# BotCam: a baited camera system for nonextractive monitoring of bottomfish species

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**Abstract**—A stereo-video baited camera system (BotCam) has been developed as a fishery-independent tool to monitor and study deepwater fish species and their habitat. During testing, BotCam was deployed primarily in water depths between 100 and 300 m for an assessment of its use in monitoring and studying Hawaiian bottomfish species. Details of the video analyses and data from the pilot study with BotCam in Hawai`i are presented. Multibeam bathymetry and backscatter data were used to delineate bottomfish habitat strata, and a stratified random sampling design was used for BotCam deployment locations. Video data were analyzed to assess relative fish abundance and to measure fish size composition. Results corroborate published depth ranges and zones of the target species, as well as their habitat preferences. The results indicate that BotCam is a promising tool for monitoring and studying demersal fish populations associated with deepwater habitats to a depth of 300 m, at mesohabitat scales. BotCam is a flexible, nonextractive, and economical means to better understand deepwater ecosystems and improve science-based ecosystem approaches to management.

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The ability to monitor stocks targeted by a fishery in order to understand the effects of regulatory measures, such as spatial or temporal fishing closures, is important to stakeholders. An understanding of species composition, age- and size-class distributions, habitat use, and other population parameters is critical for developing resource management programs and for monitoring their effectiveness (Jennings, 2001). However, acquisition of data for stock assessments within, and adjacent to, marine protected areas (MPAs) may be compromised by restrictions on extractive sampling or fishery-dependent data. Further, monitoring deepwater species is challenging because of limitations (both logistical and regulatory) on diving in deep water; catch-and-release, or other nonlethal techniques typically are used in shallow water. Because deepwater fisheries have developed rapidly over the last few years, it is important to develop reliable, nonextractive, and fisheries-independent methods for stock assessment and monitoring that will enable managers to assess fishery impacts, evaluate MPAs, and implement ecosystem-based management (Roberts, 2002).

Camera systems provide a fisheries-independent and nonextractive tool for monitoring fish stocks, associated communities, and habitat preferences. Baited camera systems have been used in a number of fisheries habitat studies (Ellis and DeMartini, 1995; Gledhill et al., 1996; Priede and Merrett, 1996; Francour et al., 1999; Willis et al., 2000; Cappo et al., 2003). Most of these studies involved deepwater deployments (>1500 m) for the study of deep-sea scavengers or they involved deployments in relatively shallow waters (<100 m) as a supplement to scuba surveys (Willis et al., 2000; Watson et al., 2007). Currently, there is a need to develop systems for use at intermediate depths.

In Hawai'i, the bottomfish fishery targets snappers, groupers, and jacks that inhabit waters down to 400 m around the archipelago. The most important commercial species live below 100 m and are often referred to as the “deep 7” (WPRFMC, 2007). Six of these are snappers that include *Etelis coruscans* (flame snapper, onaga), *Etelis carbunculus* (ruby snapper, ehu), *Pristipomoides zonatus* (oblique-banded snapper, gindai), *Pristipomoides sieboldii* (lavender snapper, kalekale), *Pristipomoides filamentosus* (pink snapper, opakapaka), and *Aphareus rutilans* (silvermouth snapper, lehi). The seventh species is an endemic grouper called *Epinephelus quernus* (Hawaiian grouper, hapu`upu`u)

(Randall, 2007). Most of these species are long-lived, slow-growing, and are assumed to have a low annual natural mortality rate and limited reproductive capacity (Haight et al., 1993a). These characteristics make these bottomfish stocks especially susceptible to overfishing and habitat destruction (Ralston et al.[1]).

The Hawaiian bottomfish fishing is primarily conducted by jigging hooks and lines on motorized reels. All of the deep 7 species eat a variety of fish and invertebrate species opportunistically. For example, *E. coruscans* are known to feed on species within the water column near the bottom, whereas *E. carbunculus* targets species on the bottom. All target species are caught by using both fish, such as mackerel (*Decapterus* spp.) and invertebrates (such as squid) as bait. Fishing vessels that anchor will often use a *palu* bag containing a mixture of baits.

Although the entire range of depths used by the Hawai`i deepwater bottomfish assemblage has not been determined, the Western Pacific Regional Fishery Management Council (WPRFMC) has defined the deepwater bottomfish essential fish habitat as all depths between 100 and 400 m, and adult habitat areas of particular concern as slopes and escarpments between 40 and 280 m depth (WPRFMC, 1998). Low light levels at these depths complicate the use of cameras. However, surveys with submersibles and remotely operated vehicles (ROVs) indicate that ambient lighting is preferable to artificial area lights or strobes because the artificial lights may repel or attract target species (Ralston et al., 1986; Ryer et al., 2009).

To address the need for a nonextractive, fishery-independent method for monitoring Hawaiian bottomfish stocks, a baited stereo-video camera system (BotCam) has been developed by the National Oceanic and Atmospheric Administration's Pacific Islands Fisheries Science Center (PIFSC) in collaboration with the Hawai`i Undersea Research Laboratory. BotCam is designed to survey the distribution, relative abundance, and size composition of bottomfish, and associated biological and physical characteristics of their habitat.

A pilot study was designed to test BotCam as a tool in making stock assessments. The main purpose of the study was to determine whether, from an operational perspective, BotCam can consistently and reliably collect the same types of data collected by other baited stereo-video camera systems, as reported in the literature, on the commercially important Hawaiian bottomfishes. More specifically, we asked if the system could obtain a metric of relative abundance, accurate information on habitat associations, and a length-frequency distribution for fish of a given fishery.

## Materials and methods

### Baited stereo-video camera system

BotCam was designed as a fully autonomous baited stereo-video camera system (Merritt, 2005). Most of the components are housed in an aluminum frame (1.2 m wide×0.5 m deep×0.45 m tall) designed to protect the cameras and maintain fixed camera positions to one another for accurate length measurements (Fig. 1). The system consists of two ultralow-light video cameras (Monochrome Navigator, Remote Ocean Systems, San Diego, CA), the video capture electronics and system controller (Viperfish Deep, Deep Development Corporation, Sumas, WA), a temperature and pressure recorder (SBE 39TP, Seabird Electronics Inc., Bellvue, WA), a custom-built battery pack and relay used to trigger a delayed bait release-system (BWR, Sexton Photographics LLC, Salem, OR), and syntactic foam blocks for positive buoyancy (Flotation Technologies, Biddeford, ME). The frame also allows for the attachment of oceanographic instruments such as current meters, temperature and depth recorders, and hydrophones. The system is moored to the bottom by anchor weights attached to an anchor line and is designed to float above the bottom and to record video by pointing horizontally down-current with a nominal downward angle of 15°. This orientation improves the view of the benthic habitat without sacrificing the field of view. Each camera provides an 80° diagonal field of view in water. Because of the depth of targeted deployments, motions of the floating system are not affected by surface waves and the platform moves only by means of the currents, which are generally driven by tides, and are therefore stable on the order of several minutes. BotCam does often rotate and change the field of view relative to the substratum over the duration of a deployment. This floating design was chosen to address a couple of concerns. First, the target species are known to school in the water column several meters above the bottom. Second, the habitat of these target species is found on extremely steep and rocky slopes and setting a system directly on the bottom would be problematic for both the deployment and recovery of the system. An extension arm attached to the frame can carry both a stereo-video synchronizing (SVS) device and a bait canister or bag in view of the cameras (Fig. 1). The SVS, a grid of lights that flash in rapid succession, was custom made by Sexton Photographics LLC (similar to a system used by Harvey and Shortis (1996)) and allows two video streams to be synchronized by time for accurate stereo-video measurements. The lights flash at 30 Hz for 1 second every minute and no reaction to the lights has been observed by any of the target species. The first of two baiting modes involves simply attaching a bait bag or trap feeder to the extension arm. The second method involves the use of a 1.7-L Niskin bottle to hold bait sealed inside; at a predetermined time the bottle opens, exposing the bait.

An acoustic release (AR701, Ixsea, Boston, MA) was placed between the bottom of the frame and a set of two

[1] Ralston, S., S. Cox, M. Labelle, and C. Mees. 2004. Western Pacific Regional Fishery Management Council bottomfish stock assessment workshop final panel report; January 13–16, 20 p. [Available from Western Pacific Fishery Management Council, 11643 Bishop Street, Suite 1400, Honolulu, HI 96813.]

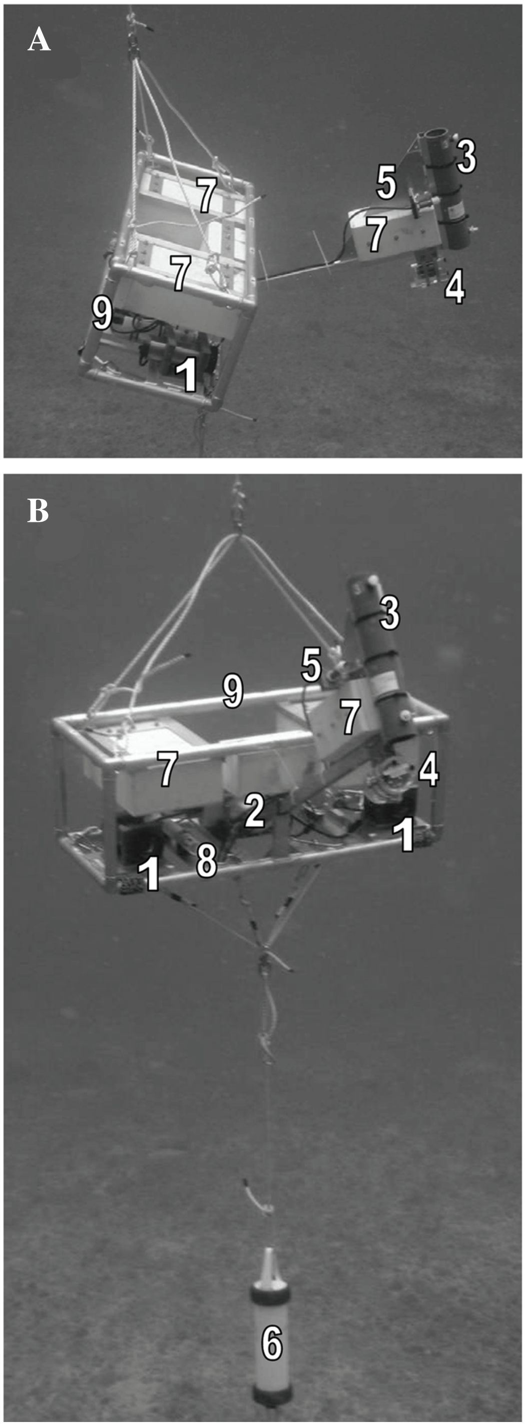


**Figure 1**

(**A**) side view and (**B**) front view of stereo-video baited camera system (BotCam). Components include (1) ultralow-light video camera, (2) controller-power supply-video capture device, (3) bait container, (4) stereo-video synchronization device, (5) bait release system, (6) acoustic release, (7) syntactic foam flotation, (8) pressure and temperature sensor, (9) aluminum frame. Not shown below the acoustic release is the anchor (concrete blocks).

or three concrete blocks that served as the sacrificial anchor. Concrete was used because it is environmentally benign, inexpensive, and readily available. BotCam was set to float 3 m above the seafloor, thus allowing deployments along steep, rocky slopes without risking entanglement of the instrument on the bottom. It was recovered when it floated to the surface after the acoustic release was triggered to separate the sacrificial anchor from the buoyant instrument frame. The instrument can also be tethered to a surface buoy to allow recovery by a line haul.

The complete system, as used during the pilot study, cost approximately $40,000; however, the systems being used presently with very similar capabilities are about $25,000 per unit. The largest single expense is the pair of ultra-lowlight cameras. In addition, charter time for an appropriate survey vessel in Hawaii runs about $1000 per day.

### Study design

During its development, BotCam was tested in approximately 50 deployments around Hawai`i, Wake Atoll, Guam, and the Commonwealth of the Northern Mariana Islands at depths down to 400 m. It was determined that 300 m was the maximum reliable deployment depth under ambient light conditions that would allow accurate species identification and sizing. Further, it was determined that by using a 30- to 60-minute recording time, a single BotCam unit could be deployed, recovered, and ready for redeployment in 90 minutes (Merritt, 2005). Ten- to 60-minute deployments are also consistent with other shallow baited camera studies (Ellis and DeMartini, 1995; Willis et al., 2003).

Given these constraints and a limited number of available charter vessel days, a study site was selected relatively close to Honolulu, home port for the charter vessel and the Pacific Islands Fisheries Science Center. The site was centered on bottomfish habitat located along the west side of Penguin Bank, between the Hawaiian Islands of Oahu and Molokai. Penguin Bank has historically been a productive bottomfish area and its proximity to the highly populated island of Oahu has resulted in high fishing pressure on both the east and west sides of the bank (Haight et al., 1993b).

Previous studies with submersibles and anecdotal evidence from bottomfish fishermen have indicated that the deep 7 bottomfish species generally prefer high-slope, hard-bottom habitats (Kelley et al., 2006; Parke, 2007), which are present at Penguin Bank. Twenty-meter resolution bathymetry and backscatter data derived from multibeam sonar were available for the entire study area and were incorporated into a geographic information system in order to derive intersections of depth, slope, and substratum hardness (i.e., backscatter). The upper and lower depth boundaries for BotCam deployments were 100 and 300 m, respectively, set by the biological and logistical constraints given above, with a resulting sampling area of 24.9 $km^2$. Within this depth range, four habitat types were defined on the basis of intersecting substratum (bottom) hardness and slope: 1) hard bottom–high slope (HB–HS); 2) hard bottom–low slope (HB–LS); 3) soft bottom–high slope (SB–HS); and 4) soft bottom–low slope (SB–LS). High slope values were considered to be 20 degrees or greater and hard substrata had backscatter values equal to or greater than 41 on a scale of 0–100 (actual maximum measurement was 92). The sampling locations were randomly selected within these four habitat types and weighted towards the preferred bottomfish habitat. A total of 38 sites were sampled on HB–HS, 14 on HB–LS, 17 on SB–HS, and 13 on SB–LS. In this way greater replication was performed where fish densities were expected to be higher and replication was lower where few or no fish were expected to be found. Adjacent sampling locations were no closer than 200 m and to avoid cross influence of the bait, no two adjacent sites were sampled on the same day.

The BotCam system was set to begin recording after its release from the boat but before its arrival on the bottom. For each deployment, the recording period was between 45 and 60 minutes. The bait consisted of equal parts of ground squid and mackerel, and the volume of bait used for each deployment was standardized to approximately 1 liter. This mixture was designed 1) to be similar to what bottomfish fishermen typically use on their rigs; 2) to provide multiple types of scent; and 3) to provide food similar to the natural diets of the "deep 7" which include both fish and cephalopods (Haight et al., 1993b).

The bait was placed in a simple plastic mesh container that allowed the bait scent to disperse as soon as the system was placed in the water. The bait station was considered to have started when BotCam arrived at the seafloor, as determined from the video recording. From that point, the cameras were allowed to record for a minimum of 30 minutes before BotCam was recovered.

### Data analysis

Each video stream from the two cameras was viewed independently. Each video was viewed in 3-minute intervals to allow for flexibility in analyzing the data. The data from the 10 intervals per 30-minute station could be combined into larger intervals or a subset could be randomly selected for statistical comparison with data from other bait stations. The maximum number (MaxNo) of each species seen in any one frame within the time interval (Ellis and DeMartini, 1995) and the exact time from the start of the deployment to the time of first arrival (TFA) of each species seen over the entire 30 minutes were recorded. Further, the largest MaxNo from all the increments was noted as the MaxNo for the deployment for each species observed.

For the purposes of this study, enumeration and measurements were performed only for the two primary bottomfish species of interest, *P. filamentosus* and *E. coruscans*, which were also the two most frequently observed of the "deep 7" species and represent the majority of the bottomfish catch in the Hawaiian Islands (Haight et al., 1993a; Parke, 2007).

Bottomfish fork-length measurements were made from the video recordings by using a software package called Visual Measurement System (SVS) (Geomsoft, Victoria, Australia). With this software, the video streams were synchronized by time by using the SVS device, and then viewed simultaneously frame by frame. Measurements of lengths for *E. coruscans* and *P. filamentosus* were conducted by using the MaxNo video frame and adjacent frames to avoid repeat measurement of individual fish congregating around the bait. Each individual fish was measured six times from different video frames to evaluate the consistency of the measurement technique. This method of only measuring at MaxNo may bias the data by possibly selecting for smaller schooling fish (Willis et al., 2003).

To specifically test the precision and accuracy of the stereo-photogrammetric method of fish measurement, a separate experiment was performed in shallow water. BotCam video was used to measure four different fish models (foam cutouts shaped like fish) of varying length (469.9 mm, 581.0 mm, 628.7 mm, and 997.0 mm) and body depth. The models were filmed at various locations in the field of view at distances of 3 m and 6 m from the cameras. The BotCam was rotated by a diver so that the fish traversed the field of view to simulate swimming. The models were moved vertically to obtain coverage of the models throughout the fields of view of the cameras and the models were measured at haphazard angles. Length measurements on each fish were made by three scientists using stereophotometric software.

The relative distributions of each species across substratum and slope categories described above were evaluated within the framework of a generalized linear model based on a Poisson distribution and log-link function. The model development for predictor variables was based on likelihood ratio tests with a comparison of the full and reduced models. A Pearson chi-square goodness-of-fit test was used to evaluate the appropriateness of the model fits (Kutner et al., 2005). Model fitting included habitat and depth categories and their two-way interaction.

## Results

Thirty-three sampling trips were conducted between June 2006 and February 2007, on which a total of 102 BotCam deployments were completed. The fabrication of a second BotCam system toward the end of the study increased the average number of deployments per boat trip to 5.5. Six to eight drops could easily be conducted per day depending on travel time from port to the deployment sites. Of the 102 BotCam deployments, 82 were successful and were distributed amongst habitat and depth categories as outlined above (Table 1). Of the 20 that failed, four landed below 300 m so their recording was too dark; four landed above 100 m outside the

**Table 1**

Number of baited stereo-video camera (BotCam) deployments that fell within the 100-m to 300-m depth contours and recorded video at Penguin Banks, Hawai'i, between June 2006 and February 2007. Deployments are separated by habitat classification (substratum and slope), depth by 50-m bin, and time period, and the average maximum number (AveMaxNo) and standard error (SE) of counts of *Etelis coruscans* and *Pristipomoides filamentosus* by habitat type and depth. na=not available.

| Multibeam habitat classification | Depth (m) | Sample size | | | | | | *Etelis coruscans* | | *Pristipomoides filamentosus* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Jun 6 | Jul 6 | Aug 6 | Dec 6 | Feb 7 | AveMaxNo | SE | AveMaxNo | SE |
| Hard bottom–high slope | 100–150 | 3 | 0 | 0 | 3 | 0 | 0 | 0.0 | na | 1.3 | 1.3 |
| | 150–200 | 9 | 1 | 6 | 2 | 0 | 0 | 0.0 | na | 3.0 | 1.5 |
| | 200–250 | 16 | 1 | 10 | 5 | 0 | 0 | 1.9 | 1.0 | 1.5 | 0.6 |
| | 250–300 | 10 | 1 | 4 | 5 | 0 | 0 | 6.1 | 3.0 | 0.0 | na |
| Soft bottom–high slope | 100–150 | 1 | 0 | 0 | 0 | 0 | 1 | 0.0 | na | 1.0 | na |
| | 150–200 | 2 | 1 | 1 | 0 | 0 | 0 | 1.0 | 1.0 | 4.5 | 0.5 |
| | 200–250 | 5 | 0 | 1 | 0 | 2 | 2 | 0.0 | na | 1.8 | 1.2 |
| | 250–300 | 6 | 1 | 1 | 1 | 1 | 2 | 0.2 | 0.2 | 0.0 | na |
| Hard bottom–low slope | 100–150 | 1 | 0 | 0 | 0 | 0 | 1 | 0.0 | na | 4.0 | na |
| | 150–200 | 6 | 0 | 4 | 1 | 0 | 1 | 0.3 | 0.2 | 5.5 | 4.3 |
| | 200–250 | 6 | 0 | 2 | 1 | 1 | 2 | 1.7 | 1.6 | 1.4 | 0.5 |
| | 250–300 | 4 | 2 | 1 | 1 | 0 | 0 | 4.3 | 4.3 | 0.0 | na |
| Soft bottom–low slope | 100–150 | 2 | 0 | 2 | 0 | 0 | 0 | 0.0 | na | 0.0 | na |
| | 150–200 | 1 | 0 | 0 | 0 | 1 | 0 | 0.0 | na | 5.0 | na |
| | 200–250 | 6 | 0 | 0 | 0 | 6 | 0 | 0.7 | 0.7 | 1.0 | 0.8 |
| | 250–300 | 4 | 0 | 2 | 0 | 1 | 1 | 0.8 | 0.8 | 0.0 | na |

Hawaiian bottomfish essential fish habitat; nine did not record because of technical failures; and three failed as a result of human errors. No equipment was lost during the study.

All of Hawaii's "deep 7" bottomfish species were recorded on videotape (Fig. 2). Other species of note observed included goldflag snapper (*Pristipomoides auricilla*), greater amberjack (*Seriola dumerili*), large-head scorpionfish (*Pontinus macrocephalus*), dawn boarfish (*Antigonia eos*) (Randall, 2007), shortspine spurdog (*Squalus mitsukurii*), and numerous carcharhinid sharks. The appearances of each species under ambient light conditions were noted, and a photo library of BotCam videotapes was developed for species identification.

MaxNo values for *E. coruscans* and *P. filamentosus* recorded by BotCam varied between 0 and 29. MaxNo distributions for the two species across the study area are shown in Figure 3, A and B, respectively. *Etelis coruscans* was recorded at 21 locations and *P. filamentosus* at 30 locations and both species were present throughout the study area. No linear relationship between MaxNo and TFA was detected, although the apparent pattern for both species was similar (Fig. 4). For both species, most TFAs were less than 200 seconds (3.3 minutes) and all MaxNos higher than five were reached within the first 200 seconds.

Depth and the interaction of depth and habitat significantly affected *E. coruscans* MaxNo ($P<0.05$). The greatest MaxNo of *E. coruscans* was reached at depths between 250 and 300 m ($P<0.01$, Fig. 5A). Within this depth category, greater mean MaxNo for *E. coruscans* were found in habitats with a slope greater than 20 degrees with either hard or soft bottom substratums ($P<0.05$, Fig. 5A). *Pristipomoides filamentosus* was more widely distributed than *E. coruscans* across the sampled depth range and substratum types. Habitat, depth, and their interaction significantly affected the MaxNo for *P. filamentosus* ($P<0.05$). The interaction of depth and slope significantly affected the MaxNo for *P. filamentosus* with the highest MaxNo observed between 150 and 200 m regardless of habitat type ($P<0.01$, Fig. 5B). No significant relationships were found between temperature and the MaxNo for either species ($r^2<0.10$, $P>0.05$).

In the experiment where model fish were measured, the average residual measurement error (the difference between the actual measurement and the measurement estimated from the photos) of the stereo-photogrammetric analysis was –3.1 mm (percent error of 0.5%) when the models were a distance of 3 m from the camera, and –8.8 mm (percent error of –1.3%) when models were 6 m from the camera. However, the percent error does not appear to be a function of fish size within the range of models measured; therefore, the residual error appears to be a more relevant statistic to use when assessing variance (Table 2).

In the video analysis from the actual survey, it was possible to measure 56 individual *E. coruscans* out of

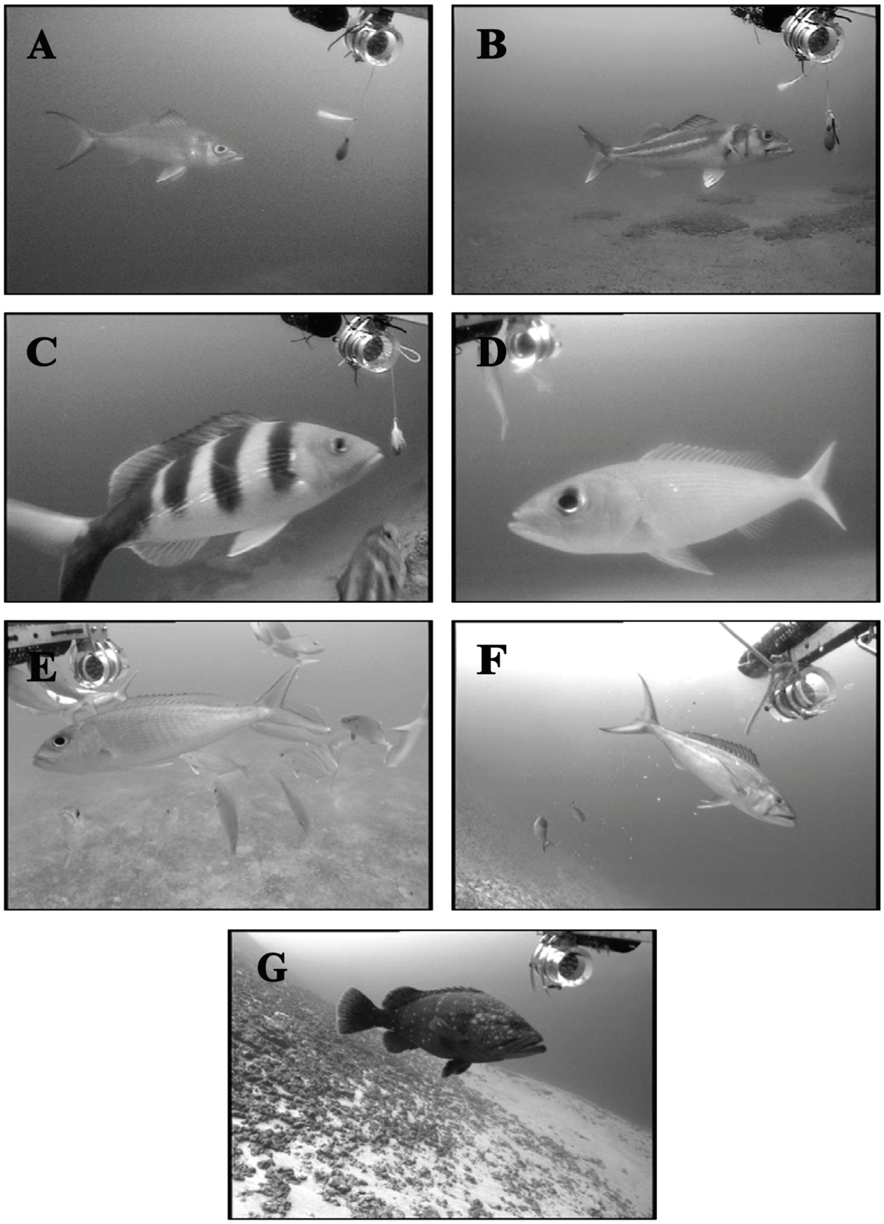


**Figure 2**

Hawaiian deepwater bottomfish fishery target species referred to as the "deep 7" as recorded by BotCam in Hawaiian waters from depths between 100 m and 300 m. (**A**) *Etelis coruscans* (longtailed red snapper or onaga), (**B**) *Etelis carbunculus* (red snapper or ehu), (**C**) *Pristipomoides zonatus* (Brigham's snapper or gindai), (**D**) *Pristipomoides sieboldii* (von Siebold's snapper or kalekale), (**E**) *Pristipomoides filamentosus* (pink snapper or opakapaka), (**F**) *Aphareus rutilans* (ironjaw snapper or lehi), and (**G**) *Epinephelus quernus* (Hawaiian grouper or hapu`upu`u).

129 counted at the time of MaxNo (43%), and to measure 78 *P. filamentosus* out of the 134 counted (58%). The ability to measure a fish was constrained by the angle of orientation of the fish to the camera, distance from the camera, amount of overlap with other fish, and video clarity. *Etelis coruscans* fork lengths ranged between 432 and 833 mm (mean ±standard deviation [SD] = 605.7 ±26.8 mm, Fig. 6A), and *P. filamentosus* fork lengths ranged between 344 and 660 mm (mean ±SD = 518.0 ±10.9 mm, Fig. 6B).

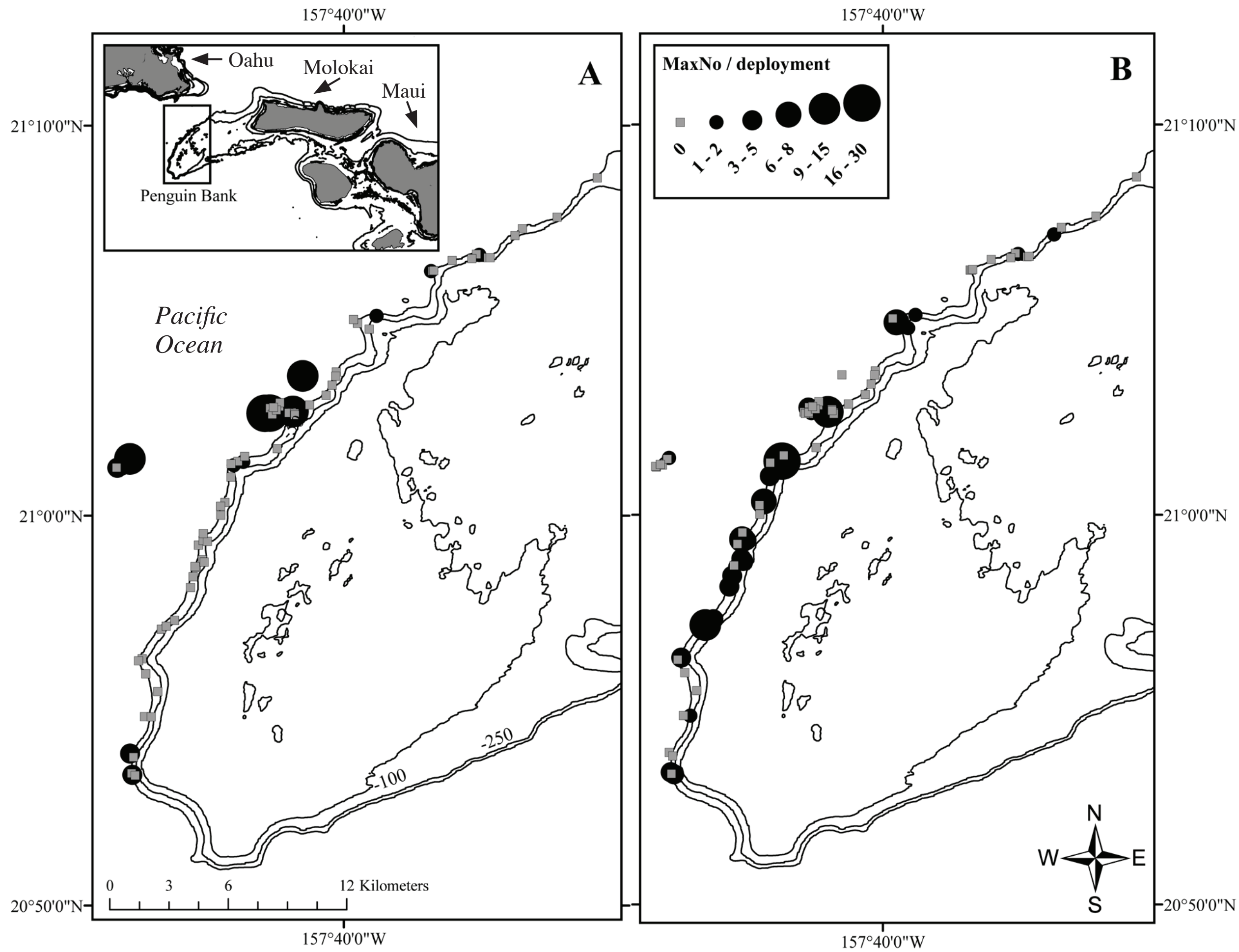


**Figure 3**

Distribution of (**A**) *Etelis coruscans* and (**B**) *Pristipomoides filamentosus* seen on the BotCam video at Penguin Banks, Hawai`i, between June 2006 and February 2007. Shown is the MaxNo (maximum number in a single frame) of each species seen at each camera deployment site, and the location of all 82 successful deployments.

**Table 2**

Measurement statistics for testing the precision and accuracy of the stereo-video camera system. A BotCam video camera was used to measure four different models of fish of varying length (469.9 mm, 581.0 mm, 628.7 mm, and 997.0 mm) and body depth. The fish models were filmed in approximately 10 m of water off the South Shore of Oahu, Hawai'i, at distances of 3 m and 6 m from the cameras. The BotCam was rotated by a diver so that the fish traversed the field of view to simulate swimming. The models were moved vertically to obtain coverage throughout the fields of view of the two cameras and were measured at haphazard angles. Length measurements on each fish were made by three scientists (user 1, 2, and 3) using Vision Measurement Software (Geomsoft, Victoria, Australia). Error is defined by the following: Error = actual fork length–fork length measured by stereo-video (also called residual).

| | User 1 | | User 2 | | User 3 | | Total | |
|---|---|---|---|---|---|---|---|---|
| | 3 m | 6 m | 3 m | 6 m | 3 m | 6 m | 3 m | 6 m |
| Number of measurements | 193 | 113 | 192 | 134 | 249 | 0 | 634 | 247 |
| Average error (mm) | –2.3 | –6.2 | –0.8 | –17.0 | –7.5 | na | –3.1 | –8.8 |
| Standard deviation of average error (mm) | 22.2 | 50.8 | 25.6 | 42.0 | 30.8 | na | 27.7 | 51.6 |
| Percent error (%) | –0.3 | –1.2 | 0.0 | –2.2 | –1.1 | na | –0.5 | –1.3 |

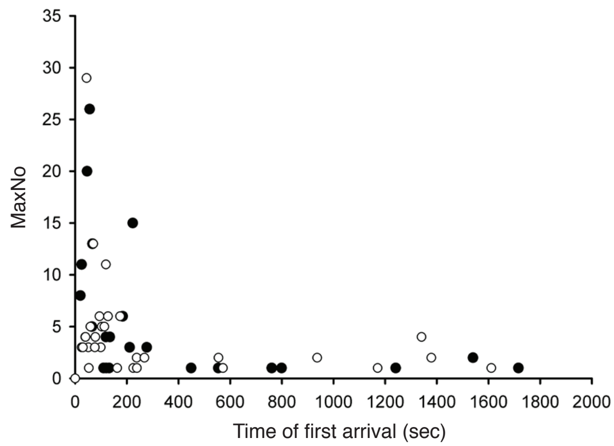


**Figure 4**

MaxNo (maximum number in a single frame) as a function of TFA (time of first arrival) for *Etelis coruscans* (●) and *Pristipomoides filamentosus* (○) recorded from BotCam deployments at Penguin Banks, Hawai'i, between June 2006 and February 2007.

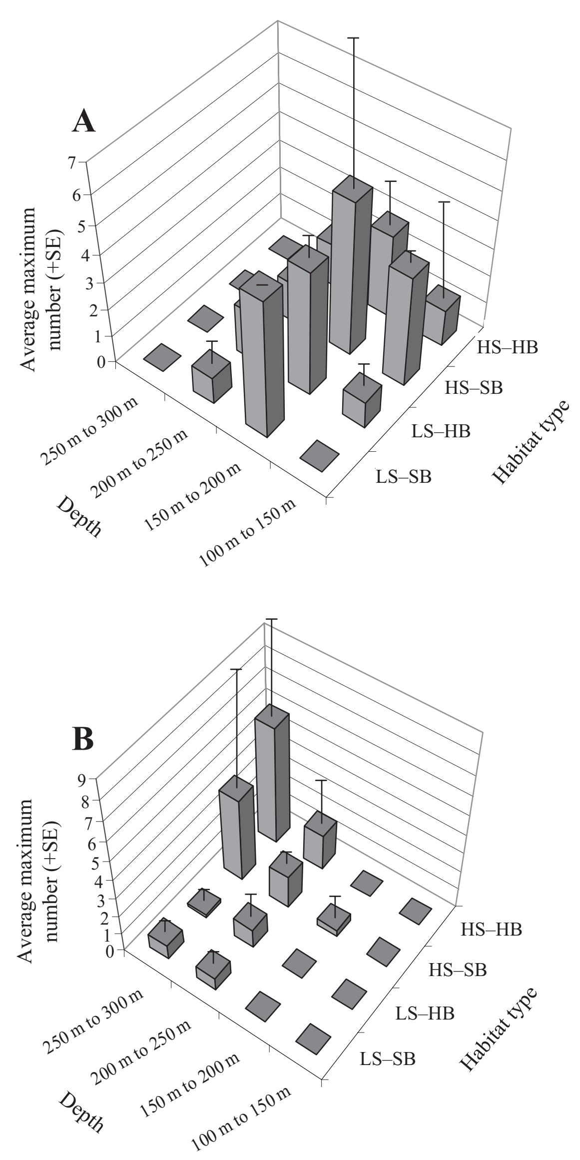


**Figure 5**

Average MaxNo (maximum number of individuals in a single frame) and standard error (SE) of (**A**) *Etelis coruscans* and (**B**) *Pristipomoides filamentosus* at Penguin Banks, Hawai'i, between June 2006 and February 2007. Depth bins and bottom or substratum types (defined by bottom slope and hardness) were derived from multibeam data during deployment planning. Error bars indicate standard error. HS: high slope, LS: low slope, HB: hard bottom, SB: soft bottom.

## Discussion

The primary objective of this research was to investigate whether, from an operational perspective, BotCam can provide reliable fishery-independent data on Hawaiian deepwater bottomfish populations that are of similar quality to data obtained from camera systems placed in shallower waters. The results indicate that BotCam can be a useful tool and furthermore illustrate the different types of data it is capable of collecting. Of particular importance, 80% of the deployments were successful in hitting their target sites and recording for the planned time interval. All of the "deep 7" species were attracted to BotCam and were recorded on videotape during the study. Thus from an operational standpoint, BotCam has the potential to collect data useful for assessment of bottomfish populations. Studies are underway to compare results of the pilot study with those from subsequent deployments to determine whether the method can lead to a greater understanding of the temporal and spatial dynamics of bottomfish populations.

As with data collected with other methods, fish count data collected with underwater video systems are confounded by a number of factors, especially when a baited design is used. One factor that affects variance is the inconsistent size of the sampling area due to an unknown size of the bait-plume. One of the outstanding questions about baited camera stations is how extensive is the area of influence of the bait (Priede and Merrett, 1996; Willis et al., 2000). Initial attempts to measure bait dispersal with the stereo-video system proved inadequate; however, measurements of current speeds were promising (Merritt, 2005). Watson et al. (2005) compared baited and unbaited stereo-video surveys with underwater visual surveys in a shallow-water environment and found that the baited stereo-video system was the best technique for obtaining consistent fish counts with the least sampling effort, and that unbaited techniques would require a high level of replication to yield similar results (see Harvey et al., 2007). Heagney et al. (2007), working in the open-water column, found that an area-based bait plume model worked well to explain variation in their count data but were unable to determine if the correlation between counts and current was a result of the bait plume size or an indication of the preferred habitat of the fishes. Further work with BotCam is necessary to evaluate the area of influence of the bait, but the skewed relationship between MaxNo and TFA (Fig. 4) indicates that attraction to the bait is rapid and, therefore, local in its effect.

Another confounding factor is the visual attraction of fish to the camera system itself. Watson (2005) refer to this as the "curiosity" effect and although it is a difficult value to quantify, it is clear from the video recordings that fish do react to the camera system. Unbaited deployments need to be carried out to better understand the magnitude of this effect.

Baited camera systems have historically been used to determine either TFA or MaxNo to estimate relative density of the attracted fishes (Bailey et al., 2007). In many studies, TFA has been used in an inverse-square model as a metric of abundance (Priede et al., 1994). It is assumed with the use of TFA that individuals are uniformly distributed in space, act independently of each other (i.e., there is no schooling behavior), all fishes that contact the odor plume swim up current to the camera, and the effect of the bait plume on fish counts is linear and dependent on local current speed. Thus, short TFAs imply greater densities than long TFAs. In more recent statistical models, the arrival rate instead of the TFA has been used, which allows an estimate of a confidence interval (Farnsworth et al., 2007), but both measures are based on the same basic assumptions. These metrics have been applied primarily to deep sea fishes (>1000 m) inhabiting low-energy, bathymetrically monotonous environments (Priede and Merrett, 1996). They are also hypersensitive at rapid TFAs (<~5 min) and insensitive at long TFAs (>~120 min; King et al., 2006; Yeh and Drazen, 2009). Shallower water environments, such as those surveyed in the current study, are more dynamic ecologically and physically than in the deep sea and therefore fishes tend to be less evenly distributed in space.

The assumptions about the uniform distribution of the target fishes or linearity of responses to the odor plume required by TFA models often cannot be met. As a result, studies examining shallow-water fishes (Ellis and DeMartini, 1995; Willis et al., 2000; Watson et al., 2005; Kelley and Ikehara, 2006; Stoner et al., 2008) have used MaxNo as an index of relative density which avoids the potential for recounts of the same fish as they exit and reenter the field of view during the survey period. Ellis and DeMartini (1995) found that MaxNo is positively correlated to catch per unit of effort (CPUE) and concluded that it is a useful index of abundance. Likewise, Stoner et al. (2008) concluded that MaxNo was the optimal measure because it is correlated with seine hauls and is consistent across habitat types. Willis et al. (2000) compared a baited camera system with visual surveys and angling surveys and also concluded that video survey techniques with MaxNo provided reliable estimates of relative density. In the present study, TFAs were very short (Fig. 4) and could produce highly variable and spuriously high estimates of abundance (King et al., 2006). This is associated with the lack of sensitivity of TFA to small densities where arrival time is dependent on the position and response to bait of the closest fish. We assumed that the bait plume was not uniform because of the variability in conditions (i.e., currents) and rugged bathymetry. Furthermore, it is well known that some species of bottomfish school, whereas others associate only with

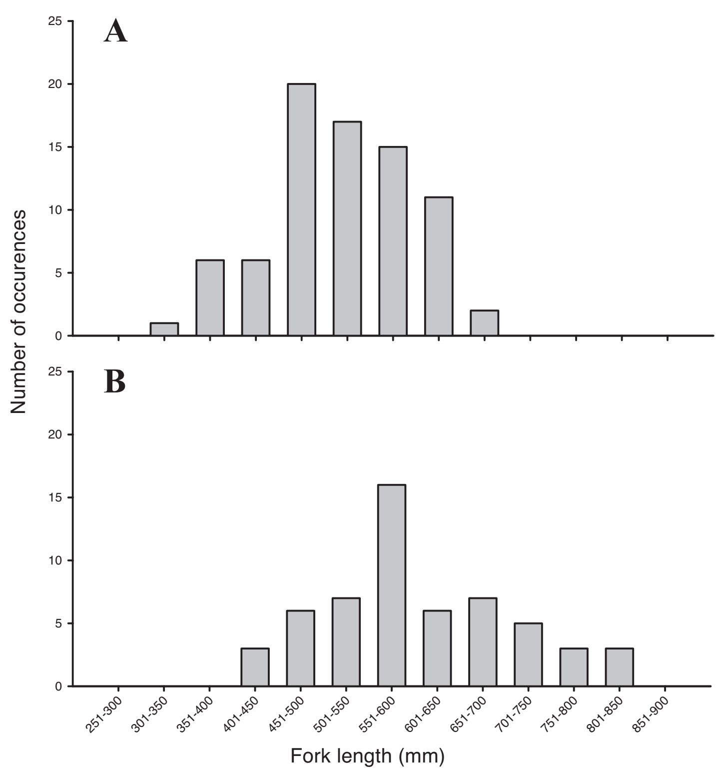


**Figure 6**

Length-frequency distribution of (**A**) *Etelis coruscans* and (**B**) *Pristipomoides filamentosus* from BotCam deployments at Penguin Banks, Hawai'i, between June 2006 and February 2007 as measured by stereo-video software Vision Measurement System (Geomsoft, Victoria, Australia). Only fish identified at the time of MaxNo (maximum number of individuals in a single frame) were measured. Each fish seen around the time of MaxNo was measured six times (from six different frames of the video) in order to tease out errors due to fish motions and human error. The average fork lengths are binned in 50-mm intervals.

hard substrate; therefore in any sampling there will be an aggregated distribution rather than a random or uniform one (Haight et al., 1993a; Kelley and Ikehara, 2006). Indeed, the present results show that MaxNo, similar to many other types of count data, were not normally distributed; many camera deployments resulted in zero fish and others with up to 29 fish (Fig. 4). MaxNo appears to be a more appropriate metric than TFA for estimating relative abundance in this case, but will likely require analysis with statistical models that are designed for nonuniform dispersion patterns.

Knowledge of the distribution of fishes among habitats is of importance to fisheries management, and such information can readily be obtained with the BotCam system. The distributions of *E. coruscans* and *P. filamentosus* among depth bins and habitat substrata types in our study (Fig. 5) indicate that *E. coruscans* on Penguin Bank prefer high slopes and deeper water, whereas *P. filamentosus* do not have a strong preference for a particular bottom type but are found in the shallowest three quarters of the depth range sampled. Modeling the distribution of both species across depth, slope, and substrate type indicated that these factors were important in understanding the association of these species with their habitat. Currently, the essential fish habitat for these species is simply defined as all waters between 100 and 400 m deep. Although beyond the scope of this study, the results show that additional work with BotCam would enable fisheries scientists to more accurately define essential fish habitats and habitat areas of particular concern on a species-by-species basis. Combined with direct observation of habitat, BotCam is also a tool that will allow for a much finer resolution of habitat classification (i.e., bedrock versus boulders versus cobbles) and enable species preferences to be discerned (see Stoner et al., 2008). Parrish et al. (1997) applied this technique to investigate habitat affinity of juvenile *P. filamentosus* and identified premium habitat by using direct observations from video cameras.

One objective of this study was to evaluate the precision and accuracy of the stereo-photogrammetric technique for obtaining accurate size measurements of bottomfishes. After analyzing repeated measurements of *E. coruscans* and *P. filamentosus*, a discrepancy was apparent between the species. The smaller number of *E. coruscans* measured and the larger standard deviation of the measurements relative to *P. filamentosus* were likely the result of *E. coruscans* being found in deeper water, where visibility and image quality decrease, making video measurement more difficult. Nonetheless, valuable information about the size distribution of these fishes was collected (Fig. 6), indicating that BotCam could be useful as a nonextractive tool for sampling size distributions for stock assessment. Additional experience in both calibrating the camera system and in using the stereo-video software will improve the precision and accuracy of size measurements as evidenced by previous studies where a similar system and software were used (Harvey et al., 2003). Harvey et al. (2002) compared fish length estimates from stereo-video and scuba divers and found video to provide consistently more accurate and precise data. Additionally, Harvey et al. (2010) conducted a similar study on the accuracy and precision of stereo video camera system and found that the length of the object measured was a major factor in reducing variance during measuring. In contrast to this finding, we suggest that size was not a factor, although our study supports the finding that precision degrades with distance away from the camera.

The size distributions of *P. filamentosus* and *E. coruscans* estimated in our study were consistent with published data for both species. Haight et al. (1993a) estimated the length at maturity of *P. filamentosus* to be 430 mm, and maximum length to be 780 mm. Our estimates for *P. filamentosus* ranged from 344 mm to 660 mm, normally distributed throughout the reported size range (Fig. 6). Everson et al. (1989) estimated the length at maturity of *E. coruscans* to be 663 mm, and maximum length to be 925 mm. Our estimates for *E. coruscans* ranged from 432 mm to 832 mm, again normally distributed across the reported size range (Fig. 6). These results indicate that BotCam can estimate relative size frequencies, both pre- and post-sexual maturity and therefore could be used for monitoring recruitment and changes in spawning potential ratios. In neither species was a fish measured near its reported maximum size. The reasons for this could be low sampling effort, size-related differences in behavior or habitat use, bias caused by measuring only at MaxNo, or simply that individuals of such large size were absent from the sampled area. Juveniles of these species were also absent from the video recordings, possibly because they remained close to the bottom near cavities because of their vulnerability to predation, as typical of other bottom associated fishes. Juveniles could have been in the vicinity of BotCam, but because of the presence of larger fish, such as *S. dumerili*, were possibly unwilling to come up to the cameras.

Monitoring deepwater fishes and their habitat is a difficult and costly undertaking. We tested the effectiveness of a new baited stereo-video camera system (BotCam) and found it an efficient tool in places where diver surveys are impossible and ROV or submersible surveys are cost prohibitive or provide data of uncertain quality (Kelley et al., 2006; Stoner et al., 2008). The success rate of data collected per deployment in this study supports the use of BotCam for studying biologic assemblages at depths ranging from 0 to 300 meters. As a nonextractive method, BotCam could prove particularly valuable in marine protected areas, where restrictions on fish removal may limit the usefulness of traditional sampling methods (Willis et al., 2003; Denny et al., 2004; Willis and Millar, 2005). Future work must include careful calibration of BotCam data with traditional population assessment data, including measures of relative abundance based on fisheries-dependent data such as CPUE. In addition, calibration with other nonextractive methods, such as acoustic surveys, is needed.

In future studies with the BotCam system, current meters should be used to model bait dispersal and its effects on fish counts and other measurements. The development of a diverse suite of methods for assessing fish stocks, including baited camera systems such as BotCam, strengthens the scientist's toolkit and allows for more reliable stock assessments and cross-validation of these assessments.

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