Developing a method for assessing blueline (*Caulolatilus microps*) and golden (*Lopholatilus chamaeleonticeps*) tilefish stocks using a baited underwater video system

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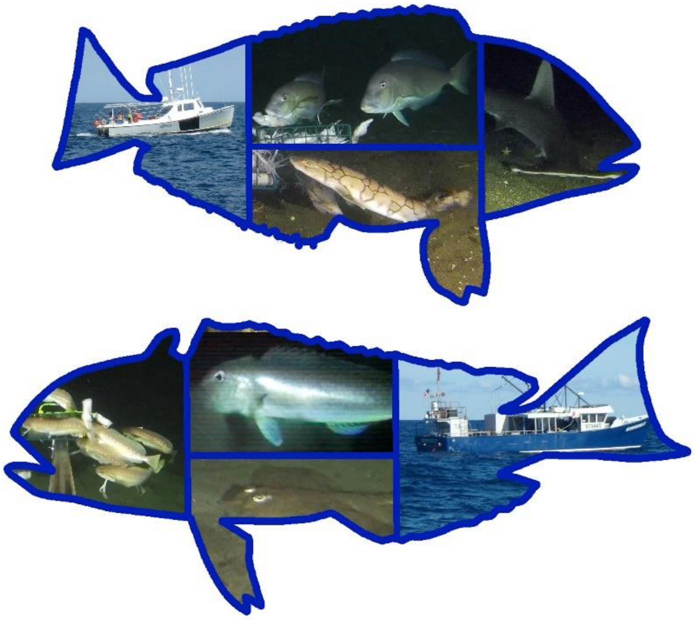

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Executive Summary

This project proposed to develop innovative supplemental surveys (proof of concept) to derive fishery-independent indices of abundance for blueline (*Caulolatilus microps*) and golden (*Lopholatilus chamaeleonticeps*) tilefish, addressing **S-K priority #2** - provide advanced fishery-independent sampling techniques to improve data collection in otherwise inaccessible habitats, and improve current stock assessments by refining estimates of population dynamics. Currently, there is no fishery-independent assessment for either species, and developing appropriate surveys is a management priority.

Golden and blueline tilefish are important recreational and commercial fish species, with 2014 commercial landings valued in excess of $10 million. Both species are large and long-lived species that are prone to being overfished due to their limited and predicable distributions. Fishery-dependent data is the primary data source for the assessment for both, and while the use of fishery-dependent data is necessary in the absence of alternative data streams, data from a well-defined, fishery-independent survey tends to be more unbiased and representative of the targeted fish. Baited underwater video (BUV) surveys are becoming common tools for surveying marine animals because they are non-invasive and non-selective. Video surveys are now routinely used for sea scallop (*Placopecten magellanicus*) assessments, and BUV survey data was included in the most recent Mexican red grouper (*Epinephelus morio*) assessment.

The specific goals of the project included (1) developing and refining BUV survey techniques for tilefish to establish the utility of this method for collecting fishery-independent data for this species and (2) comparing data collected with baited video surveys to catch data from concurrent commercial fishing trips to calibrate the video surveys. Additional analysis, beyond the original scope of the project, was also done to develop length-weight curves for blueline and golden tilefish and test automated software for detecting tilefish in BUV footage.

Two research trips were conducted, with a June trip dedicated to surveying blueline tilefish and a July trip dedicated to surveying golden tilefish. BUV surveys were conducted in collaboration with commercial vessels in locations where fishing routinely takes place. BUV drops were conducted 1-2 km away from commercial longlines, and a range of bait types and techniques were tested for each species. Longline tilefish catch per unit effort (CPUE), calculated as catch per hook per hour of soak time, and length-frequency data were compared to the BUV system tilefish CPUE (as MaxN per hour) and length-frequency data (estimated from the stereo images).

Comparisons of catch and length data collected in longline surveys were completed. BUV survey measures of blueline tilefish relative abundance were correlated with commercial catch, but a comparable correlation was not seen with the golden tilefish data. Comparisons of fish lengths measured in the commercial catch and in the BUV stereo images indicate that smaller tilefish are surveyed using the BUV method. Based on the results of this project, we believe BUVs could be used to derive fishery-independent indices of abundance for blueline tilefish. An initial survey with a stratified random sampling design weighted by area and prior catch data and strata based on depth and latitude would be recommended. In addition, automated detection and counting of tilefish in the videos could be accomplished using Video and Image Analytics for a Marine Environment (VIAME), an open-source system for analysis of underwater imagery developed with funding from the National Oceanic and Atmospheric Administration (NOAA) Automated Image Analysis Strategic Initiative.

Project Overview and Purpose

This project proposed to develop innovative supplemental surveys (proof of concept) to derive fishery-independent indices of abundance for blueline (*Caulolatilus microps*) and golden (*Lopholatilus chamaeleonticeps*) tilefish, addressing **S-K priority #2** - provide advanced fishery-independent sampling techniques to improve data collection in otherwise inaccessible habitats, and improve current stock assessments by refining estimates of population dynamics. Currently, there is no fishery-independent assessment for either species, and developing appropriate surveys is a management priority. This project was designed with a focus on this need.

The specific goals of the project included (1) developing and refining baited underwater video (BUV) survey techniques for tilefish to establish the utility of this method for collecting fishery-independent data for this species and (2) comparing data collected with baited video surveys to catch data from concurrent commercial fishing trips to calibrate the video surveys. BUV surveys were conducted in collaboration with commercial vessels in locations where fishing routinely takes place during June and July 2018 (**Figure 1 and Table 1**). BUV drops were conducted 1-2 km away from commercial longlines, and a range of bait types and techniques were tested for each species. Longline tilefish catch per unit effort (CPUE), as catch per hook per hour of soak time, and length-frequency data were compared to the BUV system tilefish CPUE (as MaxN per hour) and length-frequency data (estimated from the stereo images). Additional analysis, beyond the original scope of the project, was also done to develop length-weight curves for blueline and golden tilefish and test automated software for detecting tilefish in BUV footage.

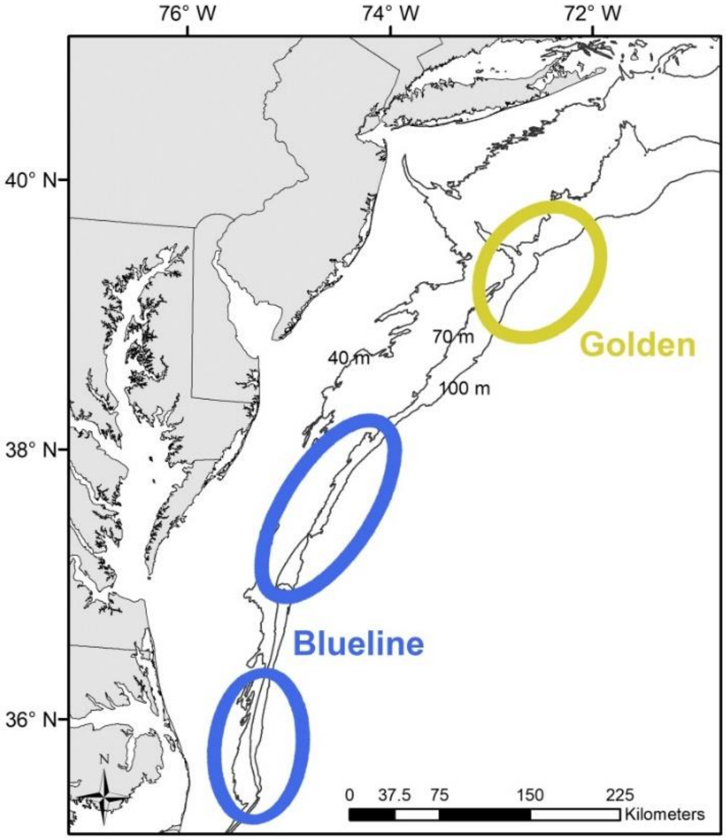

Figure 1. *Map of tilefish survey locations*

Table 1. *Research trips for NOAA Grant NA17NMF4270203*

Trip dates	Video survey vessel	Scientists on board	Tilefish vessel	Scientist on board
12 - 23 June 2018	F/V Kathy Ann	L Siemann, S Patel, and A Carlson	F/V Emily Shay	F Davis
16 - 21 July 2018	F/V Ms Manya	L Siemann and S Patel	F/V Kimberly	F Davis

Background

Blueline and golden tilefish are large and long-lived species that are prone to being overfished due to their limited and predicable distributions (Grimes & Turner 1999; NEFSC 1999, SEDAR 2013). Blueline tilefish are distributed along the outer continental shelf from Campeche Bank, Mexico to Rhode Island at preferred depths of 50-240 meters (Harris et al. 2003; Sedberry et al. 2006; SEDAR 2013), with landings highest off of North Carolina (**Figure 2**). The Atlantic blueline tilefish commercial fishery historically operated from the east coast of Florida to Virginia, but catch north of Cape Hatteras has increased dramatically in recent years (Didden 2016). Consequently, emergency management measures were established in 2015, and since December 2017, blueline tilefish have been managed using annual catch and trip limits across their range. The species is currently managed under the South Atlantic Snapper Grouper Fishery Management Plan (FMP) in waters south of the NC/VA border and through the Mid-Atlantic Tilefish FMP in waters north of this boundary. The Annual Catch Limit, derived from stock production models based on commercial catch, is divided between recreational (73%) and commercial (27%) vessels.

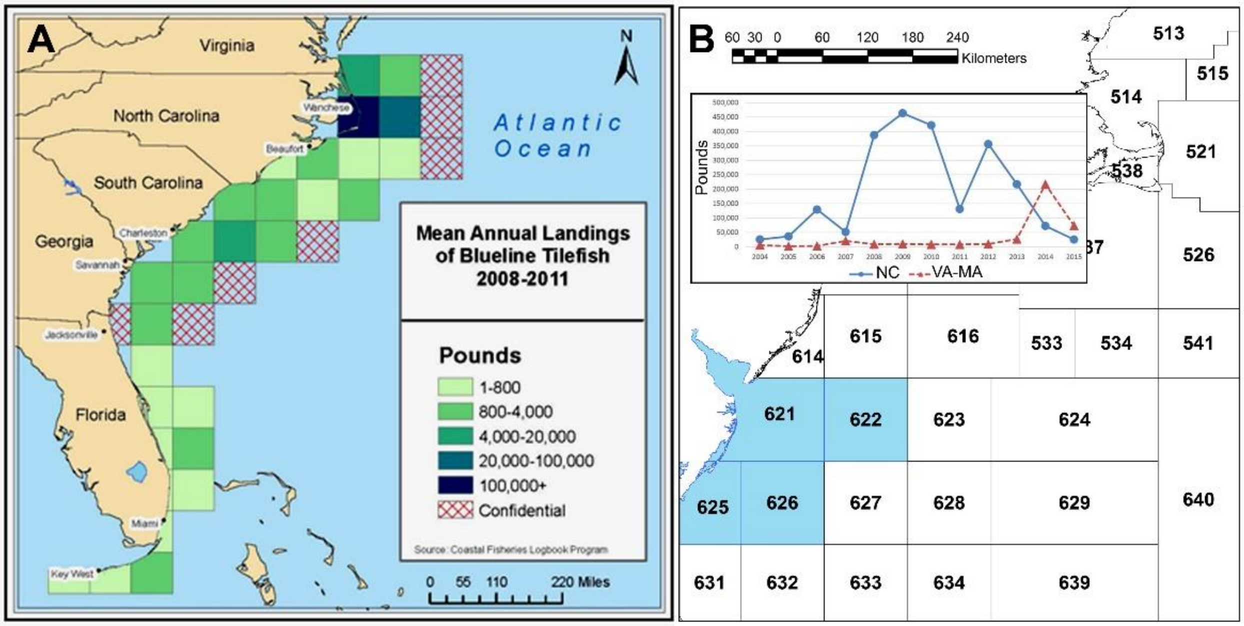

Figure 2. *A) Reported catch of blueline tilefish from the Coastal Fisheries Logbook Program from 2008-2011. From Sedar 2013. B) Statistical areas where commercial catches of blueline tilefish have increased recently. Data from MAFMC 2015a. (Inset) Blueline tilefish commercial dealer landings from 2004-2015 highlighting changes in commercial catch south (blue) and north (red) of Cape Hatteras. From Didden 2016.*

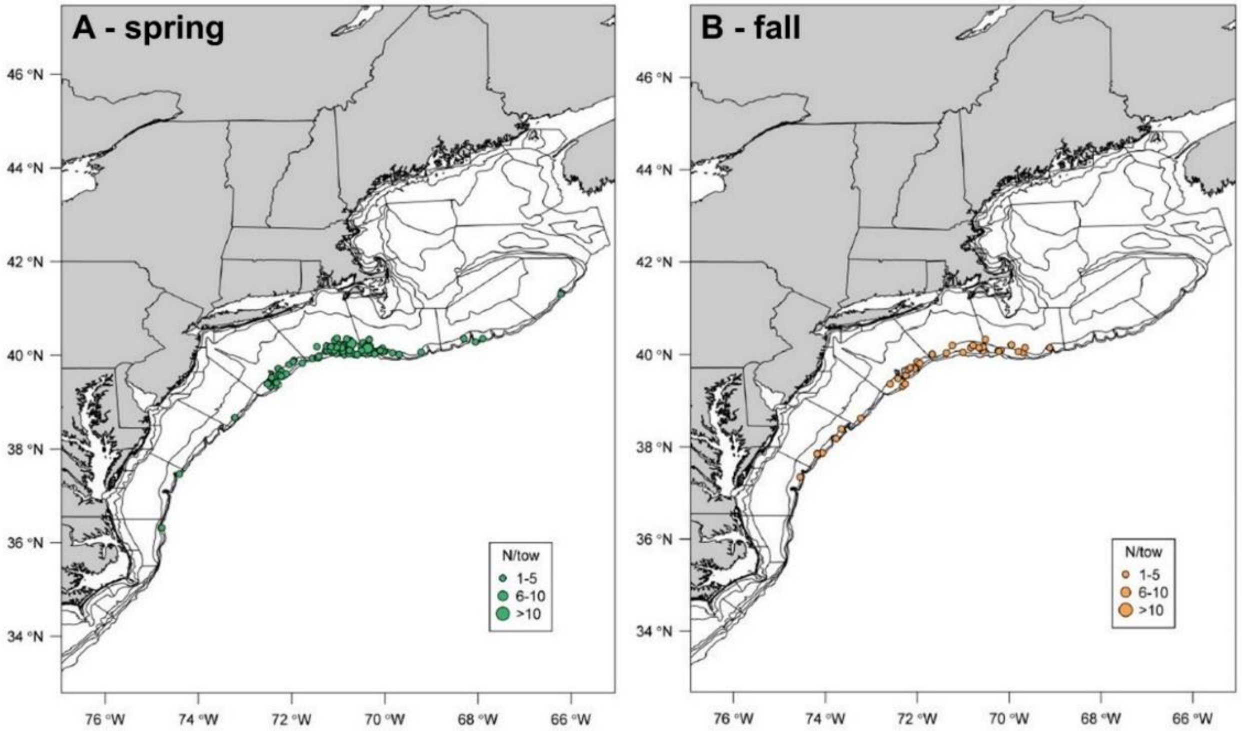

Figure 3. *Golden tilefish distribution and relative abundance maps from NEFSC trawl surveys. A) Spring survey from 1968-2012. B) Fall survey from 1963-2012. From NEFSC 2014a.*

Golden tilefish are found mainly along the outer continental shelf and upper slope in the North Atlantic from Georges Bank to Florida and are most abundant between 100-240 meters (**Figure 3**) (NEFSC 1999). The golden tilefish commercial fishery operates year-round, with fishing effort focused on regions with benthic water temperatures between 9° and 15° C and where dogfish are less abundant (Grimes & Turner 1999, MAFMC 2015b). Over 80% of commercial landings from 1996-2012 occurred in Statistical Areas 537 and 616 (**Figure 4**), with that percentage increasing to over 90% in 2012 (MAFMC 2013). These areas include Atlantis, Block, and Hudson Canyons. The directed tilefish fishery from Maine to Virginia is managed through an Individual Fishing Quota allocation program, with over 97% of the tilefish landings taken by longline gear (MAFMC 2013).

Tilefish species can be difficult to observe *in situ*, as they live in deep waters (> 100 m) and reside within the benthic substrate or shelf/canyon walls. Both juveniles and adults live in shaft burrows, often creating complexes of burrows in submarine canyon walls (**Figure 5**) (Able et al. 1987; Grimes & Turner 1999, NEFSC 1999, Guida 2007). These burrows can be several meters deep and several meters wide at the mouth. Previous efforts to develop fishery-independent tilefish surveys have been focused on counting burrows using submersibles or automated underwater vehicle surveys (Matlock et al. 1990, Guida 2007), but to date these efforts have not yielded accurate population estimates.

Fishery-dependent data is the primary data source for the assessment of both blueline and golden tilefish (SEDAR 2013, NEFSC 2014a, 2014b). For golden tilefish, effort is simplified to boat days, which is a relatively crude measurement of effort, and catch data for blueline tilefish has been inconsistently collected on a year to year basis (SEDAR 2013, NEFSC 2014a). An overreliance upon fishery-dependent data can misrepresent the status of a fish stock due to heterogeneity of fishing effort and gear selectivity (Simpfendorfer et al. 2002, Chen et al. 2003, Murphy & Jenkins

2010, Pauly et al. 2013). While the use of fishery-dependent data is necessary in the absence of alternative data streams, data from a well-defined, fishery-independent survey tends to be more unbiased and representative of the targeted fish (Hilborn & Walters 1992, Pauly et al. 2013). The development of fishery-independent data collection techniques is necessary for the proper assessment, management and long-term sustainability of the tilefish fishery.

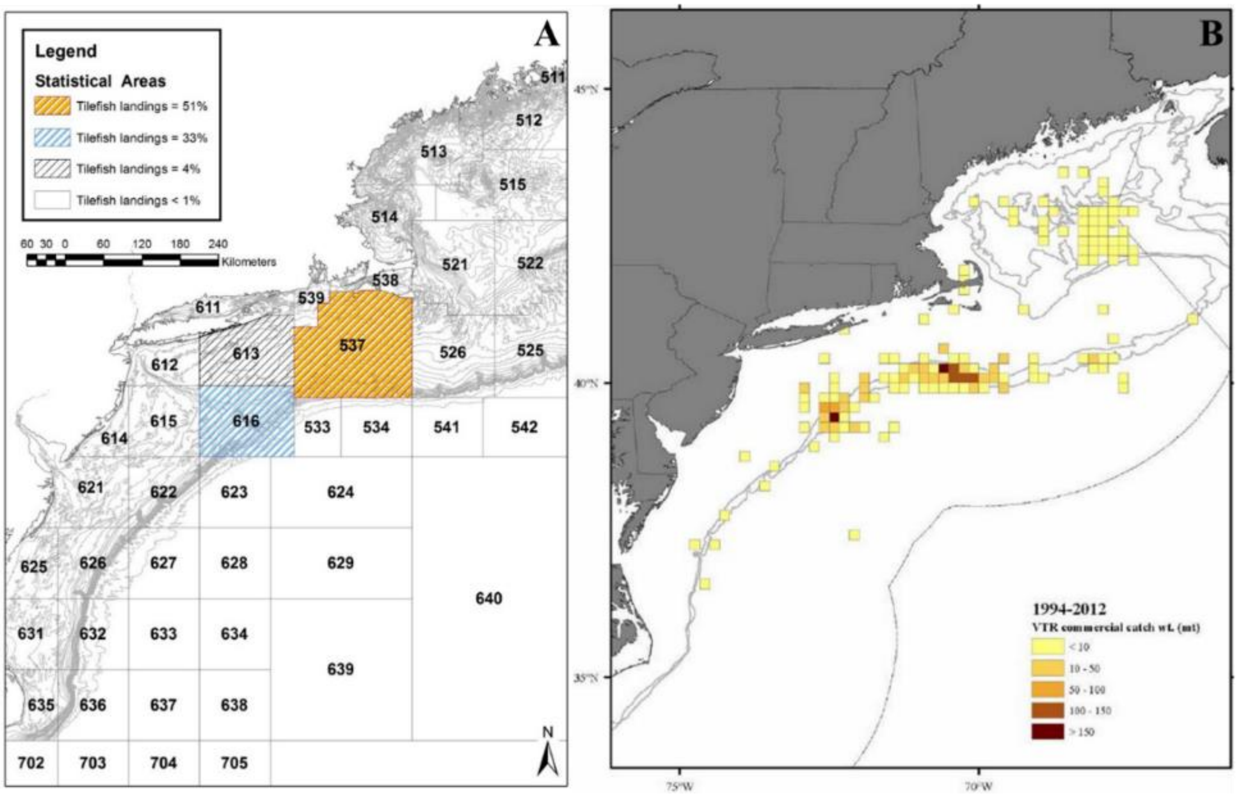

Figure 4. *A) Statistical areas with the highest landings of golden tilefish from 1996-2012. Data in MAFMC 2013. B) Golden tilefish catch weight from VTR records. From NEFSC 2014a.*

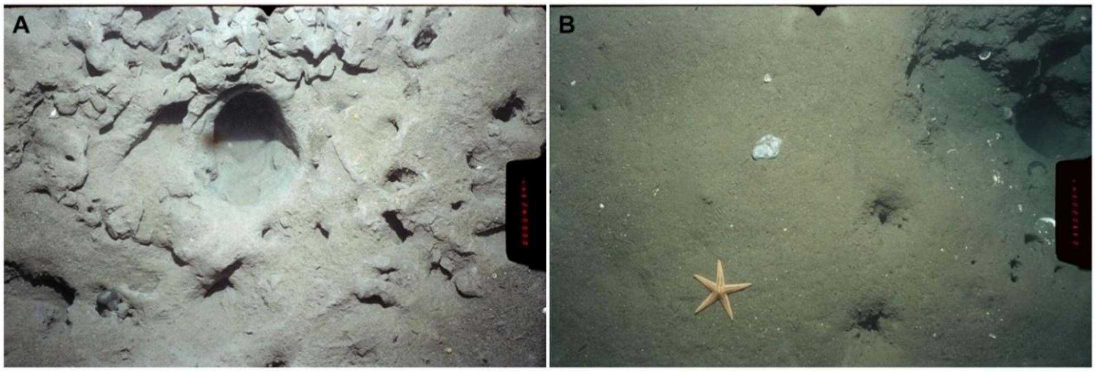

Figure 5*. Underwater tilefish burrows in A) clay and B) muddy sand. From Guida 2007.*

In an effort to reduce the reliance on fishery-dependent data for the assessment of both blueline and golden tilefish, a workshop was held by the Southeast Fisheries Science Center (SEFSC) to investigate the development of fishery-independent data collection. Recommendations from this workshop focused on the use of commercial bottom-set longlines (Carmichael et al. 2015), and a preliminary longline survey was conducted in 2017 (Frisk et al. 2018). Bottom-set longlines, however, would not be able to adequately address all of the research recommendations in SEFSC workshop document (Carmichael et al. 2015). Most critically, a longline survey may not be able to provide unbiased samples for updating reproductive models or increase habitat characterization and bottom mapping as recommended by the workshop (Carmichael et al. 2015). The use of commercial fishing gear for fishery-independent surveys has inherent biases with regards to catchability and selectivity, and longlines in particular tend to select for larger individuals relative to trawls (Otway & Upston 1996, McAuley et al. 2007). Video survey techniques remove biases due to longline gear selectivity as a result of hook size because all fish within the field of view are sampled (Cappo et al. 2003, Wells et al. 2007). Additionally, video can be used to classify and characterize substrate and habitat (Harris & Stokesbury 2005). For these reasons, we believe that the use of video techniques in conjunction with commercial longlines would be better able to address all of the recommendations put forth by Carmichael et al. (2015).

Baited underwater video surveys are becoming common tools for surveying marine animals (Cappo et al 2007). BUV surveys offer advantages over traditional assessments using fishing gear because they are non-invasive and non-selective (Brooks et al. 2011, Schobernd et al. 2014, McLean et al. 2015). Baited video systems couple camera components with bait canisters located in the field of view. Marine animals are attracted to the bait plume, and the camera footage can be used to study behavior and estimate animal abundance and diversity (Cappo et al. 2007, Martinez et al. 2011, Letessier et al. 2013, Santana-Garcon et al. 2014, Bouchet and Meeuwig 2015, McLean et al. 2015). When single-camera systems are used, coarse estimates of animal size can be obtained if paired lasers or a size reference are included; however, size measurements are limited to animals oriented roughly parallel to the focal plane of the camera (Cappo et al. 2007). The addition of a stereo camera system allows more accurate measurements of animal sizes by creating 3D imagery (Cappo et al. 2007, Langlois et al. 2012, Letessier et al. 2013, Santana-Garcon et al. 2014, Bouchet and Meeuwig 2015). Different species can be distinguished when image quality is good (Cappo et al. 2007, Letessier et al. 2013), and with recent advances in affordable underwater imaging systems, this requirement is more easily met than ever before (Letessier et al. 2013, Bouchet and Meeuwig 2015).

Video surveys are now routinely used for sea scallop (*Placopecten magellanicus*) assessments (NEFSC 2014b), and BUV survey data was included in the most recent Mexican red grouper (*Epinephelus morio*) assessment (Campbell et al. 2014, SEDAR 2015). Sea scallop assessments have included a drop camera survey since 2003 and a towed video (HabCam) survey since 2011 (NEFSC 2014b). Preliminary testing of the survey methods began in 1999 and 2006, respectively (Stokesbury 2001, Gallager et al. 2008). Final abundance estimates for the scallop resource combine estimates from the video surveys with estimates from traditional dredge surveys. Due to increasing confidence in the results of the video surveys, National Marine Fisheries Service (NMFS) survey efforts have shifted from exclusively dredge surveys to primarily HabCam video surveys in recent years. The Southeast Area Monitoring and Assessment Program (SEAMAP) has been using video systems to survey reef fish since 1992 (Campbell et al. 2015, SEDAR 2015), and their current system is a baited array of four cameras (Conn 2011). The SEAMAP baited video survey was combined with other video surveys utilizing stationary camera arrays to generate a video abundance estimate that was combined with traditional fishing surveys to generate the assessment index for red grouper (SEDAR 2015).

BUV systems, in combination with co-located baited long lines, have been used to assess deep-water fish (Brooks et al. 2011, Langlois et al. 2012, Santana-Garcon et al. 2014, McLean et al. 2015). Brooks et al. (2011) found highly significant correlations between species richness and abundance estimates for common shark species using bottom-set BUVs and stationary long lines (500-meter lines with 35 baited hooks). Santana-Garcon et al. (2014) calibrated pelagic stereo-BUV systems against scientific longline surveys (500-meter lines with 50 baited hooks) for shark species and reported that the results of the two surveys were comparable, with each pelagic BUV system giving relative abundance estimates per hour of recording that were equivalent to 5-30 longline hooks. Langlois et al (2012) and Santana-Garcon et al. (2014) obtained similar length-frequency estimates from stereo BUV systems and line-fishing surveys with a range of hook sizes for the majority of the teleost and shark species they surveyed.

Project Objectives

Initial project goals included:

(1) Developing and refining baited video survey techniques for tilefish to establish the utility of this method for collecting fishery-independent data for this species, and

(2) Comparing data collected with baited video surveys to catch data from concurrent commercial fishing trips to calibrate the video surveys.

Two additional goals were added to the project, with reasons specified below:

(3) Estimating length-weight relationships for blueline and golden tilefish from data collected aboard commercial vessels.

> Because length and weight data were collected from the catch on the commercial vessels, length-weight equation parameter estimates were generated for both species.

(4) Testing the use of automated software to detect and count blueline tilefish in the BUV footage.

> Because the use of automated detection software would significantly speed up the annotation of BUV footage for survey use, we tested the vertebrate detector that is included in the Video and Image Analytics for a Marine Environment (VIAME) software package. VIAME was developed by Kitware (Clifton Park, NY) with support from the NOAA Automated Image Analysis Strategic Initiative and is an open-source system for analysis of underwater imagery.

Project Approach - Data Collection and Analysis

Camera frame design and construction

A prototype camera frame was built and tested in the optic and acoustic saltwater test tank at the UMASS Dartmouth School for Marine Science & Technology (SMAST) (**Figure 6**), and after successful testing of the prototype, two stainless steel frames were designed and built by Dockside Repairs in New Bedford, MA (**Figure 7** with SolidWorks plans in **Appendix A**).

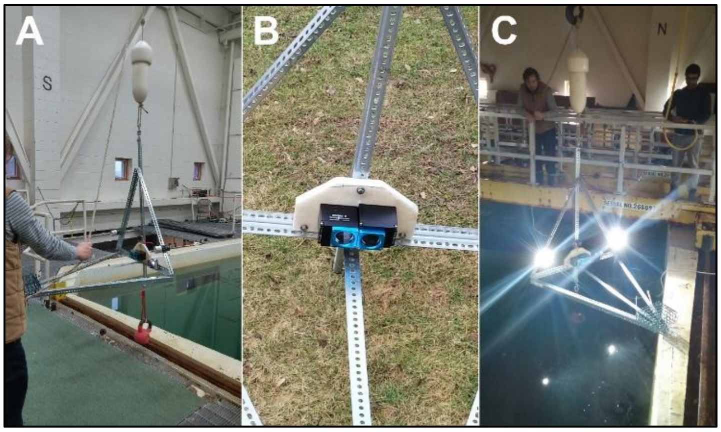

Figure 6. *Prototype BRUV frame. (A) Frame set up with cameras, lights, and bait box. (B) deep water housings made by Groupβ Inc. (C) Frame being lowered into the test tank.*

The stainless frames were tested at SMAST to verify that the frames were stable in the water and to determine the amount of buoyancy and anchor weight required for the frames to float just above the bottom during survey drops. Each frame had three cameras: two Git2p action cameras with Panasonic sensors and rectilinear lenses to collect stereo images and one Git3 camera with a fisheye lens to collect video used for annotations (https://www.gitup.com/). The cameras were in deep water housings certified to depths of 8,000 feet, more than necessary for both surveys (https://www.groupbinc.com/).

Figure 7. *BUV frame. (A) Setting up for a drop. (B) BUV frame going over the side with dangling squid bait. (C) Both BUV frames set up with Danforth anchors.*

Research trips

Two research trips were conducted, with a June trip dedicated to surveying blueline tilefish and a July trip dedicated to surveying golden tilefish (**Table 1**). The blueline tilefish trip was conducted from June 12-23, 2018. The tilefish vessel F/V Emily Shay was operated by owner/captain Wiley Coppersmith out of Wancheese, NC. Coonamessett Farm Foundation (CFF) scientist Farrell Davis was on board collecting tilefish catch data (number of tilefish, tilefish length frequencies and weights, and bycatch species and counts). CFF scientists Liese Siemann, Samir Patel, and Amy Carlson were on board the Viking Village vessel F/V Kathy Ann, captained by Corey Karch out of Barnegat Light, NJ, conducting the BUV survey. Over the course of the trip, we conducted surveys at two sites off the coast of North Carolina, separated by ~90 km, and two sites off the coast of Virginia, separated by ~35 km (**Figure 1**). Locations were selected by W Coppersmith. Fifty-two BUV drops were completed overall using two BUV frames. Longline set locations were tracked using vessel GPS coordinates recorded on a Getac F110 tablet and verified using the F/V Emily Shay chart plotter. BUV drop locations were recorded on handheld Garmin64 GPS units and with the Geotracker app on an Android phone as back-up. Paired longline set and BUV drop locations were located 0.8 - 1.3 km apart, with camera drop locations determined based on longline set locations. A Lotek temperature depth recorder (TDR) was attached to each BUV frame and to the anchor used at the start of each longline set.

The configuration of the BUV anchoring and bait changed during the first few days before we settled on the most successful configurations (**Figure 2**). Four different anchoring options were tested (Danforth anchor, Danforth anchor plus chain, single loop of chain, and three loops of chain) before we determined that the Danforth anchor worked best to collect steady video images with the bottom in view. Initial BUV drops with bait (fresh frozen squid and mackerel) confined inside the bait boxes were unsuccessful capturing footage of tilefish even though tilefish were being caught using hand lines off the video survey vessel in the same locations. Therefore, we added dangling squid to the outside of the bait box (**Figure 2B)**. With this change, we immediately began seeing blueline tilefish in the videos. Dangling bait was included for all drops after that.

The golden tilefish trip was conducted from July 16-21, 2018. The tilefish vessel F/V Kimberly, owned by Dan Farnham, was operated by captain David Tuma out of Montauk, NY. CFF scientist Farrell Davis was on board collecting tilefish catch data (tilefish/hook/hour, tilefish length frequencies and weights, and bycatch species and counts). CFF scientists Liese Siemann and Samir Patel were on board the Viking Village vessel F/V Ms Manya, captained by Pete Dolan out of Barnegat Light, NJ, conducting the BUV survey. Over the course of the trip, we conducted surveys across a 900 square km area south of Long Island (**Figure 1**), with all locations selected by D. Tuma. Thirty BUV drops were completed overall using two BUV frames. Longline set locations were tracked using vessel GPS coordinates recorded on a Getac F110 tablet. BUV drop locations were recorded on handheld Garmin64 GPS units and with the Geotracker app on an Android phone as back-up. BUV drop locations were located 0.8 - 1.3 km from the longline set, with the locations of the F/V Kimberly sets tracked using AIS on the F/V Ms Manya to aid in selecting appropriate drop locations. A TDR was attached to each BUV frame and to the anchor used at the start of each longline set.

Mushroom anchors were purchased for this trip because we expected sticky silt and mud bottom and wanted an anchor with less holding power to avoid having the BUV frame get stuck on the bottom. Squid lures were tested on the outside of the bait box as an alternative to fresh frozen squid, but when no tilefish were seen using the lures, dangling fresh squid was used for the rest of the trip.

Analysis of catch data

Catch data was compared when the longline set and BUV drop overlapped in time. Catch by the longline was summarized as the number of tilefish caught per hook per hour of bottom time.

Longline set and retrieval times were recorded on the tilefish vessel and bottom time was verified using the temperature profiles from the TDR. Hooks were counted for blueline tilefish sets, while hook counts for golden tilefish sets were reported by the vessel captain. All blueline tilefish caught by longline were counted, weighed, and measured. A total catch weight for golden tilefish was recorded for each set, and lengths and weights of individual fish were measured for a subsample of the catch. Total catch numbers for golden tilefish were determined based on catch weight and estimated length-weight curves. Length-weight curves were also generated for blueline tilefish. The length-weight curves for both species were obtained using the R package "fishmethods" (R Core Team 2017, Nelson 2018).

Tilefish videos were analyzed using Behavioral Observation Research Interactive Software (BORIS), a free open-source behavioral event logging. The coding scheme is shown in **Table 2**. Videos were annotated for 30 minutes starting 10 minutes after the frame hit the water. The annotations were used to determine MaxN, the maximum number of tilefish counted in a single video frame per hour of recording, and CountN, the total number of tilefish seen in the video during the 30-minute recording. Based on the behavior of the tilefish in the videos, we believe individual fish were regularly returning to the field of view. Therefore, we estimated tilefish relative abundance as MaxN, the estimate of abundance that prevents repeat counts of the same fish. MaxN was compared to the longline catch/hook/hour for BUV drops that occurred when the longline was actively fishing.

Table 2. *Coding scheme used for video annotation*

Variable	Point or state event	Description
Count	Point	Tilefish counter
Other	Point	Other species counter
Hit water	Point	Time when bait box hits the water
Sampling	State	Start and stop of sampling period for annotation
0	State	No tilefish in frame
1	State	One tilefish in frame
2	State	Two tilefish in frame
3	State	Three tilefish in frame
4	State	Four tilefish in frame
5+	State	Five or more tilefish in frame

Camera calibration and estimation of fish lengths

The cameras used to collect stereo images were calibrated using the work flow in OpenCV, an open-source computer vision package (http://opencv.org/). Checkerboards printed on reinforced aluminum (aluminum with Dibond) were used for camera calibration to provide a stiff target with sharp corners and edges. The video settings used during calibration matched those used during the research trips. Frames were extracted from the calibration videos using FFmpeg, and a free open-source software designed for manipulating multimedia files (https://www.ffmpeg.org/). Python code used to calibrate the cameras, rectify the BUV images sets, and estimate the parameters used for 3D reconstruction is included in **Appendix B**. An audio clapper signal was used to synchronize the stereo videos, and FFmpeg was used to extract frames from the BUV videos. Head and tail fork locations for each fish were selected from rectified images for each stereo pair, and the X-Y coordinates for the head and tail were projected into 3-dimensional space for length measurements (see **Appendix C** for examples of rectified stereo pairs).

Fish lengths were compared between longline sets and BUV drops that overlapped in time. Because tilefish appeared to repeatedly circle around and return into the camera field of view, we limited length measurements to the frames with the maximum number of fish observed during each drop.

Automated detection of tilefish in video frames

VIAME is an open-source system for analysis of underwater imagery. It was originally designed as an integration platform for several different video and image processing algorithms (Dawkins et al. 2017), but has since evolved into an end-to-end toolkit for producing analytics on an archive of imagery and/or video. At the core of VIAME is an image processing system which can link C/C++, Python, and MATLAB processing nodes together into a graph-like pipeline architecture. This can be used to easily build sequences of image processing algorithms without recompiling any source code or writing software, enabling rapid experimentation and re-use of different functional modules. Alongside the pipelined image processing system are a number of standalone utilities for object detector model training, output detection visualization, groundtruth annotation, detector evaluation (a.k.a. scoring), and image archive search.

In its current build, VIAME includes a vertebrate detector. Two sets of stills extracted from BUV video were processed using the vertebrate detector to assess the potential utility of the VIAME software for improving BUV annotation rates.

Project Management

The project was managed by the staff at CFF. Dr. Liese Siemann managed the project and participated in the video surveys, BRUV design, and data analysis. Dr. Samir Patel participated in the video surveys, BRUV design, and data analysis. Farrell Davis ran the fishing surveys at sea and participated in BRUV design and data analysis.

Results

Comparison of catch data from commercial longline sets vs BUV drops

Catch data was compared when the longline set and BUV drop overlapped in time. Therefore, the blueline tilefish analysis included fifteen BUV drops and five longline sets, while the golden tilefish analysis included 30 BUV drops and seven longline sets (**Table 3**).

BUV survey measures of blueline tilefish relative abundance were correlated with commercial catch (**Figure 8**). Blueline tilefish catch ranged from 0-0.088 fish/hook/hour, with MaxN values increasing from 0 to 3 as longline catch increased (**Table 3**). Furthermore, they were an ideal species to survey using BUV systems due to their behavior around BUV systems (lingering parallel to the camera field of view) and dominant presence (no other finfish species were seen during the June 2018 survey) (**Figure 9**).

Table 3. *Summary of longline catch data and BUV video annotations. The total weight of the blueline tilefish catch was not determined because every fish was counted.*

Date	Longline set length (hrs)	Number of hooks	Total Weight (lbs)	Number Caught	Fish per hook	Fish/hook /hr	MaxN from BUV
Blueline tilefish							
6/15/2018	1.23	330	NA	36	0.109	0.088	3
6/16/2018	1.28	207	NA	0	0.000	0.000	0
6/16/2018	1.72	330	NA	23	0.070	0.041	1
6/17/2018	2.63	494	NA	27	0.055	0.021	1
6/18/2018	1.82	300	NA	27	0.090	0.050	2
Golden tilefish							
7/17/2018	6.03	4500	1235	318	0.071	0.012	0
7/17/2018	3.53	1800	1050	301	0.167	0.047	0
7/18/2018	6.97	4500	1625	533	0.118	0.017	0
7/18/2018	3.88	1800	1040	333	0.185	0.048	3
7/19/2018	7.33	4500	1950	402	0.089	0.012	0
7/19/2018	3.78	2100	910	276	0.131	0.035	0
7/20/2018	3.50	2000	910	251	0.126	0.036	0

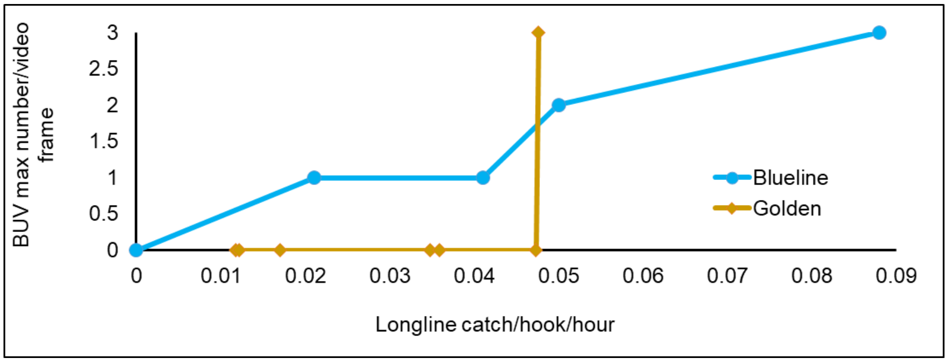

Figure 8. *Blueline and golden tilefish relative abundance from the longline catch versus the BUV survey (MaxN). MaxN in the plot is the highest MaxN for any video drops that overlapped the longline set.*

BUV survey measures of golden tilefish relative abundance were not correlated with commercial catch. Golden tilefish catch during the trip ranged from 0.012-0.048 fish/hook/hour, within the range of catch rates observed during the blueline tilefish trip. Although golden tilefish behavior and dominant presence in one video indicated they might be another ideal species to survey using BUV systems (**Figure 9**), they were not seen in 29/30 videos (**Table 3 and Figure 8**).

Figure 9. *Screen shots of (left) blueline and (right) golden tilefish.*

Comparison of fish lengths from commercial longline vs BUV measurements

Length data was also compared when the longline set and BUV drop overlapped in time, and tilefish in the images were measured in the frames with the maximum number of fish to avoid measuring the same fish repeatedly. In total, 12 blueline and 2 golden tilefish were measured in the stereo images. The numbers were too low for statistical analysis, but examination of the length frequency graphs for both species indicate that the BUV footage captured smaller fish than the commercial longline sets (**Figure 10**), even if differences in total length (used for longline catch measurements) and fork length (used for BUV measurements) were accounted for.

Tilefish length-weight relationships

Length-weight graphs (total length) were plotted for both species. Curves and parameter estimates for the length-weight equations are shown in **Appendix D.**

Auto-detection of tilefish in video frames

The vertebrate detector was reasonably successful at detecting tilefish after adjusting the detector threshold to not select the bar and bait box that were in view. Examples of successful and unsuccessful detections are shown in **Appendix E**.

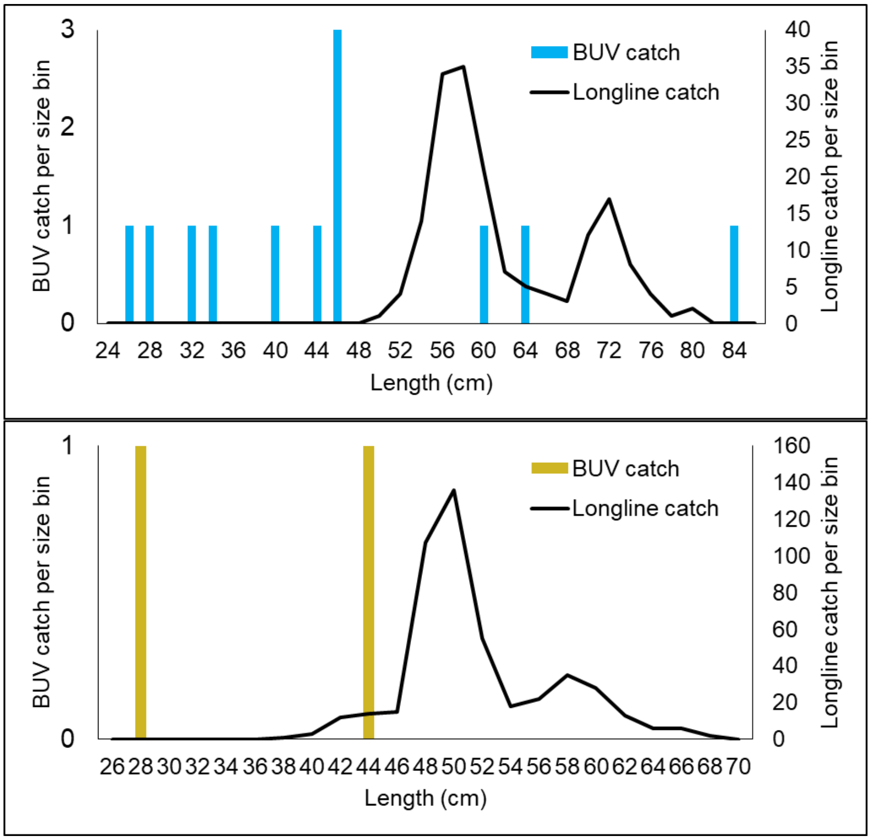

Figure 10. *Blueline and golden tilefish length frequencies from the longline catch versus the BUV survey.*

Accomplishments by Objective

(1) Developing and refining baited video survey techniques for tilefish to establish the utility of this method for collecting fishery-independent data for this species.

We successfully developed and refined BUV survey techniques for blueline tilefish. Our baiting technique (dangling squid) repeatedly brought blueline tilefish into the camera field of view. Based on the results of this project, we believe BUVs could be used to derive fishery-independent indices of abundance for blueline tilefish.

The use of the BUV survey techniques developed for blueline tilefish were not as successful for golden tilefish. We do not have a good explanation for this finding because the golden tilefish seen in one video were attracted to the bait and did not seem to mind the lights. Because the one video with golden tilefish was recorded during a drop that overlapped the longline set with the highest catch rate, BUV surveys may only be effective in areas where golden tilefish are more abundant.

(2) Comparing data collected with baited video surveys to catch data from concurrent commercial fishing trips to calibrate the video surveys.

Comparisons of catch and length data collected in longline surveys were completed. BUV survey measures of blueline tilefish relative abundance were correlated with commercial catch, while a comparable correlation was not seen with the golden tilefish data. Comparisons of fish lengths measured in the commercial catch and in the BUV stereo images indicate that smaller tilefish are surveyed using the BUV method.

(3) Estimating length-weight relationships for blueline and golden tilefish from data collected aboard commercial vessels.

Length-weight curves were generated for both species, and they are reported in **Appendix B**. Golden tilefish catch weights were successfully converted to catch numbers using the length-weight equation for this species.

(4) Testing the use of automated software to detect and count blueline tilefish in the BUV footage.

The results of the VIAME test runs were very promising. Based on the results using the built-in vertebrate detector, a better tilefish detector could be developed through repeated cycles of detector model training and scoring. The tilefish that the detector failed to correctly identify (e.g. faint or blurry fish in the distance, overlapping fish) are typical of problematic identifications in other species that can be dealt with through detector training (Matt Dawkins, personal communication).

Evaluation and Discussion

The goal of the research funded by the S-K grant program was to develop innovative supplemental surveys (proof of concept) to derive fishery-independent indices of abundance for blueline (*Caulolatilus microps*) and golden (*Lopholatilus chamaeleonticeps*) tilefish. Blueline tilefish are important recreational and commercial fish. Currently, there is no fishery-independent assessment for this species, and developing appropriate surveys is a management priority. Furthermore, surveys that would include tilefish under 25 cm in length are needed because smaller fish are rarely caught by recreational or commercial gear. Based on the results of this project, we believe BUVs could be used to derive fishery-independent indices of abundance for blueline tilefish. An initial survey with a stratified random sampling design weighted by area and prior catch data and strata based on depth (50-90 m, 90-120 m, and 120-140m) and latitude (0.5°divisions) would be recommended. A minimum of 60 stations, perhaps more due to tilefish patchy distributions, should be surveyed between 35.5°N and 39°N.

Both trips were shortened by bad weather. The blueline tilefish trip ended one day early, while the golden tilefish trip ended four days early. BUV survey work was not successful for golden tilefish and steaming time to and from the fishing areas took a day in each direction. Because we did not have sufficient sea time funding left for longer trips, and because we did not expect additional survey days to change our overall results and conclusions, we did not complete any additional tilefish survey days. Funding for the few days not spent at sea was used to explore the use of VIAME automated detection software.

Dissemination of Project Results

Project results have been disseminated through grant reports and on the CFF website, with videos posted on YouTube and highlighted through social media (Twitter, Instagram, and Facebook). A copy of the final report will be sent to the MAFMC, and we will present results at relevant council meetings upon request. We intend to publish the results of the project in a peer-reviewed journal to reach a wider audience.

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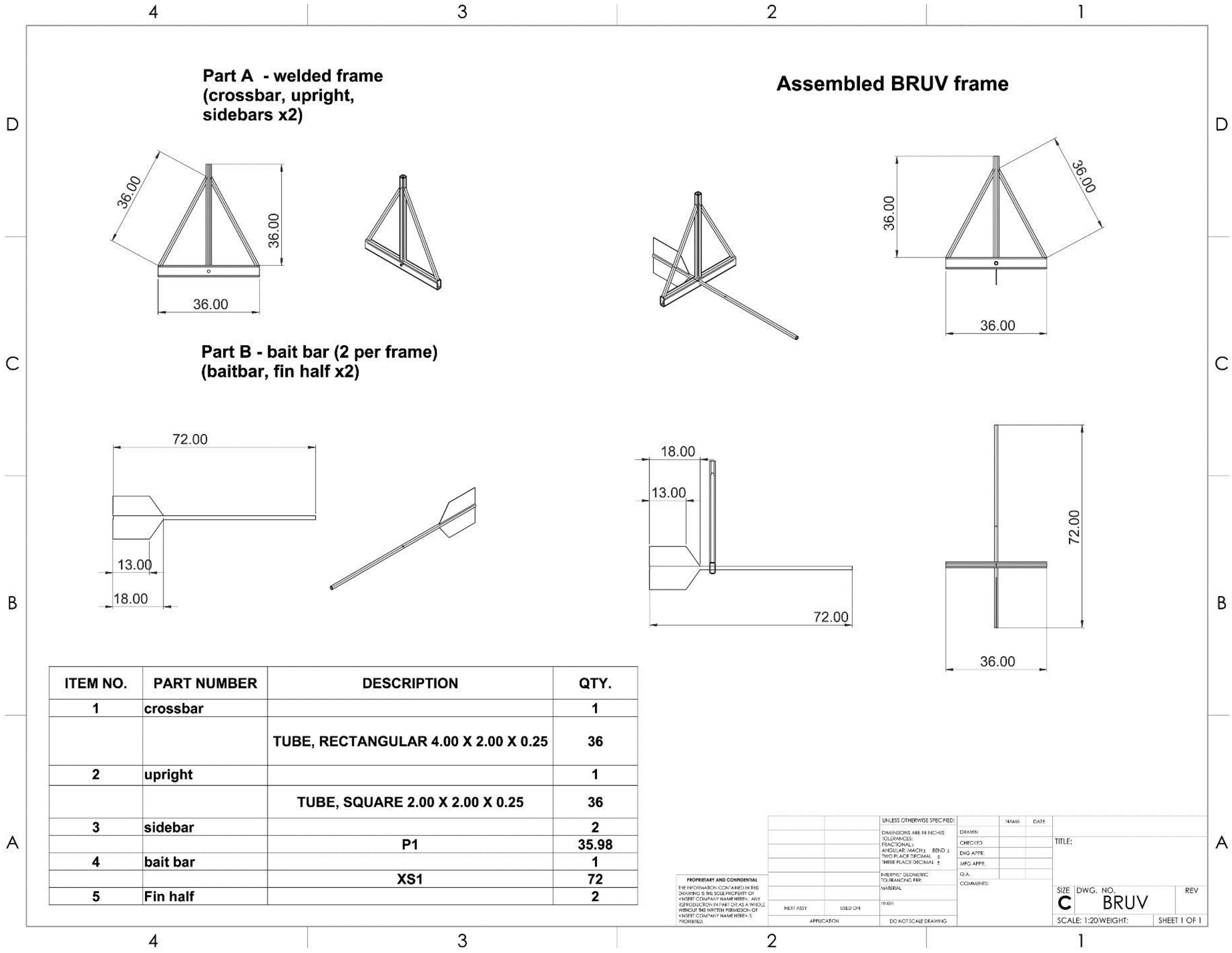
Appendix A. Technical drawing for CFF BUV frame.



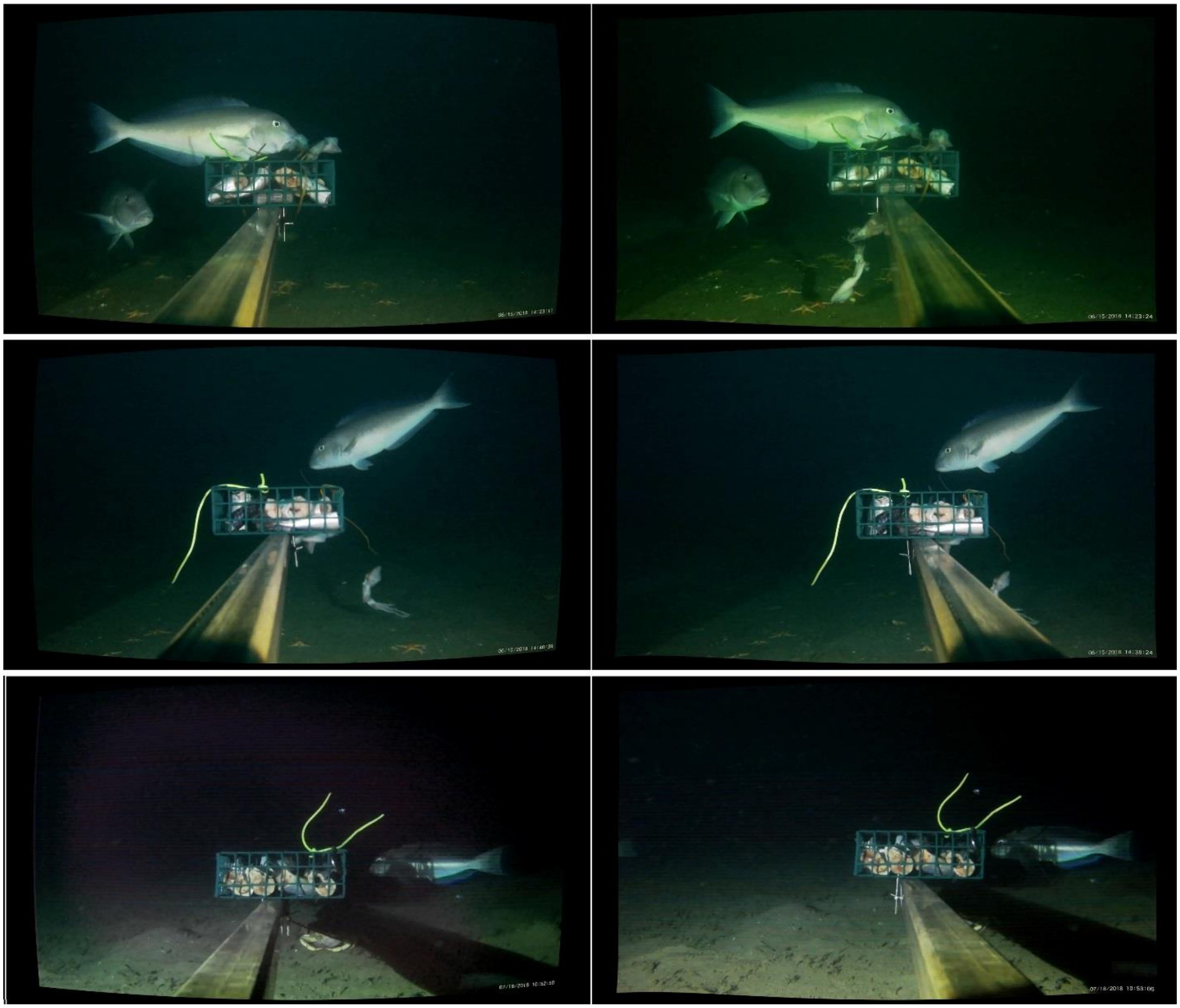
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	crossbar		1
		TUBE, RECTANGULAR 4.00 X 2.00 X 0.25	36
2	upright		1
		TUBE, SQUARE 2.00 X 2.00 X 0.25	36
3	sidebar		2
		P1	35.98
4	bait bar		1
		XS1	72
5	Fin half		2

Appendix B. Python code used to calibrate cameras (PATH refers to any path the user inputs).

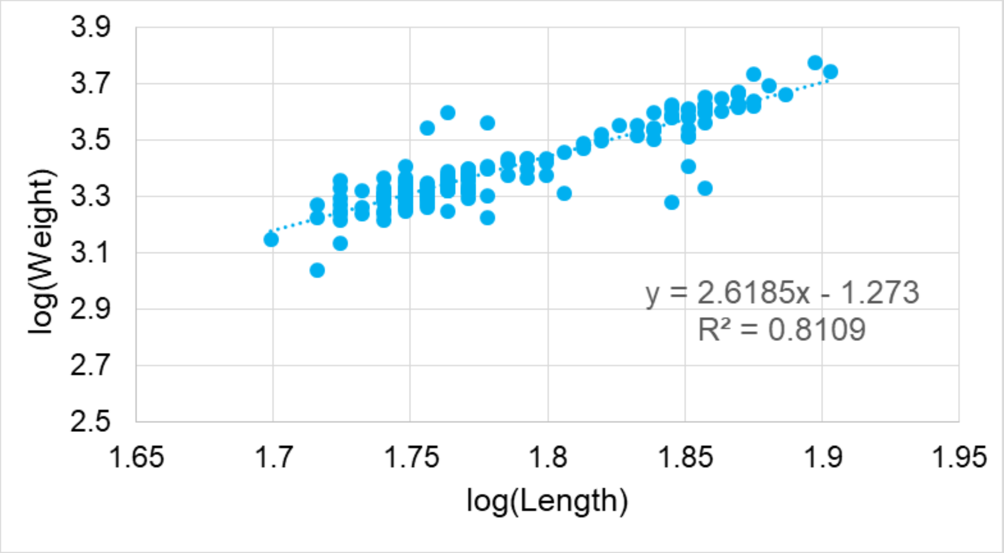
```
import numpy as np
import cv2 as cv
import glob
from matplotlib import pyplot as plt

# termination criteria
criteria = (cv.TERM_CRITERIA_EPS + cv.TERM_CRITERIA_MAX_ITER, 30, 0.001)

sqSize= 0.0432 # specific for CFF checkerboard

# prepare object points based on square size in checkerboard (in meters)
objp = np.zeros((6*8,3), np.float32)
objp[:,:2] = np.mgrid[0:8, 0:6].T.reshape(-1,2)*sqSize

imagesRight = glob.glob(r'PATH\*.jpg')

# Arrays to store object points and image points from all the images.
objpoints = [] # 3d point in real world space
imgpointsR = [] # 2d points in image plane.

for fname in imagesRight:
    img = cv.imread(fname)
    gray = cv.cvtColor(img, cv.COLOR_BGR2GRAY)
    # Find the chess board corners
    ret, cornersR = cv.findChessboardCorners(gray, (8,6), None)
    if ret == True:
        objpoints.append(objp)
        corners2R = cv.cornerSubPix(gray,cornersR, (11,11), (-1,-1), criteria)
        imgpointsR.append(corners2R)

# calibrate
retR, mtxR, distR, rvecsR, tvecsR = cv.calibrateCamera(objpoints, imgpointsR, gray.shape[::-1], None,
None)

# create rectified images
Rimages = glob.glob(r'PATH\*.jpg')

for num, fname in enumerate(Rimages, start=1):
    img = cv.imread(fname)
    dst = cv.undistort(img, mtxR, distR, None, mtxR)
    cv.imwrite(r"PATH\undistRight{:02d}.jpg".format(num), dst)

imagesLeft= glob.glob(r'PATH\*.jpg')

# Arrays to store object points and image points from all the images.
objpoints = [] # 3d point in real world space
imgpointsL = [] # 2d points in image plane.
```

```
for fname in imagesLeft:
    img = cv.imread(fname)
    gray = cv.cvtColor(img, cv.COLOR_BGR2GRAY)
    # Find the chess board corners
    ret, cornersL = cv.findChessboardCorners(gray, (8,6), None)
    if ret == True:
        objpoints.append(objp)
        corners2L = cv.cornerSubPix(gray,cornersL, (11,11), (-1,-1), criteria)
        imgpointsL.append(corners2L)

# calibrate
retL, mtxL, distL, rvecsL, tvecsL = cv.calibrateCamera(objpoints, imgpointsL, gray.shape[::-1], None, None)

# create rectified images
Limages = glob.glob(r'PATH\*.jpg')

for num, fname in enumerate(Limages, start=1):
    img = cv.imread(fname)
    dst = cv.undistort(img, mtxL, distL, None, mtxL)
    cv.imwrite(r"PATH\undistLeft{:02d}.jpg".format(num), dst)

# stereo calibration
 stereo_criteria = (cv.TERM_CRITERIA_EPS + cv.TERM_CRITERIA_MAX_ITER, 30, 0.001)
stereo_flags = cv.CALIB_FIX_INTRINSIC + cv.CALIB_SAME_FOCAL_LENGTH + cv.CALIB_FIX_K3

retval, cameraMatrixL, distCoeffsL, cameraMatrixR, distCoeffsR, R, T, E, F =
cv.stereoCalibrate(objectPoints=objpoints, imagePoints1=imgpointsL, imagePoints2=imgpointsR, imageSize
= (w,h), cameraMatrix1=mtxL, distCoeffs1=distL, cameraMatrix2=mtxR, distCoeffs2=distR, criteria =
stereo_criteria, flags = stereo_flags)

np.savez("TilefishCamCalib",cameraMatrixR=cameraMatrixR, distCoeffsR=distCoeffsR,
cameraMatrixL=cameraMatrixL, distCoeffsL=distCoeffsL, R=R, T=T, E=E, F=F)

#stereo rectify
rectify_scale = 0.5 # 0=full crop, 1=no crop
R1, R2, P1, P2, Q, roi1, roi2 = cv.stereoRectify(cameraMatrixL, distCoeffsL, cameraMatrixR, distCoeffsR,
(w,h), R, T, alpha = rectify_scale)
```

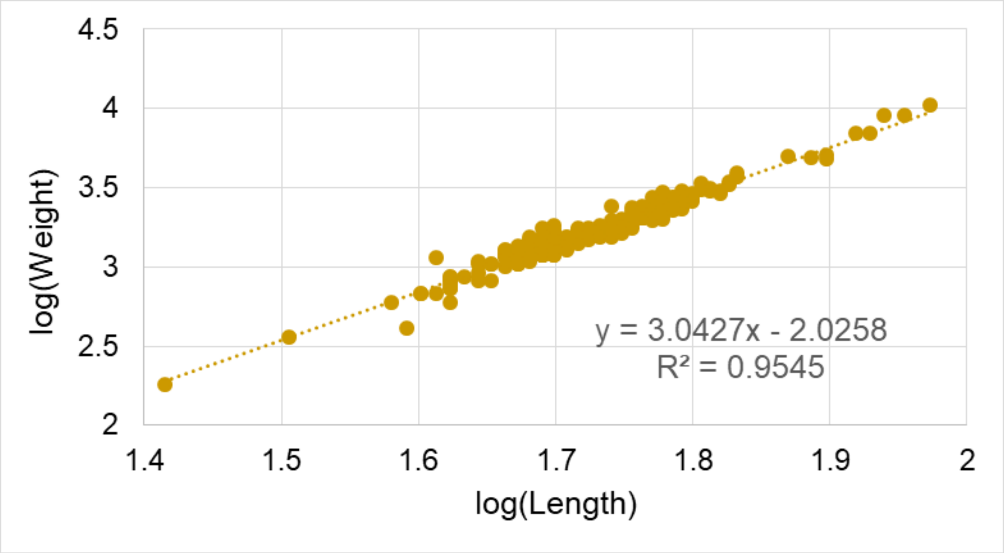
Appendix C. Examples of rectified stereo pairs used for measuring tilefish.



Appendix D. Length-weight curves and parameter estimates for blueline and golden tilefish. Length was measured in centimeters and weight was measured in grams.

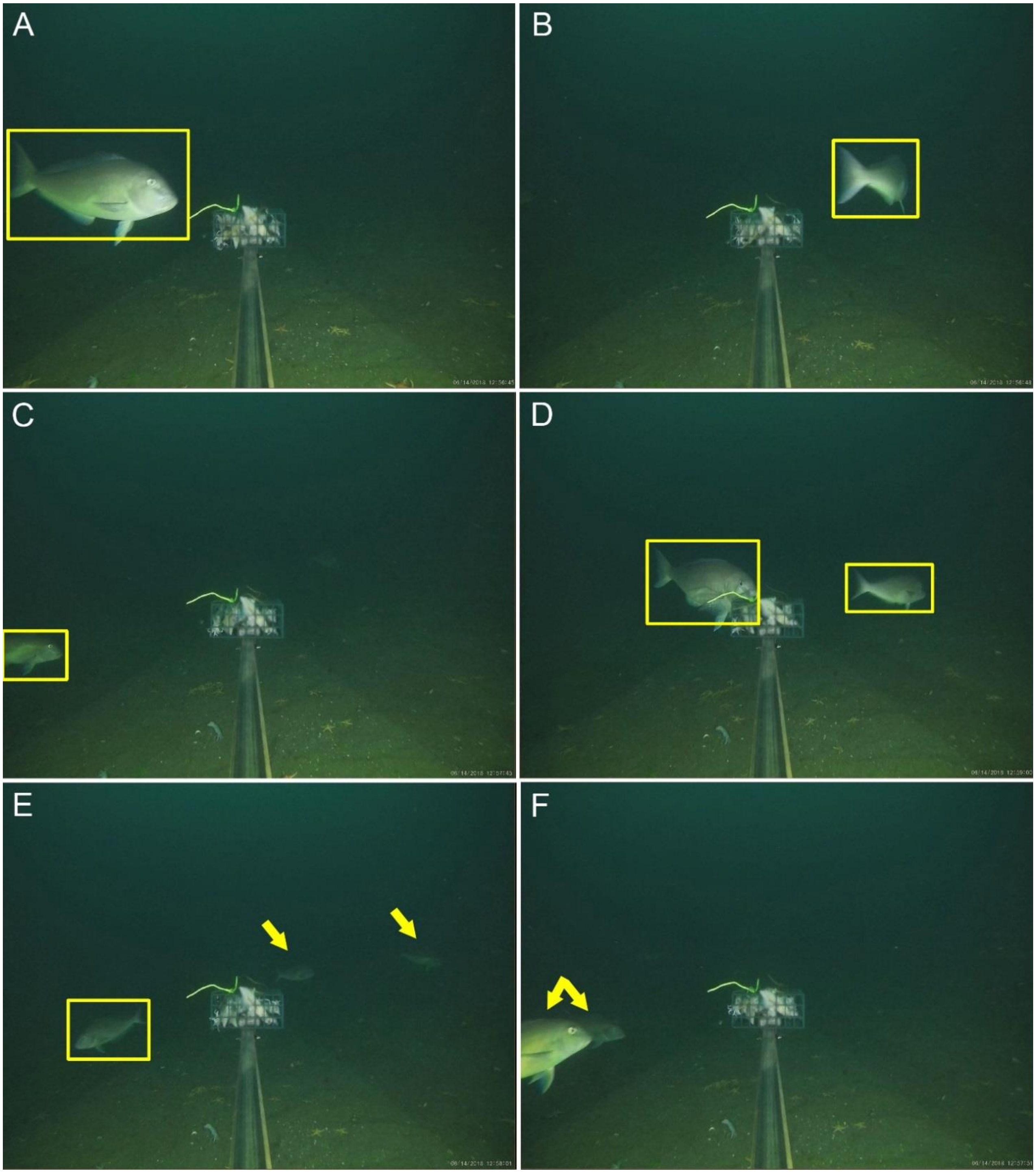


Length-weight relationship for blueline tilefish (N=164).



Length-weight relationship for golden tilefish (N=294).

Appendix E. Examples of tilefish successfully and unsuccessfully detected by the VIAME vertebrate detector.



(A-D) Examples of successfully detected tilefish, boxed with a yellow rectangle. (E-F) Examples of tilefish that were not successfully detected. The yellow arrows highlight distant fish that were faint and blurry or fish that were overlapping.