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The Camera-Based Assessment Survey System (C-BASS): A towed camera platform for reef fish abundance surveys and benthic habitat characterization in the Gulf of Mexico

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ABSTRACT

An ongoing challenge for fisheries management is to provide cost-effective and timely estimates of habitat stratified fish densities. Traditional approaches use modified commercial fishing gear (such as trawls and baited hooks) that have biases in species selectivity and may also be inappropriate for deployment in some habitat types. Underwater visual and optical approaches offer the promise of more precise and less biased assessments of relative fish abundance, as well as direct estimates of absolute fish abundance. A number of video-based approaches have been developed and the technology for data acquisition, calibration, and synthesis has been developing rapidly.

Beginning in 2012, our group of engineers and researchers at the University of South Florida has been working towards the goal of completing large scale, video-based surveys in the eastern Gulf of Mexico. This paper discusses design considerations and development of a towed camera system for collection of video-based data on commercially and recreationally important reef fishes and benthic habitat on the West Florida Shelf. Factors considered during development included potential habitat types to be assessed, sea-floor bathymetry, vessel support requirements, personnel requirements, and cost-effectiveness of system components. This regional-specific effort has resulted in a towed platform called the Camera-Based Assessment Survey System, or C-BASS, which has proven capable of surveying tens of kilometers of video transects per day and has the ability to cost-effective population estimates of reef fishes and coincident benthic habitat classification.

1. Introduction

1.1. Underwater visual census and fisheries independent surveys

The development of new fisheries survey technologies to supplement traditional sampling methods has been a research priority for over a decade (National Research Council, 2000, 1998; Walsh et al., 2002). Optical sampling approaches, in particular, are more frequently being developed and used in stock assessments (Mallet and Pelletier, 2014). Besides being non-lethal and minimally invasive, visual methods are also of particular utility in untrawlable, fishing restricted, or otherwise difficult-to-sample habitats (McIntyre et al., 2015; Schobernd et al., 2013; Williams et al., 2010). Camera systems for surveying fishes and their surroundings have been integrated into several different types of technology (Mallet and Pelletier, 2014) such as autonomous underwater vehicles (AUVs; Clarke et al., 2010; Singh et al., 2013), remotely operated vehicles (ROVs, Reed et al., 2005), stationary drop systems (Cappo et al., 2006; Devries et al., 2015; MacDonald et al., 2011), submersibles (Tolimieri et al., 2008; Yoklavich et al., 2007), and towed bodies (McIntyre et al., 2015; Taylor et al., 2008). Each of these approaches has advantages and disadvantages with some being more appropriate than others depending on regional seafloor characteristics and research or survey objectives. One of the most well-known successes in implementing visual survey technology into stock assessment is in the northeastern United States; prior to the mid-2000's, Atlantic sea scallop (*Placopecten magellanicus)* surveys were primarily conducted using dredges (Cryer, 2015; Taylor et al., 2008). An alternative approach, known as the HabCam, was developed by the Woods Hole Oceanographic Institution and the National Marine Fisheries Service. Studies showed that this bottom tending visual survey system was not only non-destructive and non-invasive, but that it also produced a more robust dataset by providing information on juvenile recruitment and

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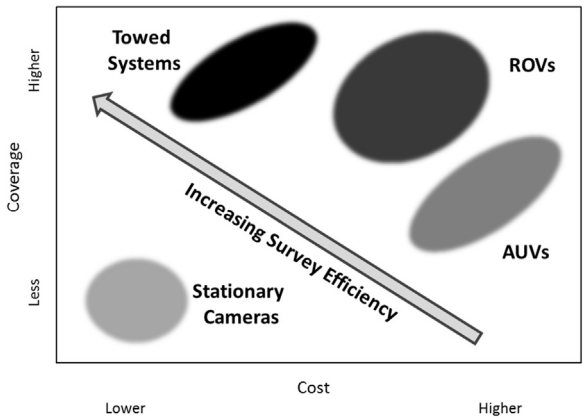

Fig. 1. A comparison of various video collection platforms relative to spatial coverage and full cost of operation with a focus on increasing survey efficiency defined as a cost per area covered.

species-habitat associations (Cryer, 2015) and resolved the ongoing controversy regarding dredge-based survey efficiency.

In the eastern Gulf of Mexico, our species of interest include several prominent managed reef fish fisheries including Red Snapper (*Lutjanus campechanus),* Vermilion Snapper (*Rhomboplites aurorubens*), Red Grouper (*Epinephelus morio),* Gag Grouper (*Mycteroperca microlepis),* and Greater Amberjack (*Seriola dumerili*). These species congregate in areas of high relief and the habitats they prefer potentially span large tracts of the West Florida Shelf (WFS). When deciding on an optimal platform for visual surveys in this region, sampling coverage, efficiency, and cost are factors to be considered. Ideally, a sampling platform would be of modest cost to develop and operate, provide synoptic coverage of multiple square kilometers of area, and have a quantifiable sampling efficiency. Numerous platforms and operational modes were considered but with the higher costs and potential operational limitations associated with AUVs, manned submersibles, and ROVs, as well as the spatial limitations of drop systems (Fig. 1), we decided that a towed camera system was most likely to provide an effective survey approach for WFS reef fishes.

Following are technical specifications and example results from pilot studies of this new towed sampling technology developed at the University of South Florida's College of Marine Science (USF-CMS) for optically-based surveys of reef fishes and benthic habitat. Known as the Camera-Based Assessment Survey System (C-BASS), this tool (Fig. 2) is a towbody equipped with cameras and performance and environmental sensors (Grasty, 2014; Lembke et al., 2013). Over the course of its

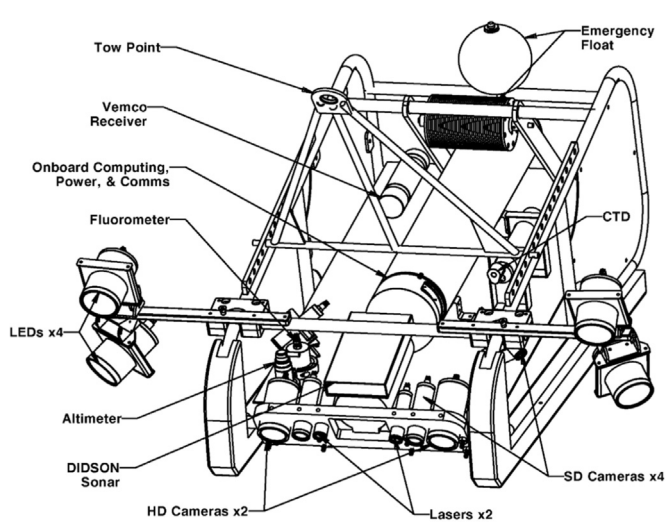

Fig. 2. Schematic of the Camera-Based Assessment Survey System (C-BASS) towbody.

development, we have collaborated with management agencies to incorporate operational suggestions in anticipation that C-BASS data would be used in future reef fish stock assessment and habitat classification work for the eastern and potentially western Gulf of Mexico. Preliminary results obtained over the past several years and continued collaboration with state and federal agencies has indicated that this technology is complimentary to current benthic habitat mapping and fisheries assessment surveys on the WFS and also provides high-resolution data on fish-habitat associations.

2. Materials and methods

2.1. Design objectives

The primary goal of the C-BASS system was to provide expansive and cost-effective habitat stratified abundance estimates for the reef fish species of interest in the eastern Gulf of Mexico. Based on literature review, consultations with underwater technology groups involved in visual survey systems, and input from staff at fisheries management agencies already utilizing visual assessment methods, the design objectives were developed consider: (1) habitat ranges of the reef species of interest, (2) bottom types to be encountered, (3) ability to identify targets (4) sampling of large areas under realistic survey operations, (5) cost to build and operate, and (6) versatility to incorporate new technologies and work on multiple vessels with minimal effort and infrastructure investment.

The eastern Gulf of Mexico encompasses bottom types which range from low relief sand and carbonate rock to modest relief ledges 5–10 m high. This meant we needed to have close bottom tracking capabilities, as the species of interest are bottom-tending organisms, but we also had to be able to respond quickly to these depth changes. Based on our camera tests, we also knew that the targets of interest for this effort were generally visible up to distances of 5–8 m ahead of the system. These constraints were important when determining the standard survey speed, optimal altitude, and camera angles that would allow for the greatest coverage without forfeiting the quality of the data. By balancing these aims, advantages and disadvantages of AUVs, ROVs, stationary camera systems, and towbodies were considered, but the utilization of a towed system presented significant cost advantages without performance sacrifices for surveys on the WFS.

The enhanced capabilities of AUVs and ROVs and the low cost of stationary camera systems are attributes to be considered, but within the context of the operational scope of the task, which is large-scale visual fish population surveys. While towed platforms are less capable of detailed maneuvers and close-bottom tracking compared to AUVs or ROVs, the added complexity and cost of these other systems decrease the cost-effectiveness of large scale sampling necessary to generate population scale abundance and demographic data being sought. Additionally, an ROV-based system is unlikely achieve comparable spatial coverage to a towed system under similar vessel support and time constraints and its advantages over a towed system with better maneuverability and ability to interact with the surroundings would not have provided significant off-setting benefits to a large scale survey. The use of AUVs presents the potential for great long term efficiency when used in fleets, however the complexities and high cost of operations at present continue to significantly surpass that needed for a towed system. There are significant system-development constraints at this time to make such fleets cost effective. However, it should be noted that these other technologies can be better suited than a towbody when the goals of the survey change, such as trying to capture cryptic species and /or more closely track the seafloor at less than two meters. Further, comparisons of fish behaviors to various platforms needs to be considered and is currently under investigation within the National Oceanic and Atmospheric Administration's Untrawlable Habitat Strategic Initiative (UHSI).

Our decision to use a towbody was ultimately made by focusing on

maximizing survey efficiency for the bottom habitat environment and target species of interest. Survey efficiency can be quantified by comparing the spatial coverage a system can deliver and the overall costs involved with procuring and operating the system. AUVs and ROVs are more costly than a comparable towed system, simply by the nature of the added complexity needed for their enhanced capabilities. While stationary drop cameras are less expensive than a comparable towbodies, the area coverage per unit time is significantly less. The balance between costs and coverage for these various systems is demonstrated in Fig. 1. In the end, our decision was a balance of synopticity over relevant spatial scales and stock assessment efficiency to help develop methods that may significantly streamline estimating fish abundance in the eastern Gulf of Mexico.

Based on the system's operating constraints the resulting C-BASS design prioritizes flexibility and simplicity in its hardware along with robust data acquisition and storage capacities. Since technological advances of electronic and sensor hardware are frequent and mission objectives can evolve during prototype demonstration, the design minimized complexity in favor of producing a simple, flexible system, capable of supporting continued development as the project progressed. Past engineering efforts at USF-CMS's Center for Ocean Technology (COT) were leveraged to speed development of the system by using successful subsystems or components from other systems (Fefilatyev et al., 2009; Samson et al., 2000; Short et al., 1999). Considerable effort was devoted to software development to ensure reliable data collection and archiving which would streamline analysis. The result is an approach that focuses on data collection and analysis which has provided valuable feedback into system design and component performance for the past several years.

2.2. The Camera-Based Assessment Survey System (C-BASS)

2.2.1. Overview

The C-BASS towbody is equipped with cameras and other sensors designed to be towed off the stern of research vessels via a winch system at a constant speed and consistent altitude above the seafloor for several hours (up to approximately 20) without surfacing the towbody. The C-BASS can be deployed from moderately sized research vessels (25–50 m in length) equipped with a winch-controlled four conductor cable capable of towing loads of at least 2000 kg. A three-conductor cable can also be used if it possesses conductive outer armor to serve as the fourth conductor. The system is intended to be towed at speeds between 1.0 and 2.0 ms^{-1} under both daytime and nighttime conditions. When bottom topography permits, target altitudes are $\geq$ 1 m to $\leq$ 5 m. The C-BASS is powered via two of the conductors in the winch cable which are connected to the ship's generators. The remaining two conductors are used for communications which affords the pilots real-time control of the cameras and other sensors via a custom web-based user interface. The C-BASS is currently configured with ports for up to six video cameras, four LED lights, a CTD, fluorometer, altimeter, compass, internal monitoring sensors, and a DIDSON sonar, all of which can be monitored in real time. It has also been equipped with an onboard computer and 1TB of data storage.

2.2.2. Hardware

The C-BASS's aluminum frame measures 179 cm long × 87 cm high × 127 cm wide and includes two side panels as well as a main horizontal aluminum chassis where most of the components are mounted (Fig. 2). Landing skids fabricated from a combination of solid plastic bars and durable rubber bumper material are attached to the bottom of the chassis which softens the impact when the towbody is recovered on deck or if the towbody makes contact with the seafloor during a deployment. The side and bottom plates assist in platform stability by acting as hydrofoils when the system is towed through the water, reducing yaw variations and, to a lesser extent, pitching. The horizontal frame is mounted at a 7° angle to the chassis base which results in a slight "tail down" attitude during tows; if the C-BASS gets too close to the seafloor this allows the aft end of towbody to impact any bottom features before the forward end where most of the sensitive equipment is located.

When the C-BASS is loaded with typical mission instrumentation it weighs approximately 230-kg in air and 85-kg in seawater. It is currently designed with a 200 m depth rating (encompasses maximum depth ranges of most of our species of interest), though this could be increased with redesign of select components, including the camera and electronics housings. The system is towed via a single bridle which is adjustable to compensate for changes in the system's center of gravity as instrumentation is added and removed. The bridle is connected to the ship's winch cable using a shackle equipped with a pin engineered to shear prior to cable failure. Should the shear pin fail due to excessive load, a secondary attachment is connected via chain at the rear of the towbody with a similar shear pin. Should both pins fail, a pressure rated buoy attached to 300 m of 1100 kg rated line is triggered to float to the surface for emergency recovery of the system.

A 1.05 m anodized aluminum cylinder, 0.2 m in diameter, is mounted longitudinally to the towbody's main chassis. In the C-BASS's original design, the onboard computer, communications equipment, power transformer, compass, hard drives, and microcontroller were all mounted within this single core housing. However, because of the large quantity of components in the housing and resulting potential for overheating, the computer and hard drives were upgraded and moved to a separate housing, with multiple copies of this computer housing created to allow for rapid replacement of storage capacity.

2.2.3. Cameras and Sensors

The C-BASS was initially configured with three forward facing cameras but early in its development the camera chassis was upgraded to contain six video cameras: two high definition (HD) and four standard definition (SD). The two HD cameras primarily used during the first three years of this work (2013–2015) were an AVT® Procilica GT1920 coupled with a Schneider® Cinegon lens collecting images at 1936 × 1456 resolution at 12 frames-*per*-second (fps) and an Arecont® AV10005 configured with a Kowa® lens collecting video at 15 fps with a 1920 × 1080 resolution. The four SD analog cameras are installed through an Axis® Q7404 Video Encoder. The original SD cameras on the system were Sony® Super HAD CCD imagers, two of which were able to automatically switch to monochrome under low light conditions. In 2015, these were upgraded to Sony® PC339HR cameras capable of auto white-balance and enhanced user control with all recording at a resolution of 720 × 480 and 30 fps. The two HD cameras and two of the SD cameras are positioned on the front of C-BASS and are parallel to one another. A separate forward facing, angle-adjustable camera chassis holds the four forward-facing cameras in addition to two parallel lasers is located at the forward end of the towbody frame. The remaining two SD cameras are on the port and starboard sides of C-BASS and angled slightly outward which results in total imagery coverage close to 180° centered on the bow. All of the cameras are mounted at a 35° angle down from the main horizontal chassis so that during tows the bottom is mostly within the field-of-view as opposed to being parallel with the bottom.

The forward facing SD and HD cameras are configured so that either pair is capable of stereo coupling. The SD cameras used for stereo measurements have a base separation of 330 mm while the HD cameras have a base separation of 490 mm. The typical target of our video is four to seven meters from the cameras, therefore angling the cameras inward to replicate field of views was deemed unnecessary. All four forward facing cameras are also parallel and in-line with the pair of green, parallel lasers. The lasers were added in 2014 for rudimentary measurement and scaling purposes. Two dimensional calibration capability for stereo video measurements was added in early 2015 following methods similar to those in Ruff et al. (1995) and Williams et al. (2010). However, as of 2016 we have moved towards in-water 3D

calibrations using the CAL software package which produces calibration files for each camera for use in EventMeasure where individual fishes can be sized (SeaGIS Pty LTD; Harvey and Shortis, 1998; Shortis et al., 2000). The lasers remain on the system and are used to periodically confirm the stereo calibrations during field work. Preliminary analysis of these methods are promising; in measuring the laser distances within video to actual distance, errors have been less than 10%. More testing is underway to validate this accuracy and compare results with other modes of use, such as stationary stereo camera systems, if these measurements are to be utilized for biomass estimates in the future.

In addition to the cameras, a forward-looking DIDSON® sonar was added in 2014 with the intent of observing fish behavior beyond the visual field-of-view. The sonar has typically been configured to collect imagery at 5 fps with a 10 m range with a standard 14° lens. The DIDSON is currently angled slightly down (approximately 5° from horizontal chassis) during standard configuration and operation. The forward-looking sonar is primarily used to test whether fish detected potentially avoid the towbody prior to being imaged by the C-BASS. Continued evaluation of this sonar's utility is ongoing with attention toward rapid analysis techniques to ascertain the value of the data sets.

The towbody is also equipped with numerous performance and environmental sensors which are continuously databased at varying rates during deployments. A Honeywell® HMR3300 compass provides towbody pitch, roll, and heading at 8 Hz. Altitude is monitored using a Tritech® PA 200/20 altimeter outputting at 10 Hz. Environmental sensors contained on the towbody include a RBR® XR 420 CTD and a WET Labs® FLNTU fluorometer; both instruments collect measurements at 1 Hz. Internal pressure vessel conditions of the core electronics and computer vessels are monitored by an Arduino® microcontroller board which is equipped to detect leaks and measure temperature using thermistors which have been placed at areas of concern. Leak detection is accomplished using two lead wires, one of which is linked to a pull-up resistor connected to 5 V of power. When a conducting medium (salt water in this case) connects the leads, this value will drop thereby alerting the operator of a potential sea water intrusion.

Other instrumentation of opportunity is often integrated into the C-BASS's configuration such as a Vemco® VR2 tag telemetry receiver and a Loggerhead Instruments® Remora-ST passive acoustic sound recorder. Lastly, there are four LED lights mounted with custom fabricated fixtures allowing them to be independently angled for optimal illumination.

2.2.4. Software & Controls

The software structure used for operating C-BASS and recording video and sensor data has an undersea towbody component and a topside shipboard component (Fig. 3). Onboard C-BASS, the computing power has evolved from a Xi3® Modular Computer to an Intel® NUC5i7RYH computer combined with a Raspberry Pi® 2B computer. The computers handle all data via a custom developed publisher/subscriber schema; the SD video, HD video, and sonar streams are piped directly to two 500 GB hard drives, stored in a directory structure based on the source (camera 1, camera 2, DIDSON, etc.), then placed in time-stamped directories with one minute files named sequentially (000001.*, 000002.*, etc.). The AVT HD camera produces a YUV411 image pipeline which is encoded as.jpeg images and stored in a similar directory structure as the videos. Post deployment, these images are then processed to create videos timed to match those from the other cameras. The serial data from C-BASS (e.g. altitude, pitch, temperature) are time-stamped and stored via a database subscriber at varying frequencies into a MySQL® database on the towbody computer. Additionally, the timing of any system adjustments are all logged into the database, such as turning on/off lights or lasers and adjusting camera settings. This onboard database is replicated on a topside desktop computer in real time while the system is running. This topside database is also capable of appending shipboard data such as vessel position and attitude. All data are synced to regular updates from the shipboard GPS time-stamp to ensure all clocks run on UTC timing.

The user controls reside on the topside computer equipped with a custom web interface. A webserver on the towbody computer sends select serial data from the publisher (altitude, depth, internal temperature, leak detection, water temperature, salinity, turbidity and chlorophyll) and merges it with a user selected SD stream from one of the four cameras served through the Axis video server for the user's main webpage (Fig. 4). These data are displayed continuously in near real-time with a typical delay of less than one second. A separate page displays periodic images at 0.1 Hz from all cameras and the DIDSON to ensure functionality of each and allow for optimization of some camera settings as needed. Lastly, a third page provides the user with system controls allowing the operator to control lights, lasers, the DIDSON, and the HD cameras. There are also controls for starting/stopping data recordings and system shutdown.

2.2.5. Communication and power distribution

Communication and power between the vessel and the towbody can be distributed through any four conductor winch cable which allows flexibility in vessels capable of supporting C-BASS. For most tows completed to date this has been done using a 3 conductor 0.322″ hydrowire cable commonly found on research vessels, with the fourth conductor being the external cable armor. The user communicates with the towbody through the tow cable using a Black Box SDSL Network Extender®. This allows moderate bandwidth communication via two conductors. When utilizing one internal conductor and the cable's armor shielding as the second conductor on a 2000 m cable, 1.0 Mbps data rates are reliable, though reduced rates have been encountered and eliminated with careful attention to other vessel noise sources. Onboard the towbody, Ethernet, serial, and USB communications are supported and controlled by the Intel NUC® and Raspberry Pi® computers.

The ship's generator has been the typical source of C-BASS's power, but a separate generator with at least 1 KVA / 220 V capability could also be used. From the source, 220 V AC is supplied to a custom waterproof power distribution box on deck. This box contains fuses, circuit breakers, a magnetic cutoff for powering on/off the C-BASS, and indicator lights displaying the system's power status. A toroidal power transformer steps up the voltage to 730 V AC before being conducted through the winch slip ring to two internal conductors of the hydrowire. This voltage increase allows up to nearly 700 W of power to be available for the towbody. Onboard the system, the voltage is stepped back down to 220 V and distributed to three AC to DC converters: a 5 V power supply utilized by the compass, DSL subscriber modem, two Ethernet switches, the arduinos, and the Raspberry Pi®; a 12 V supply for the Axis (SD) video server, Arecont® HD camera, CTD, altimeter, serial to Ethernet server, fluorometer, and SD cameras; and a 30 V supply utilized by the AVT® HD camera via a power over Ethernet converter, the lights, lasers, and the DIDSON.

2.3. Operations

The C-BASS is deployed off the stern of the survey vessel via an A-frame and winch (Fig. 5). This creates a dynamic towing tension of 300–400 kg, depending on sea state and tow speed. Deployments can be achieved from a variety of vessels equipped with a winch system able to withstand a minimum of 10 kN of dynamic tension and enough space for launch and recovery (at least nine square meters). A lifting frame capable of angling slightly away from the aft end of the vessel is preferred to help avoid damaging the system in rougher seas during launch and recovery.

Prior to deployment, the towbody is positioned on the aft of the deck while the vessel positions itself in line with the planned transect (Fig. 5). For deployment, the vessel is typically moving forward at $\sim 0.5\ \mathrm{ms}^{-1}$. Once in the water, the system is powered up while the winch lowers the towbody approximately 10 m beneath the surface. When communications are established, all cameras and sensors are

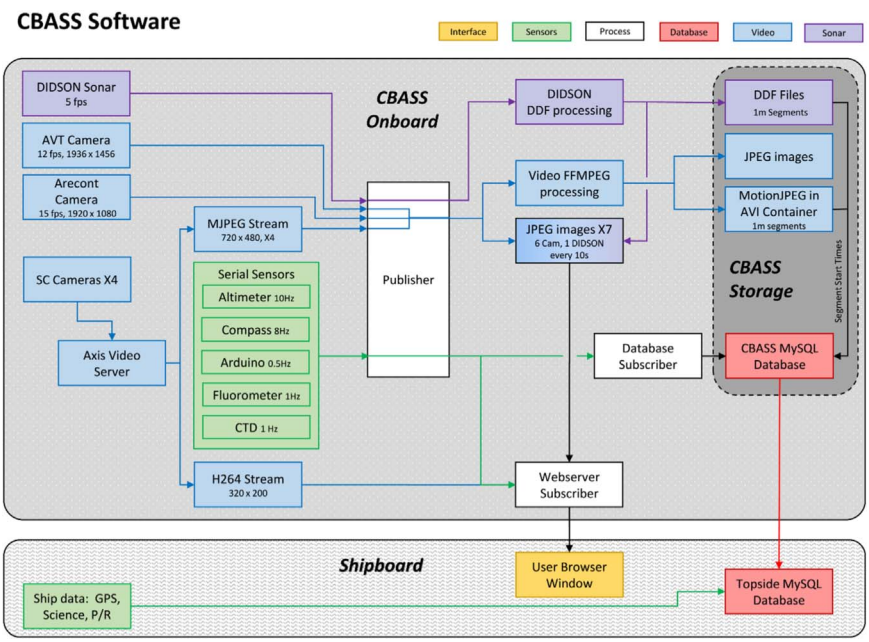

Fig. 3. Software structure of the onboard and shipboard components associated with C-BASS.

quickly checked for proper reporting. After acceptable performance is confirmed, the C-BASS pilot starts recording data and video while it is lowered to the desired altitude above the seafloor. As towing continues, the operator monitors the towbody performance with particular attention to its altitude. Adjustments to the towbody depth are accomplished via communication with the winch operator. The system is highly responsive to small (1 m) adjustments in winch cable payout which determines altitude. The key operating variable is maintaining near constant vessel speed over the bottom, as speed variations will cause the towbody to sink or rise accordingly. When a transect is complete, the towbody is raised to 10–15 m beneath the surface where recording is stopped and the power is shut off before the system is brought back on deck.

Per its current onboard storage capacity, C-BASS can be continuously towed for up to 20 h but tows between four and eight hours are the norm. For tows in 2013 and 2014, the storage capacity was the limiting factor in the amount of towing per day that could be accomplished as data had to be offloaded, typically overnight. By splitting the computer and storage into separate vessels and creating replicates of the computing/storage vessel, a swap can be done relatively quickly during a brief recovery of the towbody. This allows for nearly 24 h operations and thus enables more efficient use of ship time. Depending on the survey set up, these 24 h operations are useful for studying behavioral changes in fish communities throughout the diurnal cycle.

When planning transects for a cruise, multibeam bathymetry ($\leq$ 10 m grid size is sufficient) and backscatter maps provide detailed seafloor information and an estimation of the bottom types in a survey area. These data are necessary for knowing seafloor depth variation as well as where to concentrate effort (minutes towed) relative to potential habitat types to be sampled. When the C-BASS is in use on the R/V *Weatherbird II*, our typical survey vessel thus far, tows are conducted in conjunction with a hull-mounted EK-60 sonar which provides real-time data about bottom features and fish presence. Contemporaneously, a live feed of the ship's GPS log is piped into a computer running an ArcMap document that has been set-up to display the multibeam bathymetry data (collected during previous surveys) for the survey area. This provides information about upcoming bathymetric variations.

3. Results

3.1. Cruises

Starting in early 2013 through to the end of 2015, the C-BASS was used to complete six survey cruises aboard two different research vessels in the eastern Gulf of Mexico (Table 1; Fig. 6). During these cruises a total of 901.1 km of transect were surveyed and 152 h of imagery were collected. Towing depths ranged from 25 to 200 m and deployment durations typically ranged from three to six hours over which 18–36 km of transect were imaged. Most of these tows were conducted within marine protected areas (MPA), specifically the Florida Middle Grounds (FMG) Habitat Area of Particular Concern as well as the Madison-Swanson (MS) MPA and Steamboat Lumps (SL) MPA. However, initial sea trials were conducted along the Gulfstream Natural Gas Pipeline (GSPL) where the system could be easily tested along a constant feature of limited height variation (Fig. 6). Five of the cruises utilized the R/V *Weatherbird II* operated by the Florida Institute of Oceanography (FIO) and one was aboard the R/V *Pelican* operated by the Louisiana Universities Marine Consortium (LUMCON). The C-BASS's performance during these cruises was stable regardless of vessel which demonstrated the platform's versatility and adaptability (Table 1).

The preparation and outfitting of a vessel prior to a cruise is typically accomplished in less than 12 h, including winch cable connector customization and adaptation to the ship's power supplies. This was the case in preparation for the August 2014 cruise aboard the R/V *Pelican* when the vessel arrived at USF's docks with their own winch and cable and was in dock for less than 12 h prior to departure. This was a large consideration in the design scope of the project and induced the utilization of the DSL communication system and the software structure created to enable relatively quick and easy mobilization. This is in contrast to a fiber-optic system which may have allowed all data to be transmitted back to the ship, but is more costly and could require a more complex mobilization as it would likely require a dedicated winch and a more fragile fiber optic cable.

3.2. Optimal towing conditions and performance

Over the course of these cruises, the operational limitations and capabilities were quantified with particular focus on tow altitude, tow speed, and imagery angle to the seafloor. In order to remain a safe

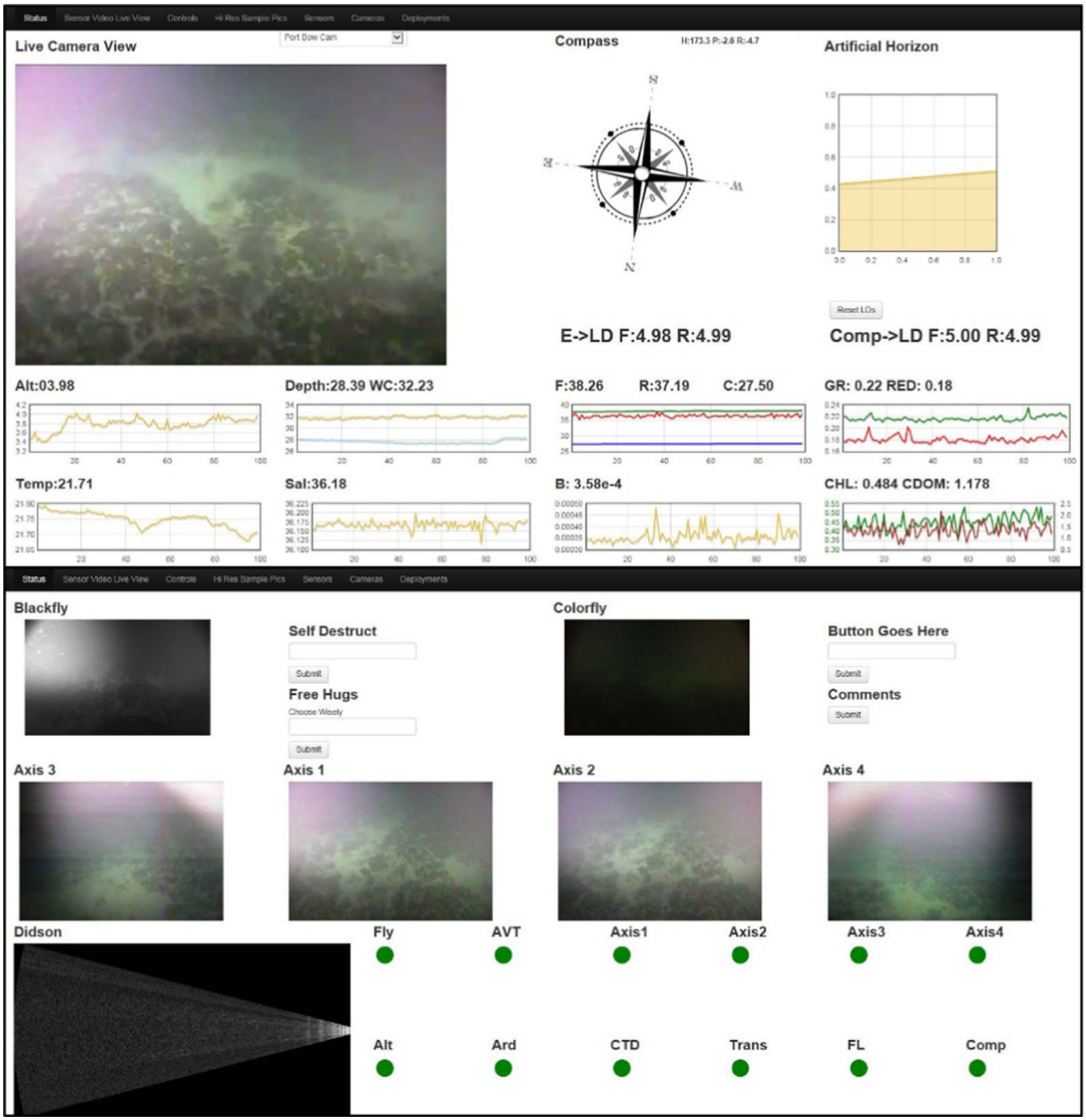

Fig. 4. Custom-written user interface for C-BASS operation during surveys. The top panel shows the video feed and sensor data streams. The compass and artificial horizon indicate how the system is trending during deployment. The bottom panel depicts periodic still images sent by all cameras and DIDSON sonar as well as status indicators of all sensors.

distance from the bottom, be able to react to any obstructions, and still record usable video for species/habitat identification, an optimal towing altitude of 2.0–3.5 m and speeds of 1.5–2.0 ms^{-1} have proven effective. Towing at higher altitudes often resulted in a reduction in detectability and identification of targets. Moving faster caused blurred imagery for too much of the camera view. At this altitude and speed, a camera angle of 30–35° from horizontal toward the seafloor provided a balance of field of view and video quality. These values were determined primarily in consultation with the image analyzers and their opinions of the optical quality since they are the ultimate quantification of the success rate of species identification.

With these operational constraints, analysis of the performance of the system during field work was needed to ensure the system is capable of these constraints. The three study areas (FMG, MS and SL) varied in their sampling difficulty so to analyze C-BASS's performance, the altimeter data for four transects completed in these three areas in 2014 were plotted to determine for how much of these tows the system was at ideal (2.0 – 3.0 m) and acceptable (1.0 – 4.0 m) towing altitudes (Fig. 7). In the FMG-South transect, towing was over relatively flat bottom with minimal depth changes and C-BASS was able to remain at ideal altitudes approximately 63% of the time and at acceptable altitudes for 94% of the transect. Along FMG-North, there were larger,

Fig. 5. Deployment of the C-BASS from the aft end of the vessel.

Table 1
Summary of the C-BASS cruises completed between 2013 and 2015 along the Gulfstream Pipeline (GSPL) and in the Florida Middle Grounds (FMG), Madison-Swanson (MS), and Steamboat Lumps (SL) marine protected areas.

Cruise Dates	Survey Areas	Total Time in Water	Transect Length Imaged (km)	Description	Vessel
March 1–5, 2013	GSPL	14 h 43 m	67.68	Sea Trials	R/V *Weatherbird II*
June 14–16, 2013	FMG, MS	29 h 17 m	172.8	MPA Survey	R/V *Weatherbird II*
Nov. 6–12, 2013	FMG, MS, SL	39 h 40 m	257.5	MPA Survey	R/V *Weatherbird II*
May 6–11, 2014	FMG, MS, SL	37 h 43 m	234.79	MPA Survey	R/V *Weatherbird II*
Aug. 16–19, 2014	FMG	18 h 29 m	99.5	UHSI[a]	R/V *Pelican*
July 31- Aug. 5, 2015	FMG, GSPL	12 h 52 m	68.8	UHSI[a]	R/V *Weatherbird II*

[a] UHSI, Untrawlable Habitat Survey Initiative.

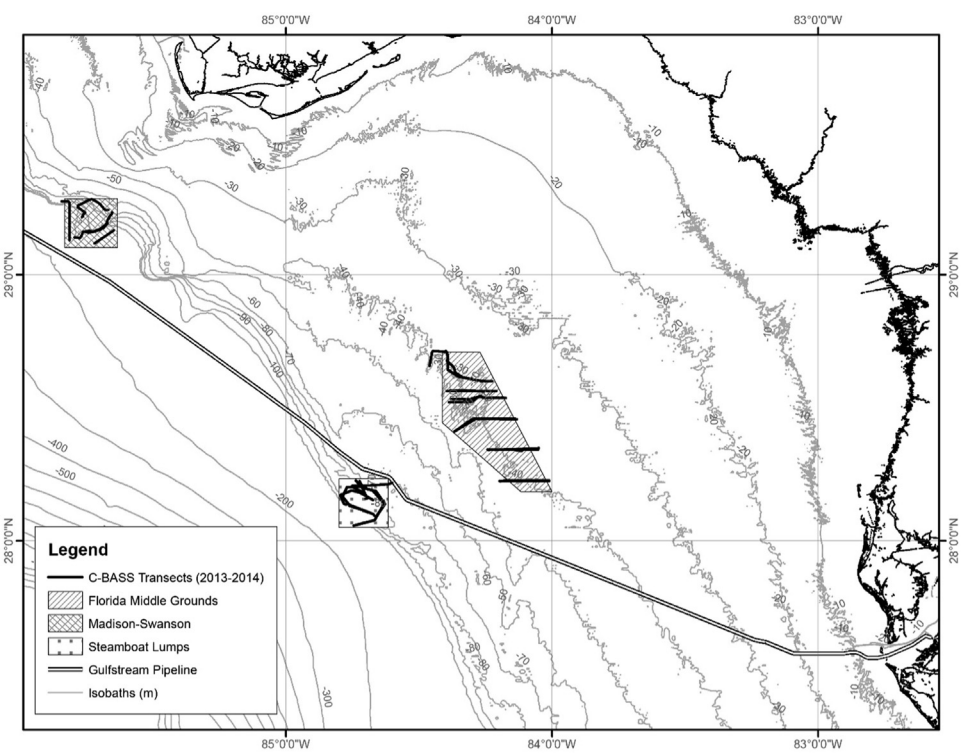

Fig. 6. Locations of the four study areas where the C-BASS was tested and where surveys were completed: the Florida Middle Grounds (FMG), Madison-Swanson MPA (MS), Steamboat Lumps MPA (SL), and the Gulfstream Natural Gas Pipeline (GSPL). Many of the transects displayed were completed several times between 2013–2015.

repeated depth changes but C-BASS was still able to remain at or below ideal altitude 77% of the total deployment time and within the acceptable altitude range for 91.9% of the transect. In Madison-Swanson, analysis of the transect following the reef in the southern portion of the MPA reveals the C-BASS staying within optimal and acceptable towing altitudes for only 61% and 88% of the time, respectively. This decrease in towing performance was expected when compared to the altimeter data from the FMG as the reef in MS has repeated, steep 10-meter changes in the form of pinnacles. Lastly, in the least rugose, relatively featureless area of SL, the time at optimal altitudes was 74% and the system was within the acceptable range for 91% of the transect. Based on these results, we feel confident that we have demonstrated the utility of the C-BASS in sampling the various bottom types that are encountered throughout the West Florida Shelf.

3.3. Imagery

Since beginning this project in early 2013, there have been several

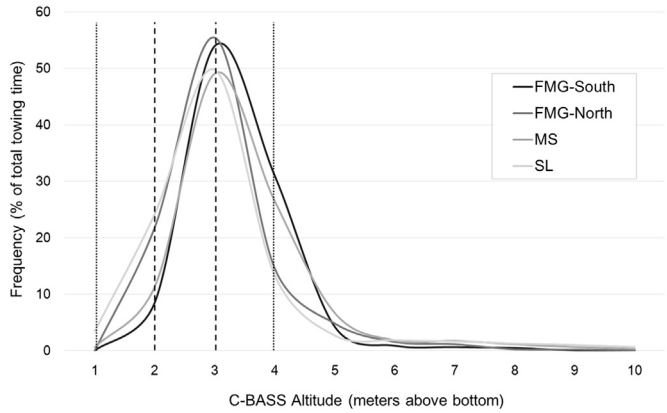

Fig. 7. Percent of total deployment time when C-BASS was at optimal (2.0 – 3.0 m; dashed lines) and acceptable towing altitudes (1.0 – 4.0 m; dotted lines). Four different deployments are shown which represent different towing conditions; FMG-South was over low-relief hard bottom, FMG-North was over moderate- to high-relief hard bottom, MS was over high-relief hard bottom (e.g. pinnacles) and SL was over flat sand.

upgrades and modifications made to the C-BASS's configuration, especially to the cameras. The first iteration of the system in March 2013 had only three cameras, two SD and one HD, which all pointed forward. By the next survey in June 2013, three new cameras were added which included two SD side cameras and another forward-facing HD camera. This configuration was used until August 2015 with only minor changes to the camera settings and lenses. Before surveying in 2015, all of the SD cameras were replaced with higher quality models. The evolution of the C-BASS's imagery can be seen in Fig. 8. Overall, we have been able to greatly improve our detection and identification abilities by using low-light, high resolution cameras. We also have not had any noticeable disadvantages in using monochrome cameras over color models and we have found that the increased detail and sharpness attained using monochrome outweighs color information for fish identification purposes.

4. Conclusions

The C-BASS towed video system has been developed, tested, and regularly used to collect benthic habitat and fish abundance data since 2013. It is a versatile platform capable of collecting calibrated stereo imagery of the seafloor over areas of varying relief. A number of considerations guided the design resulting in compromises and efficiencies optimized for the particular WFS region and the area's fisheries science needs. For instance, using DSL modest bandwidth communications results in onboard storage needs, but reduces cost and increases the platform's utilization on a larger variety of vessels, yet a fiber optic system with topside storage has a potential advantage of simplicity on the towbody contrasted with a custom winch complicating adaptivity. Creating a simple towbody as opposed to using an ROV capable of similar speed analysis has significant cost savings while still collecting

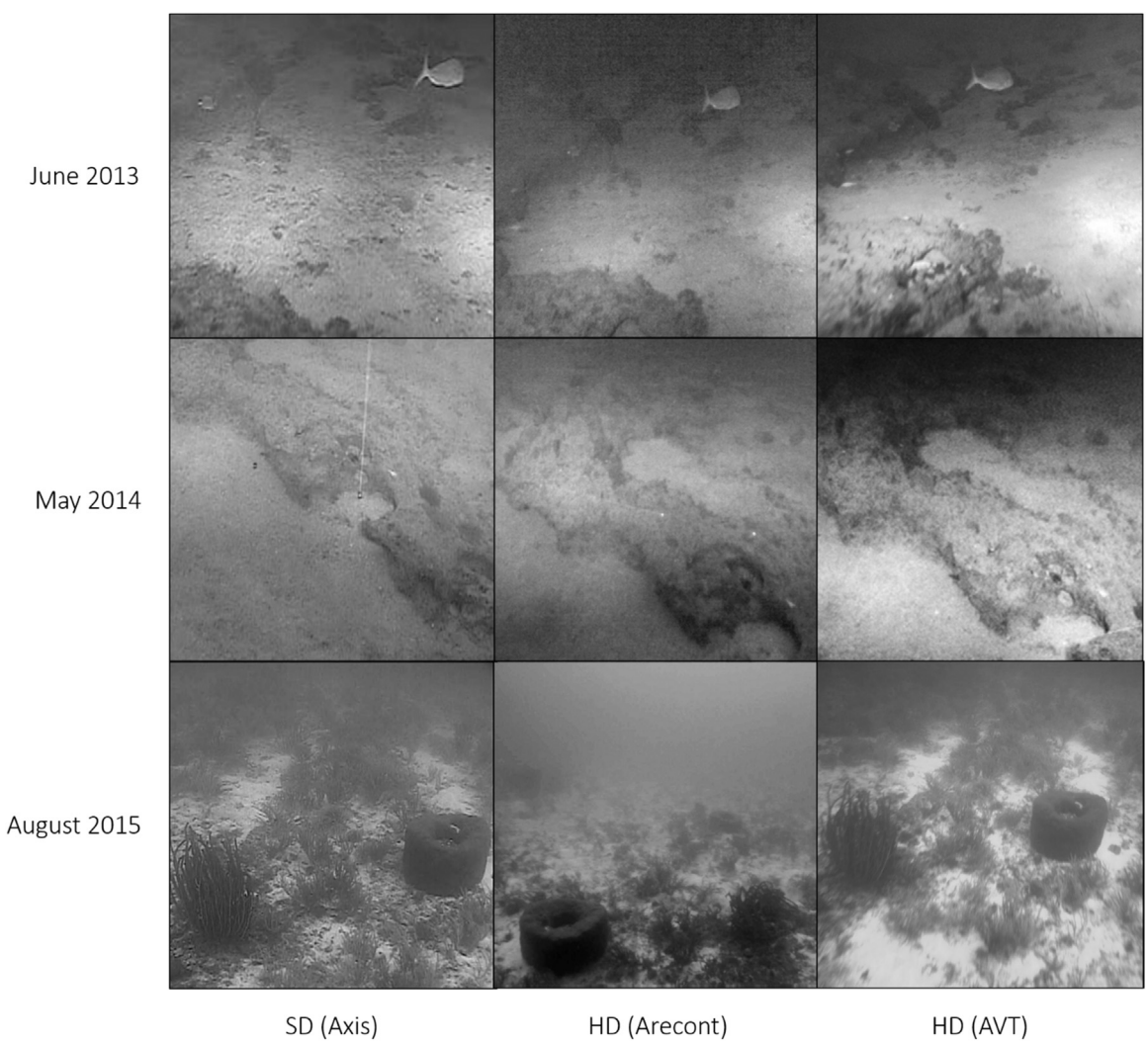

Fig. 8. Image quality progression from the SD (Axis) and HD (Arecont and AVT) cameras for survey cruises from 2013 to 2015.

data applicable toward the desired science objectives. Overall, the C-BASS presents itself as an efficient and cost-effective tool to collect large quantities of bottom imagery capable of providing species level abundance estimates over stratified habitat types. The system's robustness has been proven over hundreds of hours of tows and its versatility has been demonstrated by the evolution of the video and sensor stream capabilities during its use. We envision that the system's components will continue to evolve as technology improves and the C-BASS is equipped to handle near term advances to remain relevant for the near future.

4.1. Moving forward

In late 2014, USF was awarded a grant by the National Fish and Wildlife Foundation to utilize the C-BASS in combination with high resolution bottom mapping sonar and water column acoustics to collect baseline reef fish stock information on the West Florida Shelf. As part of this effort, in mid-2015, a steering committee was formed comprising potential users of the C-BASS and sonar mapping data; individuals hail from agencies such as NOAA, USGS, and the Florida Fish and Wildlife Research Institute (FWRI). It is our intent to continue gathering input from these potential users in order to streamline collaboration and to better engineer the C-BASS to fit management applications.

More importantly, this towed video system will continue to attempt to augment and leverage other technologies to refine habitat stratified abundance estimation techniques in the eastern Gulf of Mexico. By combining long video transects with high resolution bathymetry and backscatter maps we intend to develop large-scale benthic habitat maps. Similarly, combining the video transects with water column acoustical methods for abundance estimates has the potential to lead to more accurate abundance and biomass estimates.

System enhancements are ongoing and include refinement of the cameras utilized and onboard sensors. An upgrade to a Point Grey® (now FLIR®) Black Fly camera with better low light and light balancing capabilities has resulted in higher fish counts and better species identification. An enhanced optics package (a new fluorometer combined with two transmissometers) will assist in assessing the environment's optical characteristics which will help to more accurately quantify the depth of field during tows (i.e. estimate more accurate field of view). Efforts toward auto-recognition of bottom types and biological targets have also begun in collaboration with SRI International in the hope that more efficient imagery analysis can be achieved. The use of auto-classification is an important development for operationalizing towed video systems for purposes of large-scale fishery stock assessment (Mellody, 2014). These refinements will continue with focus on increased simplicity and ease of use and the intent of making it usable over a wider variety of applications.

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