

Development of Video Electronic Monitoring Systems to Record Smalltooth Sawfish, *Pristis pectinata*, Interactions in the Shrimp Trawl Fisheries of the Southeastern United States, with Application to Other Protected Species and Large Bycatches

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Introduction

The use of electronic monitoring (EM) has the potential to augment the collection of bycatch information and lessen the need for onboard scientific observers, which in some cases can be very costly. Video technology can also be used on vessels that cannot take a human observer for safety reasons or vessel limitations. Since the late 1990's, various fisheries programs across the globe have explored the potential to extract specific information from video for management,

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with varying levels of success (Ames et al., 2007; Kindt-Larsen et al., 2012; Ruiz et al., 2015; Stanley et al., 2015; van Helmond et al., 2015, 2017; Bartholomew et al., 2018; van Helmond et al., 2019; Briand et al.¹). Van Helmond et al. (2019) provides a comprehensive review of global EM projects and programs, including 12 fisheries that currently have some form of electronic monitoring as part of their regulatory process. Although EM is widely viewed as a way to improve monitoring programs, there is no standardized method of video data collection across fisheries. In fact, past studies have shown that the unique needs of individual fisheries must be assessed, as there is no overall single design pos-

¹Briand, K., A. Bonnieux, W. Le Dantec, S. Le Couls, P. Bach, A. Maufroy, A. Relor-Stirne-mann, P. Sabbaros, A. L. Vernet, F. Jehenne, and M. Goujon. 2018. Comparing electronic monitoring system with observer data for estimating non-target species and discards on French tropical tuna purse seine vessels. *Collect. Vol. Sci. Pap. ICCAT*, 74(6):3813–3831 (avail. at https://www.iotc.org/sites/default/files/documents/2018/09/IOTC-2018-WPEB14-18-Rev_1.pdf).

sible due to varying vessel layouts, fishing practices, processing methods, catch biomass, and catch composition (Ruiz et al., 2015; van Helmond et al., 2019; Briand et al.¹).

To date, there is not an EM program implemented in any shrimp trawl fishery across the globe; however, two pilot studies were previously conducted in Australia for prawn (Piasente et al.²). Even with similar targets and fishing practices, there are major differences in the sorting methods between the Australian and the United States (U.S.) southeastern shrimp fleets that have a major impact on EM system development. In Australia, cameras were set up over sorting conveyor belts, allowing for a more detailed view of the catch, as the animals are in a single layer (Piasente et al.²). This is not an option in the U.S. fleet, as

²Piasente, M., B. Stanley, and S. Hall. 2012. Assessing discards using onboard electronic monitoring in the northern prawn fishery. *FRDC Project 2009/076*. *Aust. Fish. Manag. Auth.*, 59 p. (avail. at <https://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2009-076-DLD.pdf>).

ABSTRACT—The National Marine Fisheries Service (NMFS) began placing at-sea observers on commercial shrimping (*Penaeidae* and *Sicyonia brevirostris*) vessels in the early 1990's in the southeastern region of the United States (U.S.) to identify and minimize the impacts of shrimp trawling on federally managed species. Recent analysis of bycatch data relative to smalltooth sawfish, *Pristis pectinata*, a species endangered globally, indicated a high level of uncertainty in the estimated take in the U.S. Due to costs associated with observer coverage, and given the rare event of capturing a smalltooth sawfish, increasing observer coverage to refine take estimates of this species is not considered

practical. We explored the use of electronic monitoring (EM) to provide a valid alternative to increased observer coverage for the purpose of documenting fishery interactions with smalltooth sawfish. This system was additionally used to document interactions with other protected species and large teleost and elasmobranch bycatches (>1.0 kg). While no smalltooth sawfish were observed, the catch and safe release of a loggerhead sea turtle, *Caretta caretta*, was recorded by both the EM system and observer. The EM system was used to record commercial shrimp vessel operations during six trips, encompassing 1,733 h of video over 94 sea days, with a certified fishery observer also being pres-

ent for the full duration of each trip. Catch composition documented by the EM reviewer was compared to observer data. Overall, 20 tows contained a total of 33 bycatch items in the observer sample that met criteria of being over 1.0 kg. Of these catch items, 87.9% were also detected by the EM reviewer compared to observer data. Detection rates for elasmobranchs were higher in comparison to teleosts, at 95.8%. Pairwise comparison of EM video to data collected by onboard observers (animals >1.0 kg in size) lead us to conclude that EM would be an effective tool for detecting protected resources and larger fauna interactions in the Gulf of Mexico shrimp trawl fishery.

all catch sorting occurs on deck, with no conveyors or processing rooms, although small vessels may use a sorting table. This difference alone highlights the need for individual fleet studies for determining the most appropriate EM system model.

The exploration of EM in trawl fisheries is approached with caution, as they involve a high amount of catch in relatively short periods of time, and discerning catch composition can be highly problematic for this reason (Ruiz et al., 2015; van Helmond et al., 2015). Applicability of EM to shrimp trawls in particular is potentially even more problematic, as they target animals with low biomass, making it difficult to identify, measure, and count individuals, which are common goals of monitoring programs (van Helmond et al., 2015, 2017, 2019). However, the use of EM in shrimp trawl fisheries as a whole cannot be discounted, as it can improve monitoring in other manners, such as determining fishing pressure hotspots, vessel compliance, and bycatch interactions (Stanley et al., 2011).

In the southeastern U.S. commercial shrimp trawl fishery, vessels began voluntarily carrying at-sea observers in 1992, deployed by the National Marine Fisheries Service (NMFS) Galveston Laboratory (Scott-Denton et al., 2012; 2020). Mandatory coverage commenced in 2007 for the Gulf of Mexico, and 2008 for the U.S. southeastern Atlantic coast, hereafter referred to as the South Atlantic (Scott-Denton et al., 2012; 2020). Within the fishery, four species are targeted, three penaeid shrimps: white, *Litopenaeus setiferus*; brown, *Farfantepenaeus aztecus*; and pink, *Farfantepenaeus duorarum*; as well as rock shrimp, *Sicyonia brevirostris*. Currently, there are 1,420 vessels federally-permitted in the U.S. to harvest shrimp in the Gulf of Mexico, while the South Atlantic has 481 and 215 permitted vessels for penaeid (*Penaeidae*) and rock shrimp, respectively (Scott-Denton et al., 2012; 2020; SERO³). De-

³SERO. 2018. Fishery permits. Southeast Reg. Off., Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla. (avail. at <https://sero.nmfs.noaa.gov/>)

tailed information on the U.S. southeastern shrimp fleet operations and effort can be found in Scott-Denton et al. (2012; 2020).

NMFS implemented observer coverage in this fishery to quantify finfish bycatch spatially and temporally, notably red snapper, *Lutjanus campechanus*, as well as to document and monitor shrimp trawl interactions with protected resources. Protected resources are species that are listed under the U.S. Endangered Species Act (ESA), the Migratory Bird Treaty Act, or the Marine Mammal Protection Act. These animals may be encountered as bycatch, and include five species of sea turtles (Kemp's ridley, *Lepidochelys kempii*; leatherback, *Dermochelys coriacea*; hawksbill, *Eretmochelys imbricata*; loggerhead, *Caretta caretta*; and green, *Chelonia mydas*); Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*; Gulf sturgeon, *Acipenser oxyrinchus desotoi*; and smalltooth sawfish, *Pristis pectinata* (Scott-Denton et al., 2012; 2020). Seabirds and marine mammal classifications cover a variety of families and genera, with all being protected through their respective Acts.

NMFS has undertaken several ESA section 7 consultations to address the effects of the southeast shrimp trawl fishery on protected resources that are listed as either threatened or endangered (NMFS⁴). Accurate estimates of fisheries take and mortality of sea turtles, sturgeon, seabirds, marine mammals, and smalltooth sawfish are critical to these consultations. Presently, data collected by onboard observers represents the most accurate and complete source for this information. How-

operations_management_information_services/constituency_services_branch/freedom_of_information_act/common_foia/index.html).

⁴NMFS. 2014. Reinitiation of Endangered Species Act (ESA) Section 7 Consultation on the continued implementation of the sea turtle conservation regulations under the ESA and the continued authorization of the Southeast U.S. shrimp fisheries in federal waters under the Magnuson-Stevens Fishery Management and Conservation Act (MSFMA). Consultation No. SER-2013-12255. Southeast Reg. Off. Natl. Mar. Fish. Serv., NOAA, St. Petersburg, Fla. (avail. at https://sero.nmfs.noaa.gov/protected_resources/section_7/freq_biop/documents/fisheries_bo/shrimp_biop_2014.pdf).

ever, despite this need, observer coverage of the entire southeastern shrimp fishery is about 2% of the total reported effort (Scott-Denton et al., 2012; 2020).

On 9 March 2010, the NMFS Southeast Regional Office requested to reinitiate section 7 consultation of the Endangered Species Act on the southeastern shrimp fishery to address new information indicating that the 2006 Incidental Take Statement (ITS) of smalltooth sawfish was exceeded. The biological opinion indicated annual sawfish take estimates to be 79.8 captures annually, based on combined effort across areas (Gulf and South Atlantic) and years (2008 and 2009) (NMFS⁴; Carlson and Scott-Denton⁵). However, the rarity of sawfish captures combined with low levels of observer coverage resulted in high levels of uncertainty in this estimate, with annual captures potentially as low as 16.88 or as high as 162.72 (Carlson and Scott-Denton⁵).

Concurrent with estimates of the levels of incidental take in commercial fishing gear is the need to estimate levels of observer coverage necessary to observe an interaction with a high level of precision, with a coefficient of variation (CV) of 30% generally recommended. Using the probability of a sawfish capture and an estimate of total shrimp effort in the eastern Gulf of Mexico, sample size estimates required to observe a smalltooth sawfish with a CV=0.3 was calculated at 11,380 tow h/yr (Carlson and Scott-Denton⁵). Applying the current average cost per sea day results in a cost over \$1,000,000 to increase observer coverage in the eastern Gulf of Mexico. Intuitively, lower CV levels will incur higher observer costs due to higher sampling fractions, and higher CV levels would be less cost prohibitive. In light of the costs associated with ob-

⁵Carlson, J., and E. Scott-Denton. 2011. Estimated incidental take of smalltooth sawfish (*Pristis pectinata*) and an assessment of observer coverage required in the South Atlantic and Gulf of Mexico shrimp trawl fishery. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., Panama City, Fla., SFD Contribution PCB-11-08, 15 p.

server coverage and the low frequency of capturing a smalltooth sawfish, increasing observer coverage may not be the most practical solution for refining the take estimates of this species (Carlson and Scott-Denton⁵). EM was suggested as an alternative for addressing the data gap at lower costs, but an effective monitoring system needed to be developed for this fishery (Carlson and Scott-Denton⁵).

Given the large size of these animals, video monitoring would have the capability to record them either entangled in the net itself, entrapped on bycatch mitigation tools (turtle excluder devices (TED's)), or on deck when catch is emptied from the net. Herein, we report a study to test electronic video monitoring hardware, software, and review protocols to determine the feasibility and reliability of the method for bycatch interaction monitoring within a shrimp trawl fishery. In partnership with the southeastern U.S. shrimp trawl industry, this pilot study sought to determine if 1) EM hardware system design is capable of maintaining high-quality operating standards in variable environmental conditions encountered at sea, 2) EM video can provide images of sufficient resolution and clarity to allow a video analyst to accurately account for smalltooth sawfish and other large bycatch interactions, 3) EM video is able to provide images of sufficient resolution and clarity to allow a video analyst to identify animals at the species level, and 4) results from video monitoring are similar to those obtained from onboard observers.

Methods

Onboard observers documented vessel and gear characteristics, tow information, and catch composition on all tows as described in Scott-Denton et al. (2012; 2020). Net characteristics, including those of the trawl body, cod end, and doors, along with TED's and bycatch reduction devices (BRD's) were recorded. Measurements of the try net, a separate, smaller net used by fishermen to evaluate catch composition throughout a tow, were also taken.

Each tow consisted of four main nets being pulled adjacent to one another behind the vessel, in addition to the try net, which was towed in front of one of the interior nets. Once a tow was complete and the nets were brought back to the vessel, the observer ensured that the catch of the two exterior nets ("outboard nets") was kept separate from each other and from the catch of the two interior nets. Any rare or large animals caught in each outboard net that could affect the catch characterization process were selected from the pile (i.e. no extrapolation was required), counted, and weighed by species (Scott-Denton et al., 2012; 2020).

The observer subsampled each outboard net by filling a shrimp basket with a mixed portion of its catch. This subsample basket was weighed prior to the contents being sorted into defined categories, including white, brown, or pink shrimp, crustaceans, teleosts, debris, and individual species of priority fishes ("characterization"). Certain categories of animals were counted, and all designated groupings weighed separately, following the protocol in Scott-Denton et al. (2012; 2020). This characterization of the sample basket, along with the selected weights from rare or larger animals, was used to determine the entire net's catch through extrapolation, as detailed in Scott-Denton et al. (2012; 2020). This process was repeated for up to two outboard nets per tow throughout the duration of the trip (Scott-Denton et al., 2012; 2020).

During a typical tow, the try net was deployed and retrieved multiple times, and being the only net typically exempted from having both a TED and BRD present, it had the potential to allow for higher catches of bycatch species, including protected resources (Scott-Denton et al., 2012). Observers did not characterize catch within a try net; however, they measured, sampled, and documented any incidental captures with all U.S. federally protected species. Once the trip was complete, all observer data was sent to the NMFS Galveston Laboratory, where

it was housed, managed, and archived, following a trip debriefing session with an observer coordinator.

The Southeast Fisheries Science Center (SEFSC) contracted with Saltwater Inc.⁶ to develop, install, and monitor an EM system on two vessels selected for the study. The EM system was comprised of a control box, four internet protocol (IP) cameras, a rotation sensor ("sensor"), GPS receiver, keyboard, and a monitor. Other than the sensor and cameras, the entire system was installed in the wheelhouse of each vessel and was roughly 0.5 m² in size. The monitor allowed the user to see, in real-time, the status of the sensor, position of the vessel, data storage status, whether or not the system was recording, and what was being recorded.

The control box was equipped with open-source software⁷ and two hard-drive bays with removable 2 terabyte drives that stored all video and sensor data during each trip. The sensor was mounted on the winch of the fishing vessel, and when the winch was activated to set and haul the gear, the sensor sent a reading back to the control box. Sensor output was read by the on-board software, which determined if the vessel engaged in fishing activity. Since the retrieval of the try net does not utilize the same winch as the main nets, the system was set to record continuously, as long as it had power, to capture these events. Sensor data for hauling of the main nets allowed the reviewer to more quickly and efficiently identify fishing events and other data.

When the system was initially installed on the vessels, EM technicians consulted with vessel operators to determine the best positions for the four cameras so that all pertinent fishing data could be captured. Two cameras were focused on the gear as it was set and retrieved, one at port and one at starboard. Two other cameras were

⁶Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

⁷Accessed via written request to Saltwater Inc., 733 N. St. Anchorage, AK 99501.

Table 1.—Counts of specimens > 1.0 kg documented by observer compared to EM reviewer at species level, split by classification.

Common name	Scientific name	Observer	EM	Detection rate
Atlantic guitarfish	<i>Rhinobatos lentiginosus</i>	1	1	1
Atlantic sharpnose shark	<i>Rhizoprionodon terraenovae</i>	8	7	0.875
Blacktip shark	<i>Carcharhinus limbatus</i>	6	6	1
Bonnethead shark	<i>Sphyrna tiburo</i>	2	2	1
Finetooth shark	<i>Carcharhinus isodon</i>	2	2	1
Smooth butterfly ray	<i>Gymnura micrura</i>	2	2	1
Smooth dogfish	<i>Mustelus canis</i>	3	3	1
	Total elasmobranchs	24	23	0.9583
Lane snapper	<i>Lutjanus synagris</i>	2	0	0
Red drum	<i>Sciaenops ocellatus</i>	1	1	1
Red snapper	<i>Lutjanus campechanus</i>	4	3	0.75
Southern flounder	<i>Paralichthys lethostigma</i>	1	1	1
	Total teleosts	8	5	0.6250
Loggerhead sea turtle	<i>Caretta caretta</i>	1	1	1
	Total protected resources	1	1	1
Total specimens		33	29	0.879

installed to monitor the catch as it was being processed, with one camera focused on the sorting area, and the other at a scupper for observation of discarded bycatch. The two cameras pointed toward the gear were set to record at 360p (480 x 360 pixels) and 10 frames per second. This setting allowed the reviewer to identify larger catch items in the nets upon retrieval without using excessive space on the hard drives. The sorting and scupper cameras were set to 1,080p (1,920 x 1,080 pixels) at 10 frames per second so that the reviewer would be able to better identify the catch as it was being separated on deck.

At the end of a trip, hard drives were returned to Saltwater Inc. for video assessment and catch documentation. Personnel that reviewed the videos were current or prior at-sea observers, and therefore trained in the use of taxonomic keys and other methodologies for identifying species to the lowest taxonomic level possible. Reviewers were given an overview of the data collection protocols used by the on-board observers, as well as an overview of common fishing practices used by the U.S. shrimp fishing fleet to ensure a complete understanding of the activities documented in the videos. Each tow was identified by the reviewers based on the data from the rotation sensor, and video was reviewed from the time the net winch started the gear haul back to the time the crew finished sorting catch on deck. When larger by-

catch animals were seen in the out-board nets, reviewers documented the time, location, and species identification, in addition to taking screenshots and relevant notes. Video was also analyzed for all try net tow catch emptied on deck. Reviewers prepared a trip summary report for each trip that included total sea days, video hours, review hours, number of tows, and comments on other identifiable species, protected resource interactions, and other pertinent notes. All reviewer data underwent a proofing and debriefing process with the EM review team at Saltwater Inc.

After completion of all debriefings, the observer data and the EM video data were compared and evaluated for the capture of a sawfish during a tow. In the absence of a sawfish or other protected species (e.g., sea turtle), EM data was compared to observer data to see if the reviewer annotated the animals documented by the observer as being >1.0 kg in weight. This value was determined to be sufficient for comparison of a “typical” large

bycatch species by EM reviewers and SEFSC staff. Weight was chosen over length because observers only record lengths for red snapper and protected resources, whereas all weights were present for characterized catch.

In cases where multiple animals of the same species in a net were weighed together ($n=5$), whether selected directly or as part of the characterization process, an average weight was calculated to validate that criteria were met. Following Ruiz et al. (2015), observer data were treated as the independent sample for analysis, while EM data was associated with potential statistical error. Detection rates were determined by dividing observer data by that of the EM reviewer for each species, as well as by classification category (Table 1).

Results

The EM hardware operated for the duration of the trips with no water ingress to the deck components, and there was only one significant gap that may have been caused by a system component malfunction. Minor issues encountered, such as water droplets affecting view and damaged wires, were manageable by vessel operators at sea or EM technicians in a single shore visit. Overall camera framing of the towing activity for the project was well placed and documented all major areas of the vessel in which there was normal fishing activity. Reviewers were able to see the nets as they were brought alongside the vessel, as they came out of the water, and as they were brought onto the deck where they were emptied and sorted.

Examination of the observed trips took approximately 181 hours to eval-

Table 2.—Individual trip information.

Vessel	Trip	Sea days	Tows	Total video (h)	Review time (h)
1	1	22	43	453	41
1	2 ¹	16 ¹	27 ¹	0 ¹	0 ¹
1	3	14	21	268	24
1	4	20	38	298	30
2	1	8	13	161	15
2	2	13	25	253	32
2	3	17	29	300	39
Total Recorded	6	94	169	1,733	181

¹Trip in which video was lost in shipping process due to hurricane; Sea Days and Tows values excluded from Total Recorded.

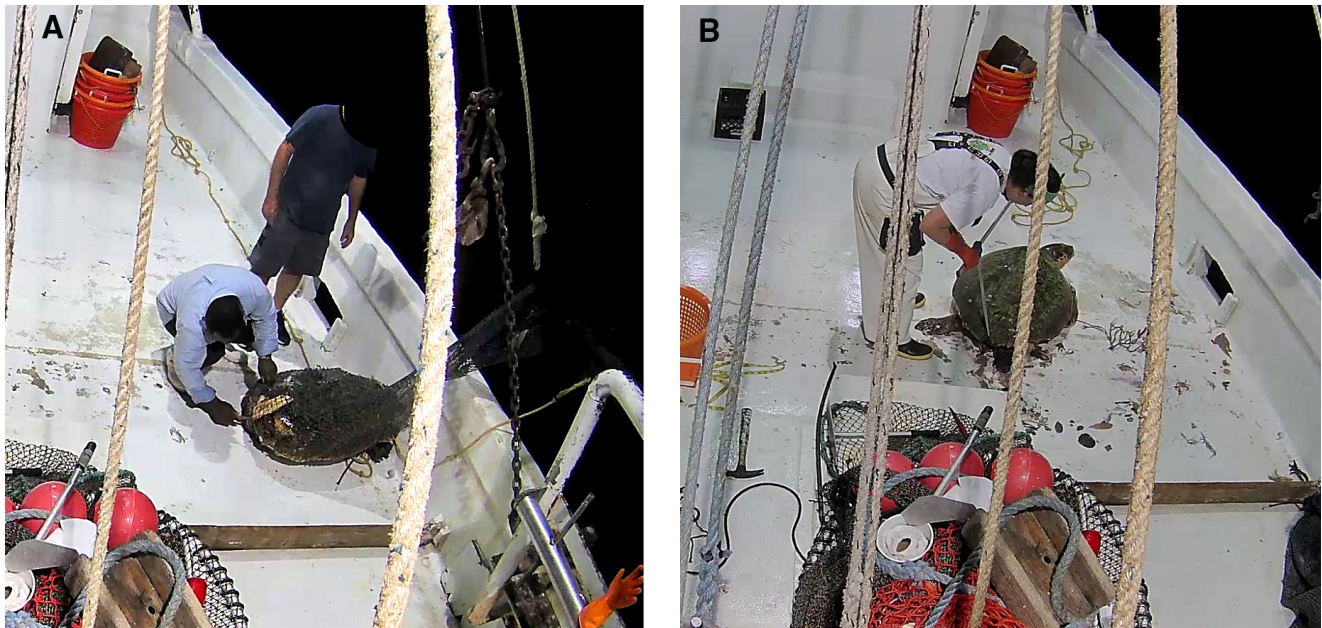


Figure 1.—Loggerhead sea turtle, *Caretta caretta*, A) brought on board in try net. B) being measured by observer prior to release.

uate 1,733 hours of video (Table 2). A total of 94 observed sea days were recorded, consisting of 169 tows (Table 2). No smalltooth sawfish were captured during the pilot study, and therefore no comparisons could be made for this species. A single loggerhead sea turtle captured in a try net was documented by both the observer and EM reviewer (Fig. 1, Table 1).

EM reviewers were able to identify many animals to the species level, including those smaller than the 1.0 kg threshold, such as the presence of rock shrimp, tricorn batfish, *Zalieutes mcgintyi*; Atlantic bearded brotula, *Brotula barbata*; and calico box crab, *Hepatus epheliticus*. Even during periods of low light, the EM reviewer was able to detect and identify larger bycatch items such as sharks and rays (Fig. 2). The EM systems' performance quality allowed for accurate identification throughout the duration of the study period, April 2017 through March 2018.

During 19 tows, 32 bycatch specimens were recorded by the observer as being over 1.0 kg. The EM reviewer was able to identify 28 of these specimens, a detection rate of 87.5%.

Of the animals missed by the EM reviewer, most were teleosts ($n=3$), with a detection rate of 62.5% (Table 1). For elasmobranchs, the detection rate was 95.8%, with a single Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, being undetected. Inclusion of the loggerhead sea turtle capture provides a total detection rate of 87.9% for 33 bycatch items. There were no situations in which the EM reviewer documented a greater number of large bycatch specimens than the observer in the compared data.

Discussion

The overall detection rate of 87.9% supports the use of EM for bycatch monitoring in the U.S. commercial shrimping fleet for large animals, including many protected resources. Sharks, rays, and sea turtles have exaggerated body shapes in comparison with bony fishes, potentially leading to higher observation levels by EM reviewers.

While teleosts were detected at a rate of 62.5%, it is anticipated that adjusted camera angles specific to vessels could improve this value. This rate was also credited to observer sorting

methods by EM reviewers, a situation that would not arise on trips where an observer was not present. While the crew of a vessel sorts catch in a single, central area with catch spread on deck, observers tend to take their sample baskets to a corner of the vessel and sort straight into smaller baskets for the characterization, inhibiting view of individual items. The addition of a fifth camera at the stern of the vessel could assist in preventing this issue, while expanding overall coverage of the vessel. This lower rate can also be attributed to the higher variability caused by the small sample size obtained in this pilot study. The low number of large animals for quantitative comparison in this analysis was likely influenced by the use of BRD's and TED's, which decrease large bycatch specimens as intended.

Despite the high detection rate for larger species, electronic monitoring does have limitations and issues. For example, the electronic data for an additional observed trip was lost during shipping due to a hurricane, and therefore had to be excluded from analysis, resulting in a loss of approximately 290 hours of video. The only EM



Figure 2.—Sharks documented with the EM system.

system performance issue of the study occurred during this trip, with a single camera having intermittent connectivity issues due to a damaged wire, which was fixed when the vessel returned to the dock. Since the electronic data was lost, we were not able to evaluate the impact this performance issue had on the data collection process. This occurrence shows a serious weakness of EM data collection, and future work would need to address this source of loss, whether it is electronic submission of the data while in port or duplication of hard drive data prior to shipping.

System malfunctions at sea from accidental damage or hardware tampering also need to be priorities when designing large-scale monitoring programs. These issues can be rectified once the vessel has returned to port, but investigation of remote repair options and incorporation of fines for monitoring equipment tampering should be considered. Limiting opportunities for data loss of any kind is

necessary in future program development so that uncertainty in data quality is kept to a minimum.

While some discrepancies between the EM reviewer and observer were found, potential modifications could be implemented to correct these. For instance, tarps are often used to block the sun on many shrimp vessels to prevent reduction in the quality of the shrimp catch. This was recorded on one of the study vessels during an un-observed trip, so was able to be corrected without impacting the data (Fig. 3A). In this case, standard camera mounting was lowered so there was an unobstructed view of catch sorting (Fig. 3B). Camera placement on each vessel will vary, with no single standard able to cover all vessels due to catch processing procedures, as well as vessel size and layout differences. Future work should also consider placing fine resolution cameras more directly over the scupper holes in order to see discarded by-catch more clearly. However, obtain-

ing a direct scupper view may be a challenge due to limited options for camera mounts and wire placements. Wires run across the deck are more frequently damaged by regular deck activities, and they can also be a safety hazard for the crew.

Goals in the development of an EM program for shrimp trawls should take into consideration opportunities for improvements to fisheries compliance, as well. An EM system can be used to determine if vessels are following gear regulations, by including the presence of TED's and BRD's in review criteria (Piasente et al.²). Also, determining a method in which catch weight can be estimated, such as by counting retained product containers as they are moved into the storage area at the end of a tow, is possible (Piasente et al.²).

Additionally, this study used software capable of only managing one rotation sensor, causing the entire trip duration to be recorded. This resulted in a higher amount of video, which increased review time, as well as stor-

age needs. Current software versions, however, are able to include multiple sensors, allowing for a second sensor to be placed on the try net, therefore marking those tow times in the EM video and improving monitoring of that net alone.

The availability of additional data collected by the EM system can be incorporated in further program development and evaluation. Although the EM system and review process were able to record large bycatch on all tows, the observer is obtaining a subsample, so only those animals documented by the observer could be compared for this analysis.

While EM could supplement low observer coverage rates, it does not replace onboard observers, who are able to collect different types of data (i.e., measurements and biological samples), and attach tracking tags to protected resources. EM can be used instead to validate observer data, improve data quality, and increase coverage rates and protected resource take estimates.

EM can bolster observer coverage by allowing for data verification both at sea and upon completion of a trip. In cases of a protected resource being returned to the water without visual confirmation and evaluation by the observer, video could be reviewed for documentation. Benefits of EM include the opportunity to review video as many times as needed, as well as to have more than one person identify questionable specimens.

Observers are less likely to witness all try net operations, as this will generally cause them to exceed safe working hours due to interrupting mandated sleep times. Having EM cameras recording this vital information has the potential to increase documentation of protected resource interactions, both with and without observers present.

It is most beneficial to an EM program that video reviewers are current or former observers for that specific fishery, as they will be the most familiar with the practices and species encountered of that fishery (Chavance et



Figure 3.—Deck of vessel with A) tarp covering deck during sorting, inhibiting view, and B) adjusted view to prevent tarp from obscuring images.

al.⁸). In future monitoring scenarios, a current observer can serve as a video reviewer when not deployed, such as in times of low fishing pressure due to weather or fishery closures. This will help maintain observer morale as they are kept employed continuously, while also being able to vary their work practices, which aids in employee retention and career satisfaction (van Helmond et al., 2019).

⁸Chavance, P., A. Batty, H. McElderry, L. Dubroca, O. Dewals, P. Cauquil, V. Restrepo, and L. Dagorn. 2013. Comparing observer data with video monitoring on a French purse seiner in the Indian Ocean. IOTC-2013-WPEB09-43, 18 p. (avail. at <https://www.iotc.org/documents/comparing-observer-data-video-monitoring-french-purse-seiner-indian-ocean>).

The lack of capture of any small-tooth sawfish was expected, due to few specimens being observed in the program annually, if any. The majority of documented interactions in observer program history occurred in the same area where fishing effort took place in this pilot study (Scott-Denton et al., 2012; 2020). Smalltooth sawfish become quite large (≤ 5.18 m), have unique body shapes, and are sufficient in size at birth to be recorded with EM throughout their lifespan.

The accurate identification and documentation by the EM reviewer of the loggerhead sea turtle capture in the try net supports the use of EM for this and other sea turtle species once they reach sufficient size (> 1.0 kg). Sea

turtle bycatch in the shrimp trawl fleet has been a concern for many years, as this fishery historically had the highest number of interactions compared to any other U.S. fishery, at one point responsible for nearly 98% of sea turtle bycatch (Moore et al., 2009; Finkbeiner et al., 2011). Requiring TED's, including a larger escape opening size mandated in 2003, as well as a major fleet reduction since the early 2000's have greatly lowered these rates (Finkbeiner et al., 2011). Uncertainty in these bycatch rates and associated survivorship values caused by low observer coverage levels has raised the suggestion of incorporating electronic monitoring for these species as well, and our pilot study may present a valid model for future testing (Moore et al., 2009).

Filling in these types of data gaps provides opportunity for improved take estimates of protected species bycatch through increased observations of fishing efforts, greatly strengthening our fisheries management processes in the U.S. shrimping fleet of the Gulf of Mexico and South Atlantic.

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Literature Cited

- Ames, R. T., B. M. Leaman, and K. L. Ames. 2007. Evaluation of video technology for monitoring of multispecies longline catches. *N. Am. J. Fish. Manage.* 27:955–964 (doi: <https://doi.org/10.1577/M06-029.1>).
- Bartholomew, D. C., J. C. Mangel, J. Alfaro-Shigueto, S. Pingo, A. Jimenez, and B. J. Godley. 2018. Remote electronic monitoring as a potential alternative to on-board observers in small-scale fisheries. *Biol. Conserv.* 219:35–45 (doi: <https://doi.org/10.1016/j.biocon.2018.01.003>).
- Finkbeiner, E. M., B. P. Wallace, J. E. Moore, R. L. Lewison, L. B. Crowder, and A. J. Read. 2011. Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. *Biol. Conserv.* 144(11):2,719–2,727 (doi: <https://doi.org/10.1016/j.biocon.2011.07.033>).
- Kindt-Larsen, L., J. Dalskov, B. Stage, and F. Larsen. 2012. Observing incidental harbor porpoise *Phocoena phocoena* bycatch by remote electronic monitoring. *Endang. Species Res.* 19:75–83 (doi: <https://doi.org/10.3354/esr00455>).
- Moore, J. E., B. P. Wallace, R. L. Lewison, R. Zydels, T. M. Cox, and L. B. Crowder. 2009. A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management. *Mar. Pol.* 33(3):435–451 (doi: <https://doi.org/10.1016/j.marpol.2008.09.003>).
- Ruiz, J., A. Batty, P. Chavance, H. McElderry, V. Restrepo, P. Sharples, J. Santos, and A. Urtizberea. 2015. Electronic monitoring trials on in the tropical purse-seine fishery. *ICES J. Mar. Sci.* 72(4):1,201–1,213 (doi: <https://doi.org/10.1093/icesjms/fsu224>).
- Scott-Denton, E., P. Cryer, M. Duffy, J. Gocke, M. Harrelson, D. Kinsella, J. Nance, J. Pulver, R. Smith, and J. Williams. 2012. Characterization of the U.S. Gulf of Mexico and South Atlantic shrimp fisheries based on observer data. *Mar. Fish. Rev.* 74(4):1–26 (avail. at <https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/MFR/mfr744/mfr7441.pdf>).
- _____, P. Cryer, B. Duffin, M. Duffy, J. Gocke, M. Harrelson, A. Whatley, and J. Williams. 2020. Characterization of the U.S. Gulf of Mexico and South Atlantic Penaeidae and rock shrimp (Sicyoniidae) fisheries through mandatory observer coverage, from 2011 to 2016. *Mar. Fish. Rev.* 82(1-2):17–46 (avail. at https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/mfr821-22_0.pdf).
- Stanley, R. D., H. McElderry, T. Mawani, J. Koolman. 2011. The advantages of an audit over a census approach to the review of video imagery in fishery monitoring. *ICES J. Mar. Sci.* 68(8):1,621–1,627 (doi: <https://doi.org/10.1093/icesjms/fsr058>).
- _____, T. Karim, J. Koolman, and H. McElderry. 2015. Design and implementation of electronic monitoring in the British Columbia groundfish hook and line fishery: a retrospective view of the ingredients of success. *ICES J. Mar. Sci.* 72(4):1,230–1,236 (doi: <https://doi.org/10.1093/icesjms/fsu212>).
- van Helmond, A. T. M., C. Chen, and J. J. Poos. 2015. How effective is electronic monitoring in mixed bottom-trawl fisheries. *ICES J. Mar. Sci.* 72(4): 1,192–1,200 (doi: <https://doi.org/10.1093/icesjms/fsu200>).
- _____, _____, and _____. 2017. Using electronic monitoring to record catches of sole (*Solea solea*) in a bottom trawl fishery. *ICES J. Mar. Sci.* 74(5): 1421–1427 (doi: <https://doi.org/10.1093/icesjms/fsw241>).
- _____, L. O. Mortensen, K. S. Plet-Hansen, C. Ulrich, C. L. Needle, D. Oesterwind, L. Kindt-Larsen, T. Catchpole, S. Mangi, C. Zimmerman, H. J. Olesen, N. Bailey, H. Bergsson, J. Dalskov, J. Elson, M. Hosken, L. Peterson, H. McElderry, J. Ruiz, J. P. Pierre, C. Dykstra, J. J. Poos. 2019. Electronic monitoring in fisheries: Lessons from global experiences and future opportunities. *Fish Fish.* 21(1):1–28 (doi: <https://doi.org/10.1111/faf.12425>).