr)	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%

Table 2

Mean fork length ($\bar{x}$) and corresponding swimming speed (V_f, ms^{-1}) calculated at 3 body lengths per second (Ellis and DeMartini, 1995) for each of the 10 target species.

	Opakapaka	Kalekale	Gindai	Ehu	Onaga	Lehi	Hapuupuu	Uku	Greater Amberjack	Almaco Jack
$\bar{x}$ (cm)	48.88	32.79	36.61	40.03	57.69	71.44	67.85	67.72	74.53	64.00
V_f (ms^{-1})	1.47	0.98	1.10	1.20	1.73	2.14	2.04	2.03	2.24	1.92

Table 3

Minimum and maximum effective ranges of attraction (*AR*) in meters with respect to camera soak time for the target species with the slowest and fastest swimming speeds (Kalekale and Greater Amberjack; Table 2) based on the minimum and maximum current velocities at each of the ten sampling locations in the main Hawaiian Islands. Calculations were made using the equation, $AR = 60 \times (S_t) \times ((V_f \times V_c) - V_c^2)/V_f$, from Cappo et al. (2004) where S_t = soak time, V_f = fish swimming speed, and V_c = current velocity.

		S_t (min)	15		30		40	
Location		V_f (ms^{-1})	min	max	min	max	min	max
		V_c(ms^{-1})	0.98	2.24	0.98	2.24	0.98	2.24
Niihau	min	0.023	20	21	41	41	54	55
	max	0.438	219	317	437	634	583	845
West Oahu	min	0.060	50	52	101	104	134	139
	max	0.348	203	265	405	529	540	706
East Oahu	min	0.025	22	23	44	45	59	60
	max	0.231	159	186	318	372	424	496
Penguin Bank	min	0.026	23	23	46	47	62	62
	max	0.331	198	254	395	508	527	677
Auau Channel	min	0.045	39	40	78	80	103	106
	max	0.147	112	124	225	247	300	329
Pailolo Channel	min	0.035	31	31	61	63	82	83
	max	0.392	212	291	424	582	566	776

Kealaikahiki Channel	min	0.037	32	32	63	65	84	86
	max	0.455	220	326	440	652	587	869
Kahoolawe Island Reserve	min	0.033	28	29	57	58	76	77
	max	0.184	135	152	270	304	359	406
Alenuihaha Channel	min	0.057	48	50	97	100	129	133
	max	0.243	165	195	329	389	439	519
Hilo	min	0.020	18	18	36	36	48	49
	max	0.272	177	215	354	430	472	573
Overall	min	0.020	18		36		48	
	max	0.455	326		652		869	