Designing and Implementing Electronic Monitoring Systems for Fisheries

A SUPPLEMENT TO THE

CATCH SHARE DESIGN MANUAL

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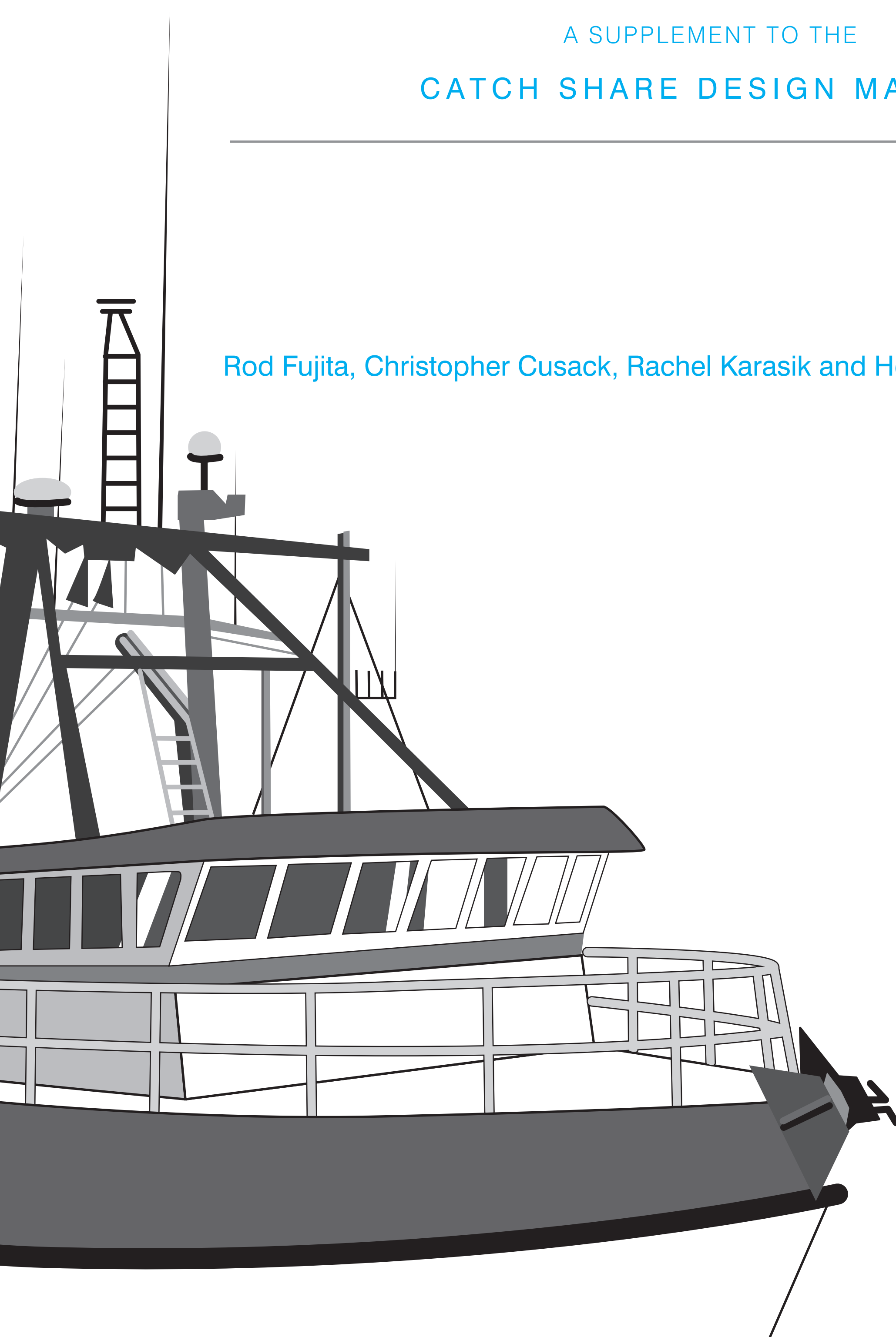

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WHY IS FISHERIES MONITORING IMPORTANT?

Fisheries produce more than 90 million metric tons of healthy seafood each year and employ tens of millions of people. Many fisheries are already well regulated and performing at or near their potential. However, thousands of other fisheries could be producing much more food and profit by maintaining catches at scientifically determined levels, even in the face of climate change (Gaines et al., 2018). Moreover, illegal fishing is widespread, contributing to overfishing, bycatch and discarding (FAO, 2002; Pitcher et al., 2008; Agnew et al., 2009; Le Manach et al., 2012). These issues reduce long-term fishery yield, adversely impact ocean wildlife, and take profits away from legitimate fishermen.

Fishery monitoring is essential for addressing these issues and allowing fisheries to reach their full potential for producing food, revenues and jobs, while protecting ocean ecosystems. Monitoring systems generate the data needed to ensure compliance with fishery regulations aimed at achieving these goals. Monitoring also generates data necessary for scientific stock assessments, which can then be used to set sustainable catch limits. Fisheries that use monitoring data to inform stock assessments, set sustainable catch limits and hold people accountable to regulations perform much better with respect to food production, revenue generation and conservation goals than fisheries that do not engage in monitoring and science-based management (Costello et al., 2012). Monitoring can also be of value to fishermen wishing to demonstrate that they are fishing sustainably in order to access certain markets, or for other reasons.

Despite these important benefits, fishery monitoring is far from ubiquitous. There are many reasons for this, including the lack of legal mandates for monitoring, lack of commitment to monitoring, the perception that monitoring costs too much, privacy concerns and resistance to change. Electronic Monitoring (EM) programs that use cameras and other sensors along with sophisticated data analysis to monitor catch and discards are emerging as viable ways to generate high quality monitoring data in fisheries with sufficient infrastructure, budget, and capacity to implement them. This guidebook is aimed at helping fishermen, fishery managers, NGOs, seafood buyers and others interested in monitoring fisheries to understand how EM works, what EM systems can do and how to design and implement an EM program that overcomes barriers to full implementation.

HOW ARE FISHERIES MONITORED?

Fisheries are monitored using a variety of tools and processes (Lowman et al., 2013). Monitoring *tools* commonly used in fisheries include self-reporting tools, such as fishermen's logbooks, hails and landing records, as well as tools that do not rely on self-reporting by fishermen, such as observers, port samplers and EM.

Monitoring *systems* are collections of tools designed to produce a specific set of monitoring outputs. An example of a monitoring system is a Vessel Monitoring System (VMS), which uses a GPS receiver to record vessel position and a satellite transceiver to transmit that position on a regular basis to fishery managers. Monitoring *processes* describe how data are collected, stored, transmitted, analyzed and used for management; and define monitoring responsibilities of each participant in the management of that fishery. For example, a monitoring process might consist of fishermen self-reporting catch data in logbooks and mailing them to managers at the end of every fishing trip. In this guide we define a fishery monitoring *program* as the collection of all tools, systems and processes employed to monitor a fishery. EM programs often integrate Electronic Reporting (ER) tools such as electronic logbooks or satellite VMS systems with EM systems.

Both the tools used in a fishery monitoring system and the way they are deployed depend on the specific attributes of the fishery. Important attributes include monitoring objectives, the types of gear used, infrastructure, monitoring budgets and other factors that influence the feasibility and effectiveness of different monitoring systems.

All monitoring tools have constraints. The transcription of paper logbooks into digital form can introduce errors. Data collected by human observers can suffer from bias and transcription errors if the overall monitoring system is not designed well, and deploying human observers over a diverse fleet is often hampered by vessel space, logistical issues and significant financial cost. Sometimes constraints arise because information collected over the course of a monitoring program conflicts with the self-interest of fishery participants. For example, if a fisherman reports high catch levels of a protected species that is subject to a hard cap, their future fishing opportunities could be restricted. These conflicts of interest are a common feature of self-reporting tools; thus, a key design challenge for a monitoring system is deciding how much to rely on these types of tools, and to what extent tools that collect data independently of fishermen are required. While many fishermen will report truthfully, even when doing so affects their immediate livelihoods, the fact remains that self-reported data will always be subject to credibility challenges. These constraints have impeded the ability of many fishery managers to implement monitoring programs that generate enough high quality data to achieve management objectives such as high and sustainable yields, good profits and lower impacts on ocean wildlife and habitats.

Because of these constraints on monitoring, fishery monitoring programs do not usually arise spontaneously. The main drivers of fishery monitoring are regulations that are designed to achieve good fishery performance (i.e. that achieve a target level of sustainable catch and ensure good economic outcomes) and may include catch, bycatch, and discard limits, as well as spatial and temporal restrictions on fishing. However, a growing number of fisheries have industry-led monitoring programs that are designed to not only generate data on landings and fishing effort, but to ensure accountability and transparency in terms of illegal fishing, human rights concerns and seafood traceability (Evans, 2018; Stop Illegal Fishing, 2018). Global and regional mandates also drive monitoring; for example, vessels that weigh more than 300 gross registered tons are required by international law to be equipped with AIS, which results in automatic tracking of 2% of the global fishing fleet (Gutierrez et al., 2018). Regional Fisheries Management Organizations (RFMOs) also commonly establish monitoring requirements for vessels under their jurisdiction, with differing requirements for vessel size and gear across the regions (Koehler, 2016).

Most fisheries that use large vessels that generate large catches are monitored in some way, but the majority of the world's fisheries are probably not monitored very well or even at all. Unmonitored or poorly monitored fisheries may include newly emerging industrial-scale fisheries that are underregulated (Standing, 2008; McCauley et al., 2018), as well as the many thousands of small-scale fisheries that deploy small vessels operating mostly in nearshore waters (Allison and Ellis, 2001). Lack of regulatory drivers and/or social commitment to monitoring, coupled with known barriers, prevents progress towards increased monitoring efforts. This in turn blocks progress toward achieving sound fisheries management for the majority of the world's catch that would unlock much greater catches, higher revenues and better conservation performance.

To catalyze widespread growth in fisheries monitoring, the barriers to monitoring must be overcome in a wide variety of fisheries that use different kinds of gear and vessel sizes, differ in profitability and have different kinds of infrastructure. Moreover, drivers and value propositions for monitoring will have to be introduced in more fisheries if they are to realize their full potential to produce food and profits while sustaining stock and ecosystem productivity over the long term.

HOW CAN ELECTRONIC MONITORING HELP?

EM programs have evolved over the past 20 years to help overcome some of the constraints of monitoring programs and other barriers to fishery monitoring. Electronic logbooks can help reduce errors in capturing self-reported catch and effort data. Catch, bycatch and discard rates can now be monitored with cameras onboard vessels, instead of by human observers on vessels or catch enumerators in ports. Monitoring data can now be stored in digital form and analyzed later, or potentially even streamed live. Inexpensive GPS trackers can be used to track the locations of vessels too small to carry VMS or AIS systems (Fujita et al., 2018). In fisheries requiring intensive monitoring that is currently done by human observers, EM programs are producing high quality, reliable monitoring data at a lower cost to fishermen (Michelin et al., 2018).

The effectiveness with which EM programs can help to achieve monitoring goals is well documented, with more than 30 studies conducted to test the performance of a variety of EM systems. These studies show that EM systems can generate monitoring data that is comparable and compatible with data generated by human observers on landed catch, bycatch, discards and more (McElderry et al., 2004; McElderry, 2008; McElderry et al., 2008; Bonney et al., 2009; Piasante et al., 2009; Cahalan et al., 2010; Jaiteh et al., 2014). EM programs have been continually refined since the first EM program was designed and implemented about 20 years ago in the British Columbia Dungeness crab fishery (Michelin et al., 2018).

While in some fisheries EM has helped to overcome barriers to the expansion of independent monitoring, significant barriers to the broader use of EM remain. These include: failure to recognize the need for independent monitoring; lack of policy and regulatory frameworks to drive or support technology-based monitoring; lack of commitment to fund monitoring programs; lack of clarity around monitoring objectives; lack of effective program design processes to ensure cost efficiency; resistance to change; and privacy and data ownership concerns. Currently, about 1,000 fishing vessels operating in about 30 fisheries have EM systems, equating to only about 0.25% of fishing vessels more than 12 meters in length (Michelin et al., 2018).

We developed 20 “snapshots” of EM programs in fisheries around the world (Appendix) that offer a broad representation of their different characteristics, management environments and socioeconomic contexts. The snapshots are listed in Table 1. These fisheries utilize a range of gear types and vessels, operate under differing monitoring goals, generate differing levels of revenue and exhibit a range of institutional and social contexts. These snapshots informed our analysis of how barriers to EM may be overcome in a range of situations. The information was then distilled into practical guidance for fishery practitioners wishing to design and implement an EM program to reap the benefits of intensive monitoring.

TABLE 1 | SNAPSHOTS OF EM IMPLEMENTATIONS USED TO INFORM THIS GUIDE[1]

CASE #	LOCATION	SPECIES TARGETED	GEAR	PROJECT TYPE[2]
1	U.S., Hawaii	Swordfish, Tuna	Longline	Protected Species Monitoring
2	U.S., West Coast	Groundfish	Trawl	Compliance Monitoring
3	U.S. Pacific Ocean	Swordfish, Thresher Shark, Opah, Tunas	Drift Gillnet	Catch Monitoring
4	U.S., New England	Groundfish	Trawl, Gillnet	Catch Monitoring
5	U.S., New England	Haddock	Longline	Catch Monitoring
6	U.S. Atlantic, Caribbean and Gulf of Mexico	Tuna, other Pelagics	Pelagic Longline	Protected Species Monitoring
7	U.S. Atlantic	Herring, Mackerel	Midwater Trawl	Catch Monitoring
8	U.S., Gulf of Mexico	Snapper, Grouper	Vertical Line	Catch Monitoring
9	U.S., Alaska	Halibut, Sablefish	Fixed Gear	Catch Monitoring
10	U.S., Alaska	Groundfish	Trawl, Longline, Catcher/ Processor	Compliance Monitoring
11	British Columbia, Canada	Halibut, Sablefish, other Groundfish	Hook and Line	Catch Monitoring
12	British Columbia, Canada; U.S., West Coast	Dungeness Crab	Pot	Gear Theft Avoidance
13	British Columbia, Canada	Pacific Salmon	Troll	Catch Monitoring
14	Western and Central Pacific	Skipjack Tuna, Bigeye Tuna, Yellowfin Tuna	Purse Seine	Catch Monitoring
15	Australian Fisheries	Tuna, Billfishes, other Pelagics	Longline, Gillnet, Traps	Catch Monitoring, Protected Species Monitoring
16	New Zealand	Snapper	Trawl	Catch Monitoring
17	New Zealand	Rig, School Shark, Elephant Fish	Set Net	Protected Species Monitoring
18	Denmark	Cod	Gillnet, Seine, Trawl	Catch Accounting
19	Ghana	Tuna	Purse Seine	Catch Monitoring
20	Southern Ocean	Patagonian Toothfish	Longline	Demonstrate Good Fishing Practices, Traceability

(1) The case studies include both pilots and scaled fisheries.
(2) See glossary for definitions.

WHAT DO ELECTRONIC MONITORING SYSTEMS LOOK LIKE?

EM programs include technology to collect data at sea (e.g., cameras and other sensors) and processes for data analysis and the creation of data products (e.g., reports) that can be used to achieve goals such as ensuring compliance with catch and discard limits, and to document that compliance. This section is taken from Stebbins and McElderry, (2018). The specifics of an EM program will vary from fishery to fishery, but we depict a generic EM program for illustrative purposes in Figure 1.

At-Sea Technology

The at-sea technology necessary for EM consists of a control center and sensors that monitor different aspects of fishing operations, depending on the goals of the EM program. Cameras record video data which is generally stored on a hard drive for retrieval after the fishing trip.

The control center is relatively compact (approximately 10cm h x 30cm w x 200cm d) and houses computer circuitry and the hard drive. It usually mounts in the bridge and has a user interface (keyboard and display monitor) so that fishermen or technicians can assess the view from the active cameras, sensor readings, data storage capacity and overall system status. EM systems use relatively small amounts of power from either AC or DC power systems.

The hard drives used to store camera and sensor data are usually high capacity solid-state drives, to increase their durability at sea. Hard drive capacity varies by fishery application, but is usually at least 0.5 TB. All data are encrypted and recorded on the hard drive, and retrieved by a technician or vessel personnel when the fishing vessel returns to port, depending upon program rules. In more remote EM system installations, vessels are equipped with satellite communications to enable synoptic summary reports for the purposes of vessel tracking and EM system performance monitoring.

An EM system can generally support up to eight digital cameras, with the number used and their location determined by the vessel layout and monitoring objectives. In general, camera placements are set to capture either wide panoramic or close-up views of certain areas of the vessel. The panoramic view provides a good overall view of vessel activities but may not resolve detail, such as individual fish, or measure lengths, which require close-up views.

In addition to cameras, EM systems generally have other sensors to activate image recording when certain vessel operations occur, and to record fishing operations to allow analysts to zero in on them when reviewing EM data. These sensors include:

GPS Receiver – The GPS receiver mounts in the vessel rigging and delivers data on time, vessel position, speed, heading and position fix quality.

Hydraulic Pressure Transducer – These are generally mounted on the hydraulic system supply for deck winches and fishing equipment. Pressure readings indicate when the equipment is activated.

Drum Rotation Sensor – This is a photoelectric sensor that detects motion by rotating drums that spool fishing gear by sensing the reflective tape mounted on the drums.

Radio Frequency Identification (RFID) – This technology uses electromagnetic fields to automatically read information stored on tags. More recent UHF-based RFID provides a very cost-effective way to identify tags on gear at distances of more than five meters.

Monitoring technologies differ greatly in the resolution, accuracy and spatiotemporal coverage of the data they generate, as well as initial and ongoing costs, ease of installation and acceptability to the fishing industry. Moreover, the state of all of these technologies must be considered to ensure that the technology used is neither out of date nor too cutting edge.

The challenge is to choose EM equipment and processes such that an acceptable balance of performance, cost and practicality is achieved. EM systems vary widely in their objectives and thus very different configurations are necessary to achieve this balance. For example, in the British Columbia area 'A' Dungeness crab fishery, an EM system was designed using extensive performance feedback from fishermen, with the goal of ensuring that all crab pots pulled are registered to the vessels that pull them (Snapshot 12). The resulting EM system does not use video footage to quantify catch as many EM systems do. Instead, a RFID tag that is inserted into each crab buoy is passed over a scanner onboard that reads the tag. This record is integrated with GPS data that tracks vessel position, and video footage from a single camera onboard that verifies that pots are not being pulled illegally. A similar system is also being used in the U.S. dungeness crab fishery by the Quinault Indian Nation. These systems ensure that crab fishermen are fishing the correct pots in the correct area, in order to reduce theft of gear and catch. While relatively simple EM systems (e.g., a single camera with data storage capability) may suffice for certain applications (see Fujita et al., 2018), they are unlikely to meet the needs of many fisheries. For example, multiple cameras and sensors may be necessary to capture catch, discard and fishing events on a large vessel. Moreover, more sophisticated EM systems that encrypt data, detect errors and have other features that make video processing more efficient, can result in cost savings and higher quality data.

Monitoring technologies are changing rapidly, and it will be important for those wishing to implement EM to stay apprised of current technological options and prices. Please refer to the EM Resources section for more information.

EM Processes

In addition to the physical EM system, EM *programs* also include processes for ensuring that the system functions correctly, as well as for managing, analyzing and interpreting data. These include rules for how data are transmitted to managers, how often this occurs, how much of the video is analyzed and who owns the data, among many others. Field service technicians and data technicians must be retained to support these processes.

Enabling Conditions for EM

To be effective, EM programs must be embedded within fishery management systems that allow for the use of EM data in guiding decision making. These can include determining when an infraction has occurred, or whether or not to adjust stock assessments and management measures. It is also essential to have measures in place that hold fishermen and managers accountable to any discrepancies between EM-generated data and fishery goals and regulations. An emphasis on coordination between different components of the EM program can ensure program efficiency and the generation of high quality, timely data.

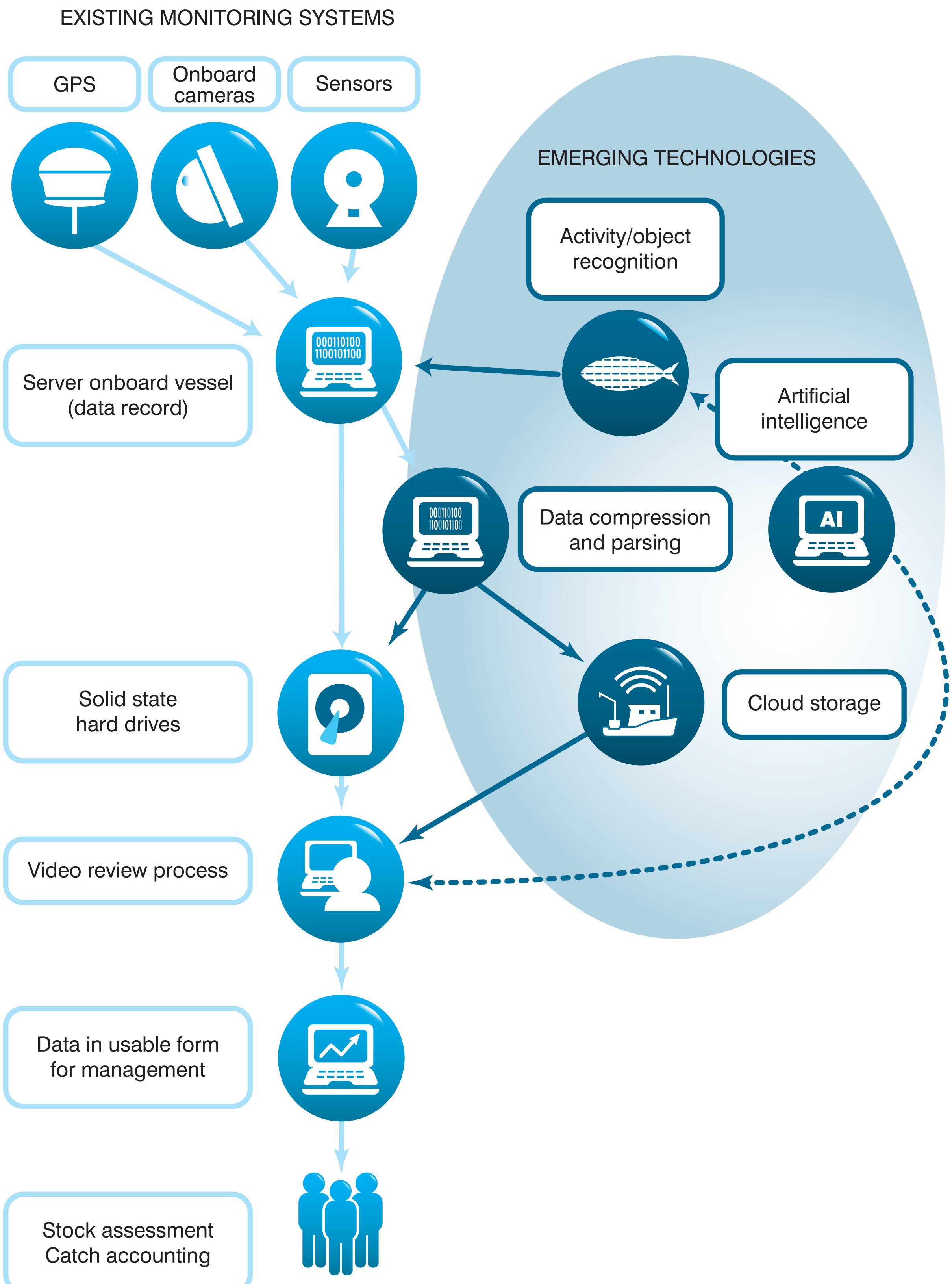
The Future of EM

The preceding description of what an EM program looks like (Figure 1) reflects the current state and use of technology in most large, operational programs; however, EM technology is rapidly evolving. Below are some EM technology developments that are likely over a three- to five-year timeline:

- Higher capacity data storage at lower cost to accommodate future EM systems that generate more data
- Faster data processing with lower power consumption, which may or may not be less costly
- Improved digital cameras with higher resolution, but not necessarily lower costs
- More wireless connectivity between sensors and cameras
- Higher rates of wireless data transmission between EM components that may or may not keep up with larger amounts of data being generated, in the range of two to three gigabytes/day
- Better power consumption efficiency
- Improved data transfer (via satellite, WiFi, cell and land-based portals)
- Improved remote real-time monitoring and management

FIGURE 1 | *A Generic Monitoring System*

Cameras and other sensors collect monitoring data which are then stored on removable hard drives, reviewed and transformed so they are usable by managers and scientists. Emerging technologies such as artificial intelligence are starting to reduce video review costs and enable wireless data transmission and cloud data storage.



- Consumer grade electronics that can suit some fishery monitoring needs, expanding EM possibilities to the current fringe of the market but not likely to replace existing EM systems (see Fujita et al., 2018)

Artificial Intelligence could provide:

- Automatic detection, classification and measurement of capture species (although some elements of this capability are still in early stages of development)
- More real-time alerts when the system is not operating properly
- Real-time pre-processing to identify events of interest and more intelligently control data recording and transmission (e.g., cameras that follow fish across the field of view instead of capturing the whole field of view all the time)
- Greater integration of EM with ER and other tools (e.g., AIS, VMS, etc.)
- Improved tools to analyze EM sensor and image data sets

KEY ELEMENTS OF DESIGNING AND IMPLEMENTING AN EM PROGRAM

Every fishery is unique—as such, differences in gear types and vessels used; the goals and structure of management; the level of engagement of fishermen in the management process; the value of the fishery; the institutional framework that governs management; and the level of infrastructure in the fishery all mean that implementing EM programs is never a "one size fits all" process. These varying characteristics of fisheries also result in different kinds of barriers to EM. For example, if there is no clear mandate for fisheries monitoring, uptake of any monitoring system is likely to be difficult. If the level of revenue in a fishery is barely enough to sustain participation in the fishery, subjecting fishermen to further monitoring costs will likely just result in a sharp decline in participation in the fishery and EM program.

To help fishermen, fishery managers and other stakeholders design and implement EM programs in their fisheries, we identify nine elements (Table 2) that have emerged as consistent factors associated with successful implementation—or whose absence prevents successful implementation—of an EM program. In the next section, we describe these elements and how they inform the design and implementation of a successful EM program that can overcome the main barriers to EM.

EM DESIGN AND IMPLEMENTATION GUIDANCE

Because EM can represent a profound change in both the nature of the fishery and the fishing process by introducing a very high level of monitoring and accountability, it is important to ensure that stakeholders and managers are sufficiently motivated to take on the task of creating an EM program. Barriers such as the perception of high costs and privacy concerns must be addressed. Governance of the EM program must be established, and roles and responsibilities made clear and agreed upon. This is all in addition to the work of choosing and testing EM technologies, designing the EM program, removing barriers to EM implementation and adapting to change.

The design and implementation elements presented in the following section include guidance on how to achieve these steps in ways that increase buy-in, practicality and effectiveness.

TABLE 2 | THE ELEMENTS OF SUCCESSFUL EM DESIGN AND IMPLEMENTATION

ELEMENT	SUMMARY
1. Motivate EM adoption	Mandates and other incentives are necessary to motivate the investment of time, energy and resources needed to design and implement an EM program
2. Assemble an EM working group	The EM working group is responsible for designing the EM program in a participatory way that creates industry support, which is essential for EM programs to function well
3. Set clear objectives	Fishery management goals must be connected to specific monitoring objectives that guide the development of the EM program
4. Establish governance for the EM program	Roles and responsibilities for every aspect of the EM program must be made clear and committed to by the responsible parties
5. Design and optimize the EM program	There are many options to choose from; the set of tools and processes must minimize costs and disruption to fishing operations while still achieving the monitoring objectives
6. Understand and articulate the EM value proposition	Perceptions of the costs and benefits of EM compared with those of alternative monitoring programs often vary within a fishery; a common understanding must be reached in order to decide whether or not to develop an EM program
7. Practical learning through pilots	EM tools and processes should be tested onboard vessels to prevent problems during implementation
8. Communication and outreach	Effective two-way communication is essential for engaging all stakeholders in the EM design and implementation process in order to understand and address concerns
9. Implementation, optimization, evaluation and adaptation	Much will be learned during implementation, and conditions will change over time, so evaluation of EM program performance and periodic adjustment will be required

Element 1. Motivate EM Adoption

Designing and implementing an EM system and embedding it in an effective monitoring program requires managers and fishery stakeholders to devote significant amounts of resources. The process can be difficult, costly and time-consuming, so all stakeholders will need to be sufficiently motivated to make the investments necessary to address these challenges.

Establishing Program Commitment

This first phase of motivating EM adoption involves establishing stakeholder commitment to EM as a monitoring tool in their fishery. The suitability of EM for a particular fishery depends on many factors, but the one essential ingredient for uptake of EM is the presence of a clear data need that drives commitment to improved monitoring. For example, the US Pacific coast groundfish and whiting fisheries had already agreed to 100% monitoring with observers in response to fishery closures triggered by the catch of depleted stocks, and because lack of data created uncertainty which resulted in large closed areas and other restrictions on fishing opportunity (Snapshot 2).

The extent to which stakeholders and fishery managers will be motivated to implement EM will vary from fishery to fishery and depends on who stands to gain value from implementing EM, who faces the barriers and who bears the costs. In some cases there is a clear value proposition for all stakeholders and managers to implement an EM system. For example, in British Columbia's groundfish fisheries, a clear need arose for managers to properly account for all catch and discards of the overfished yelloweye rockfish stock in a fishery that was logistically difficult to monitor via other tools. This combined with the implementation of an Individual Vessel Quota (IVQ) system to align incentives of all stakeholders to explore EM as a monitoring tool. To maintain the value of their IVQ, fishermen needed to know that other fishermen were not cheating the system, and an effective EM system promised to achieve this (see Snapshot 11).

Motivation for EM also depends on the attitudes of current fishery participants towards accountability. Exceeding catch limits, high-grading at sea and the use of illegal gear are detrimental to the sustainability of the fishery resource, but have become commonplace in some fisheries because fishermen deem them necessary to achieve short-term economic viability, especially in depleted fisheries where catch rates are low. In these cases fishermen may perceive increased monitoring by any means to be a threat to profitability, or even to their continued participation in the fishery. Conversely, when there is a widespread perception among fishermen that there is a low incidence of infractions, fishery participants may see no need to increase or change monitoring efforts (Michelin et al., 2018).

Building Acceptance of EM

Communication of the gaps in a monitoring system, and an understanding of how these gaps contribute to a failure to meet fishery goals, as well as of the potential consequences, are necessary for building and maintaining motivation for EM. When designing and undertaking a communications strategy, the retention of a skilled facilitator to elicit positions, beliefs and interests from diverse groups of stakeholders can be effective (PPRI and CBI, 2008; Tyler, 1999).

Structured meetings aimed at eliciting from the stakeholders an understanding of the consequences of failing to fill monitoring gaps—which are often related to lower allowable catch rates, tighter management measures and lower profits in highly regulated fisheries—may be necessary. This is because research has shown that many people have an aversion to loss that is even stronger than their attraction to benefits or gain (Tversky and Kahneman, 1991). Communicating how EM programs can be used to avoid these consequences, and then providing a process that encourages stakeholders to air concerns in a way that encourages a problem-solving mindset, can help build motivation and create buy-in among stakeholders for the design and implementation of an EM program (Hanna and Smith, 1993; Berkes, 2009; Röckmann et al., 2012; Ommer et al., 2012).

Even the most effective communication strategy may not generate sufficient motivation and support for an EM system. Providing information is necessary, but not sufficient enough, to change the behavior or attitudes of the full spectrum of fishery stakeholders (Kollmuss and Agyeman, 2002; Berkes, 2009; Aceves-Bueno et al., 2015). Although efforts should be made to provide this information in the most compelling, participatory way possible, other motivational strategies are likely to be necessary.

In most cases new rules and regulations that mandate monitoring requirements, and that are designed to accommodate the use of EM, are necessary. For example, U.S. fishery legislation includes mandates to set annual catch limits designed to prevent overfishing of low productivity stocks in mixed species fisheries. This focus on accountability has led to requirements for 100% observer coverage in some U.S. fisheries to document total catch, including bycatch and discards at sea. The logistical and cost challenges of observer programs then motivated pilot studies of EM in several U.S. fisheries, with regulatory frameworks currently being developed for EM in most U.S. fisheries.

Increasing Support for EM by Reducing Barriers

Reducing barriers to EM implementation is essential for building support for EM adoption. All of the design and implementation elements discussed in this guide include guidance for overcoming many different kinds of barriers.

Participatory Processes to Increase Acceptance of EM Systems

Change can be difficult, especially when stakeholders are uncertain about EM equipment, how the program will affect their fishing operations and bottom lines, and whether they will be cited by enforcement officers more frequently. Uncertainty about how EM would affect fishing operations or about other aspects of EM often raises concerns. Making the process of planning the EM system transparent and participatory (see Element 2) may go a long way toward reducing uncertainty, fear and reluctance to change (Stanley et al., 2014; Eayrs et al., 2014). Pilots can also reduce this uncertainty by providing the industry with an opportunity to gain some experience with EM (see Element 7), which tends to increase support for the program over time (Michelin et al., 2018).

Decision Points

Electronic monitoring is not appropriate for all fisheries. Current data collection systems must be seen as inadequate to support management needs, or cost more than EM, to motivate EM adoption; other drivers such as legislative or regulatory mandates are often also necessary to motivate the use of EM. The EM system must be affordable for the fishery, and sufficient industry support is essential. Where trust is lacking and/or the relationship between fishermen and managers is extremely polarized, EM may not be adopted, and even if it is, it may never be effective due to lack of acceptance. If these conditions exist, it is useful to consider other ways to collect necessary data that may be more acceptable to fishermen (Fujita et al., 2018). If there is agreement in the fishery that EM is necessary and could be cost-effective and practical, it is time to begin the work of designing the EM program, starting with the creation of an EM working group.

Element 2. Assemble an EM Working Group

There are numerous technical, institutional and operational hurdles that need to be overcome when implementing an EM system. Often, the best way to address these hurdles efficiently and in a way that encourages communication, transparency and stakeholder buy-in is the formation of an EM working group that has an early and ongoing role in the implementation process.

It is the responsibility of government agencies to establish monitoring goals; however, it is crucial to design and implement EM systems aimed at achieving these goals in a way that builds acceptance of EM through participation and transparency.

The EM working group is a cooperative decision-making group responsible for designing the EM system and providing oversight over EM implementation. Specific tasks include the specification of EM system components and how they will interact to achieve the monitoring objectives; the development of protocol within the industry for handling catch and operating EM equipment; the articulation of proposed rules for using EM data; and the recommendation of funding mechanisms. The working group should also develop a service delivery model that specifies operational responsibilities, including who provides the requisite hardware and services, who processes the data and who maintains the system.

The EM working group should be relatively small (no more than 20 members) and made up of representatives of the entities that would use EM data (e.g., managers, enforcement agencies, NGOs), be impacted by the EM system (e.g., fishermen leaders from each affected gear sector), and experts familiar with EM tools and systems. Members must commit to working over a two- to four-year period, with four to five meetings per year in addition to outreach to constituencies. The group should include individuals with the proper skillset and knowledge to design the EM system, including in-depth knowledge of how the fishery operates, regulatory process requirements and standards of evidence. Fishery managers must be active participants, as they will need to relay monitoring goals to the fishermen and use feedback from stakeholders to identify potential future pitfalls during the implementation phase.

It is essential to incorporate representatives of all groups that will be impacted by the implementation of an EM program in order to make implementation participatory. Partnerships among managers, fishermen and EM experts to design and implement EM based on participatory processes have resulted in highly functional programs that both incentivize fishermen to increase the accuracy of self-reporting and improve maintenance of the monitoring system, all of which leads to a higher probability that management and conservation goals will be achieved

(Stanley et al., 2014). Many of the examples of successful EM programs involved stakeholder participation in the implementation process from an early stage. In the Atlantic herring and mackerel mid-water trawl fishery, for example, early collaboration among all users of EM data was identified as an essential component of planning for EM implementation (Snapshot 7).

When establishing an EM working group it is important to explicitly define the responsibilities of the group, perhaps through establishing a set of Terms of Reference (TOR). These TOR should include procedural rules for how the working group functions as well as the group's expected length of tenure. The implementation of an EM program is often a lengthy process, and while fishery managers often undertake such responsibilities in the course of their employment, many other participants are unpaid. Clearly communicating expectations for participation in an EM working group, including work commitments, can contribute to a successful process.

Element 3. Set Clear Objectives

The overall goals of management for each fishery should inform specific monitoring goals. These goals, in turn, should be used to set achievable monitoring objectives for the EM system. For example, a *management goal* of achieving Maximum Sustainable Yield (MSY) could imply a *monitoring goal* of 100% catch accountability. An *objective* that would support this goal could be to monitor 100% of fishing and discarding events. Objectives should be measurable so that the performance of the EM system can be quantified in relation to performance targets. Some typical fishery management objectives and their implications for monitoring are shown in Table 3.

Once monitoring objectives are identified, the EM working group (see Element 2) can evaluate the extent to which objectives are being achieved with the current monitoring system. This process can serve to identify challenges with the current monitoring program and gaps in existing data streams. Once monitoring gaps are identified, the extent to which EM can fill these gaps can be explored and new EM objectives formulated. Challenges that can lead to gaps in data streams include the high cost of existing monitoring systems, unreliability of existing systems, and an inability of existing monitoring systems to generate sufficient temporal or spatial coverage. For example, a key challenge in the Gulf of Mexico reef fishery was that small vessels could not easily and safely accommodate human observers, which led to a very low observer coverage rate that did not achieve monitoring goals (Snapshot 8). An objective of EM system implementation was therefore to increase the monitoring rate in the fishery. Other objectives of an EM program may include achieving the same level of monitoring as an existing system but at a lower cost, reducing logistical burdens on fishermen, and increasing the types of information collected in a fishery and allowing the integration of market facing tools such as traceability systems.

While fishery agencies are responsible for articulating monitoring goals, other stakeholders will have their own goals and concerns. The EM working group provides a forum for these to be shared and accommodated to the extent possible in the design of the EM program. For example, a series of EM pilot studies have been conducted on vessels in the New England groundfish fishery since 2010, with a goal of full-scale implementation (see Snapshot 4). These studies have been difficult to undertake due to fishermen's reluctance to participate in monitoring, the variety of fishing vessels (e.g., gear types, size and other characteristics) participating in the fishery and the large geographic spread of the fishery. After an initial pilot from 2010-2013 that demonstrated the feasibility of EM to achieve a goal of increased fishery monitoring, a collaborative project that involved fishermen's groups, government, researchers and NGOs was initiated in 2013. The motivation for this EM project was to determine if EM could be used to collect information on catch and discards that fulfilled overarching monitoring goals cost-effectively, and in a way that did not interfere with fishing operations. Objectives were discussed collaboratively and derived directly from these goals. Two objectives were to: 1) assess whether groundfish could be identified to the species level on a wide variety of vessels, and 2) assess whether accurate

TABLE 3 | TYPICAL FISHERY MANAGEMENT GOALS, MONITORING OBJECTIVES AND IMPLICATIONS FOR MONITORING SYSTEMS

FISHERY MANAGEMENT GOAL	ASSOCIATED MONITORING OBJECTIVE	IMPLICATION FOR MONITORING SYSTEM
Ensure compliance with catch and bycatch limits to ensure high sustainable yields and reduce adverse impacts on ocean wildlife	Account for 100% of the catch and bycatch; or Audit logbooks to ensure reliable catch accounting	Full camera views of all catch handling activity with full recording Relatively high video review costs for 100% review rule Risk of misreporting with audit rule
Ensure high compliance with spatial fishing restrictions to protect habitat, reduce bycatch of vulnerable species, or protect biodiversity and ecosystem function	Increase probability that violations will be detected to levels that result in deterrence	Fine-scale GPS data and gear sensor data to determine vessel activity and location of activity May need software that alerts enforcement officials to violations based on VMS or GPS tracker data in order to focus enforcement efforts
Conduct scientific assessments of stock status to drive harvest control rules	Generate catch, effort and length composition data	Use catch and effort data both for monitoring compliance with limits and for stock assessment Need images of individual fish to enable measurement from images
Ensure compliance with bycatch limits	Quantify bycatch and discards	High resolution cameras required to identify species Need clear catch handling requirements to accurately identify discarded and kept catch from images
Ensure compliance with size limits	Generate data on length composition of the catch and discards	High resolution cameras likely required

length estimates of individual fish discarded at sea could be made using the EM system (Snapshot 4).

Element 4. Establish Governance for the EM Program

A governance framework is needed to ensure that an EM program operates effectively, meets obligations for deliverables and clearly defines responsibilities of participants. Governance considerations include who makes the decisions within the program, what mechanisms are in place for the decisions to be binding, how accountabilities are distributed and how questions and ideas are considered and acted upon. Governance frameworks are often confused with regulatory frameworks established under the authority of the fishery management agency, when actually governance is far broader in scope.

Part of establishing a governance framework is defining deliverables and creating shared expectations for each group involved in the implementation process. For fishery managers, these deliverables are often defined by the amount of data delivered to data users, when those data are delivered, and the quality and other characteristics of the data products. For EM service providers and other industry partners, deliverables are often structured around the quality of the service provided that enables EM data collection to be conducted in a timely manner, with limited impact on fishing operations. This often includes ensuring that comprehensive technical support is available to fishermen and managers whenever needed. Fishermen and managers may have different expectations for service quality; EM service providers can provide feedback that may result in adjustment of expectations. Among private companies involved, the provision of products and services must occur in a way that meets both agency and industry requirements but fits a business model that does not impose undue risk and uncertainty. Similar group-specific program requirements can be made for other EM program participants, such that the governance framework serves everyone's needs.

Before designing an EM program it is important to carefully consider the options available in setting up an effective governance framework. Governance and program design are intertwined in the sense that governance may specify some components of a particular program design, and conversely, program design may enable certain types of program governance.

Regulatory Framework

Often, program governance discussions become narrowly directed toward the fishery regulatory framework and do not adequately consider other areas where governance plays a significant role. Most fisheries management systems have established authority outlined in regulations and well-defined processes for development of new regulations. While the authority to place observers on vessels is often well established, EM may not be explicitly and comprehensively addressed in regulation. This can be an obstacle to EM program implementation because of the timeline and consultation process required to promulgate new regulations. While authority vested through regulations is important, other approaches may achieve a similar effect with less regulatory rigidity. For example, the Canadian Department of Fisheries enabled the use of EM simply by agreeing it could be used as an alternative to a human observer, provided that specific program-defined measures were followed. This made EM participation a conditional privilege, rather than a specified option. Measures may be established at different administrative levels of the EM program, including as part of license-specific guidelines or in business agreements with service providers. In U.S. fisheries, EM program implementations have occurred through the Exempted Fishing Permit (EFP) process, a temporary fishing permit which allows for more regulatory flexibility and can easily be revoked if EFP requirements are not met. These latter options enable a more nimble approach to rule setting, which can be helpful during the early stages of program implementation.

Program Oversight

As EM programs generally involve the participation of many different stakeholders, it is important to establish a decision-making framework that considers everyone's needs. This collaborative approach should not undermine the agency's authority to manage the resource, but should provide an avenue to incorporate many elements of the program that directly affect different participants. Some operational decisions should be delegated—at least in part—to industry participants, while other decisions should not. For example, determination of service levels (e.g., ports of activity, response times, etc.) should not be the sole purview of the agency, while fleet coverage levels, consequences of incomplete data sets, data delivery timelines, and other considerations that are critical for compliance and the achievement of specific monitoring objectives, are clearly within the purview of fishery agencies.

Importantly, the governance framework needs to ensure that the EM program delivers credible results, but that it is also *perceived* to be delivering credible results. This is subjective and assessed differently by the different groups involved, underscoring the need for broad participation in program governance. Perceptions must be considered as they influence the normative behavior of program participants; those who are confident in the program's effectiveness because they perceive its benefits are more likely to cooperate with the various requirements that make it work properly.

Cost Recovery and Program Governance

Often, the cost of an EM program is shared among various stakeholders. While there is no set model for determining who should be responsible for paying for components of the program, this issue can strongly affect program governance. Those who contribute financially to the program generally assume they have the right to participate and thus are more likely to become engaged. This link is strengthened if costs are clearly allocated towards a specific program cost, such as video review and data analysis, rather than to a general program fund. These cost structures can be used to effectively reduce program costs by creating strategies for efficient program participation. For example, a landings tax has no additional cost implication if the vessel shows up three hours late for a service appointment, whereas hourly fees for technical services incentivize participants to show up for appointments and organize their activities to minimize the amount of time necessary to perform these services.

Program Delivery Plans

While the core of an EM program centers around two parties—an agency that requires data and an industry that must satisfy the data requirement—it is seldom the case that program delivery is limited to these two groups. Private monitoring companies are often involved for three reasons: first, agencies often have limited capacity to fulfill EM equipment service requirements, particularly in geographically isolated and highly seasonal fisheries. Second, private companies have developed specialized EM products and services necessary to support an EM program. Third, private companies can be independent of both the agency and industry, creating the accountability relationships needed to ensure that the needs of different parties are met, as well as ensuring "neutrality" of the data. The management agency, fishermen and private monitoring companies can have different roles and responsibilities, depending on the specifics of the EM program; these roles and responsibilities should be spelled out in a program delivery plan.

The program delivery plan should consider each element of the EM program and determine how best to assign responsibilities, and how parties should interact. For example, participants may be responsible for facilitating the collection of EM data by handling the catch in a certain way, private monitoring companies may be responsible for collecting and analyzing these data sets and the management agency may be responsible for ensuring cleaned data sets are transferred to data users.

Often, the program delivery plan is strongly guided by the origin of the funds and rules governing how funds are disbursed. Agencies often provide some funding, yet government procurement policies restrict how these funds are disbursed, usually requiring an open tendering process which may contain very specific pricing structures for bid selection. Similarly, industry may be obligated to provide funding for an EM program through regulations, yet the government may be limited in the amount of input they can have in how these private funds are spent. Industry may also impose levies on themselves to share EM costs, which may enable them to exert more control on how funds are spent. However, this may have direct implications for the effectiveness of any governance framework. When industry is required to directly pay for certain parts of the program there is usually a desire to request bids from multiple EM vendors to ensure that funds are used efficiently. These payment-driven forces can result in a poor program delivery plan unless other factors are taken into consideration. For example, agency-driven purchasing of some program elements and industry-driven choices for others may result in different, misaligned monitoring companies trying to collaboratively deliver a single cohesive program, something which may be difficult to execute. Monitoring companies operate best with a stable tenure, a clear timeline, clear definition of responsibilities and a clear payment avenue.

A program delivery plan should first specify the most practical distribution of program functions, and then consider how this best aligns with funding channels. Building a common understanding of the manner in which funding influences program delivery, and then considering ways to mitigate potentially undesirable outcomes through the development of a program delivery plan, is one of the most important components of the implementation process.

Element 5. Design and Optimize the EM Program

Once the objectives of the EM program are clear and a governance framework for the EM program established, the EM working group can begin the design process. This requires choosing EM technologies, program rules and governance (e.g., roles and responsibilities) and putting together an EM program that can achieve the monitoring goals within the constraints imposed by budgets, infrastructure and industry concerns.

To begin this design process, the EM working group can produce a schematic of the EM program which describes how data would flow from sensors to analysts to data users; the physical equipment required; and the necessary services. This can help foster thinking about how different components of the program will work together to produce the data products needed to achieve monitoring goals. As part of this process, the characteristics of the fishing fleet, including size of the vessels, ports of delivery, fishing seasons, gear types and lengths of trip, should be defined. Defining these characteristics is essential for informing the design of the EM program.

Elements that should be considered as part of the design process include:

- Cameras, sensors, GPS transmitter and other instruments that record data
- Onboard data storage and data processing
- Onboard user interface (e.g., monitors)
- Data transmission mechanisms
- Data cleaning and analysis
- Specific data products
- Integration with data from other monitoring tools
- Entities that receive and make use of the data products
- Decisions that the data products would inform

If the fishery has other monitoring tools in place, the EM program schematic should show how the data streams generated with the other tools would be used in combination with EM tools. We provide an example of a generic EM program schematic in Figure 1.

Choosing EM Hardware

Cameras: Cameras vary in resolution, rate of frame capture, field of view, low-light performance, seaworthiness and ease of installation. Most EM service providers use fixed lens, closed circuit, waterproof video cameras that are proven in the marine environment and cost on the order of $80-400.

Gear Sensors: In many system configurations, sensors that are connected to a vessel's fishing gear—either a drum rotation sensor or a pressure sensor—are used to signal the EM system to begin recording. Research is currently being conducted on the use of object or motion recognition techniques to identify when fishing events are taking place, which would remove the need for gear sensors but necessitate image recording (albeit at a lower frame rate and/or resolution) for the entire time the vessel is on the fishing grounds.

Data Storage: Camera, sensor and GPS data are stored on reliable solid-state hard drives with capacities commonly on the order of one to four terabytes. Most hard drives are removable to facilitate data transmission.

Control Units: Control units are onboard computers that operate the EM system onboard, conduct preliminary data processing and power the EM user interface. They range from off-the-shelf desktop computers to servers that are designed for the transportation sector.

User Interface: Displaying camera footage in real time on a dedicated computer monitor is important so that fishermen can see when the system is functioning well, or if cameras become obstructed (by condensation, for example). In most cases fishermen are able to see the data being recorded but are not able to tamper with it.

Monitoring technologies are changing rapidly, and so it will be important for the EM working group to stay apprised of current technological options and prices. Please refer to the EM Resources section for more information.

EM Processes

In addition to hardware, EM programs also include processes for ensuring that data are analyzed, interpreted, managed, transmitted, and used to achieve fishery management goals. These processes require rules for how much of the video is analyzed, who owns the data, how frequently data are collected and transmitted, and for many other aspects of the EM program.

The storage and transmission of data are closely related and should be considered jointly. A decision should be made regarding whether the data will be stored onboard, or removed and analyzed later. Storage considerations include the size and number of hard drives that record EM data, whether the hard drives need to be removable, whether a cloud storage service is being used and how long to store the data. Transmission considerations include how often removable hard drives should be sent to managers and by whom, how these hard drives are transported (e.g., via mail courier) and whether systems that use cellular or satellite transmission are a feasible option. Most EM systems transmit data manually, through the removal and shipping of hard drives to managers. This can be a logistical challenge when fishing takes place in remote locations or when video data are required for real-time management. Many EM providers have the capacity to offer wireless data transmission (through satellite or cellular networks) as an option. However, high costs, large data volumes associated with EM, the lack of infrastructure and lack of a defined process by which fishery managers can accept data wirelessly have impeded progress toward widespread wireless EM data transmission.

To be effective, the EM data must be quality-controlled, analyzed and formatted for use in fisheries management. This means that a data management system must be developed, along with rules for how the EM data will be used and accessed. There are many ways in which EM equipment and data can be used, each with its own pros and cons that must be considered within the context of specific fisheries in order to make the best choices.

Who analyzes the EM data, and where, when and how data are analyzed, is determined partly by the nature of the link to management. If data are used for in-season management, analysis must be conducted on a much shorter time scale than if they are used after the season ends. The way that data will be analyzed and used also bears strongly on these decisions.

The data review process should be designed with the goals and objectives of the monitoring program in mind. Video reviewers should be well trained in species identification and the review software, and a minimum performance level should be established prior to actual review. Software for review video data varies substantially in how efficiently useful information can be derived from raw sensor and video data, which has a strong influence on EM program cost. Ensuring that video reviewers are independent of both fishery managers and fishermen can improve program transparency and build trust with stakeholders. Deciding between an audit-based approach to video review (i.e., a certain proportion of video footage is randomly selected to audit self-reported logbooks for errors) or a census-based approach (i.e., all EM data are analyzed), depends on several factors, including cost of review, whether or not self-reported data are treated as the main catch record, the reliability of logbook data, the level of trust in the system and the objectives of the monitoring system. For example, if a fishery generates high quality logbook data with occasional misreporting, EM tools like cameras and video audits of random fishing events to verify the logbooks may provide sufficient incentive to reduce misreporting rates to acceptable levels. This was found to be the case in the British Columbia integrated groundfish fishery (Stanley et al., 2014; Snapshot 11). When there is insufficient information on misreporting rates or the effects of audits on reporting behavior to determine the appropriate frequency of audits, or even the need for 100% review of EM video data, a phased approach with incentives may be appropriate. For example, the program can start with 100% review, with costs internalized by fishermen, who would then have a strong incentive to improve reporting. Some EM companies are developing machine learning capabilities that may help reduce video review time without sacrificing data generation or accountability; for example, by detecting fishing events that are likely to result in high bycatch.

An EM program schematic should explicitly specify how EM data products will be generated and transmitted to data users; how the EM data products will be used; who owns the EM data; and who can access EM data under what conditions and for what purposes. This will require an agreement on common data formats, protocol for removing and replacing hard drives if necessary, protocol for transmitting data and agreements specifying access and ownership rights to the EM data. This is important, as uncertainty about who can access EM data and how they can be used can result in privacy concerns, which have emerged as a common barrier to EM adoption. These concerns are felt very deeply by some fishermen (Michelin et al., 2018) for a number of reasons, including fear of divulging favored fishing spots or practices, concern that video footage could be used to attack the industry and a general opposition to being surveilled that is shared by almost all fishermen. Considerations must therefore be made to protect the privacy expectations of fishing vessels and crew (McElderry et al., 2007). The specific locations of individual fishing grounds and other aspects of the fishing operation should be closely guarded as proprietary trade data. Part of this expectation of privacy means that, in many cases, the data should not be used for purposes beyond achieving the established fishery management objectives (Piasente et al., 2012). There may also be other cultural or societal expectations around personal privacy that will need to be taken into account. Privacy concerns can be addressed both in the design of the EM system and in how communications about the EM system are structured (see Element 8).

Ensuring Adequate Infrastructure for EM

Obviously, the fishery needs to have the right infrastructure to use EM. This not only means that the vessels have to be capable of carrying EM equipment, but also that a data management system is in place, and that personnel are available to install and maintain systems and to collect, review, analyze, store and act upon EM data. It is important that fishery managers and fishermen understand their responsibilities and the consequences of failing to fulfill them. For example, fishermen play a critical role in maintaining EM equipment; proper maintenance training is an important enabler of successful scaling (Battista et al., 2017). Having technical support accessible to fishermen is also an important enabler of successful EM systems. To support EM processes, field service technicians must be available to manage EM systems on vessels and to work with vessel crew to ensure that obligations for catch handling and system maintenance are being upheld. In addition, a group of designated data technicians is required to process sensor, GPS and image data from fishing vessels, facilitated by data analysis tools designed to format and integrate multiple streams of data into a form that can be reviewed.

The EM working group should gather information on all of these infrastructure elements, in order to ascertain whether infrastructure is adequate for EM or to show where needed infrastructure is missing.

Service Delivery Model

The EM working group should consider several factors when choosing an EM service delivery model: who will be responsible for overseeing the EM system? Will a single provider install the EM equipment, train users on how to operate it, service the equipment, quality control the data, analyze the data and produce data products? Or will several different contractors perform different tasks? The details and effectiveness of the service delivery model can potentially affect the performance and cost of the EM system. For example, low responsiveness to equipment failure resulting from the use of several providers that are not well coordinated can interrupt the flow of monitoring data and potentially result in lost fishing revenues. High staff or vendor turnover can introduce uncertainty. Lack of clarity about who is responsible for overseeing the EM system and making sure that it is being effective can also impair performance. Choosing an excellent EM service provider with a good track record is key, in part due to high transaction costs associated with changing service providers, and resistance to changing EM technologies.

EM service providers have unique product and service offerings. The particular provider that can best service a fishery's EM system may be clear from the moment that an EM system is conceived. In this case, the fishery agency may choose to include this EM provider in the EM working group. In other fisheries, it may be desirable for the EM working group to interview EM providers to determine the best fit of the provider's technology and services for the infrastructure, monitoring needs and other attributes of the fishery.

Estimating Costs and Cost Sensitivities

Because the perceived costs of an EM system can be a significant barrier, costs should be minimized to the extent possible through EM program design (see Element 6). It is also often useful to conduct analyses that create accurate perceptions of EM costs relative to alternatives; without analysis, many people automatically put more emphasis on costs (which are often easily quantified) than on benefits (which are less so), and fail to consider the costs of alternatives to EM.

A cost-benefit analysis (CBA) compares the costs and benefits of a management alternative (i.e., a particular EM program configuration) to the costs and benefits of alternatives for a specified set of people with "standing" (i.e., those for whom impacts matter) (Stanley et al., 2014). If a CBA indicates a positive net benefit of adopting EM, successful implementation is more likely than if the overall net benefit is negative. A sensitivity analysis that simulates a range of different costs and benefits for each component of an EM program can help to reduce decision-making ambiguity when costs and benefits are uncertain.

Quantitative evaluations of benefits and costs can help decision makers to decide which components of an EM system are necessary in order to achieve management goals. A CBA can help focus interest and analysis on actual data needs, and can be updated to balance the increasing complexity of data needs against the increasing incremental costs of data collection (Piasente et al., 2012; Stanley et al., 2014). A formal CBA was an integral part of the implementation process of EM in British Columbia's integrated groundfish fishery (see Snapshot 11). The Department of Fisheries and Oceans (DFO) conducted a CBA to analyze the costs of various configurations of the EM system, including video review requirements, against the benefits of these configurations in terms of their ability to achieve monitoring goals. This rigorous quantitative analysis led to a recommendation that fishermen's logbook records be considered the default catch record, and that this catch record be verified using review of video imagery. Fishery managers also conducted a CBA to analyze the net benefits of various monitoring system configurations for the implementation of EM in Australia's Eastern Tuna and Billfish Fishery (see Snapshot 15).

One of the major challenges in conducting a CBA is to objectively compare costs, which are often easy to quantify, with benefits, which are often difficult to quantify. For example, more intensive monitoring might be expected to create benefits associated with a reduction in stock assessment uncertainty, if this results in lower uncertainty buffers and higher allowable catch limits and thus more fishing opportunity and higher profits. However, this would require a sophisticated sensitivity analysis and projections to quantify. In cases where performance standards and objectives are clearly defined and rigid, cost-effectiveness analysis (CEA), which compares just the costs of alternative systems in achieving these objectives, can be conducted. A CEA does not attempt to assign a monetary value to expected benefits and may be more appropriate than a CBA during certain stages of some EM planning processes.

Evaluation and Refinement Through Iteration

As the EM program takes shape, fishery stakeholders should be kept apprised to ensure that what is being suggested is feasible and likely to succeed. In addition, equipment tests conducted by placing EM components on a small number of vessels, or tests of the entire EM program at a pilot scale (see Element 7), can inform the design of an efficient program. Although an initial monetary outlay to undertake the pilot will be required, testing can often result in future cost savings by discovering what works and what doesn't in the real world. All aspects of the EM program should be subject to evaluation and refinement to ensure ongoing effectiveness (see Element 9).

Element 6. Understand and Articulate the EM Value Proposition

Whether the integration of an EM system into a fisheries monitoring program is successful or not depends strongly on the perceived value of implementation by all participants. The value proposition is an articulation of the benefits of an EM system relative to the costs for managers and fishermen.

It is important to note that while many managers think of monitoring costs in terms of the dollars spent purchasing, installing and maintaining EM equipment, economic costs also include impacts on fishermen's time and/or revenue that arise from accommodating a particular monitoring system, and could include lost fishing opportunities or inefficient catch handling practices. The success of the EM program will therefore depend on the extent to which stakeholders and managers perceive that EM is less expensive with respect to all these costs than alternative monitoring options, and the extent to which EM is perceived to interfere with optimal fishing operations.

The way that monitoring costs are incurred can influence perceived costs and hence the EM value proposition. Human observers are expensive, ranging from $300 to $1000 per day in the U.S., and there are often logistical problems associated with deploying observers in fisheries that are spread over large geographic areas and/or are made up of small vessels on which space is at a premium. These logistical difficulties often result in lost fishing opportunities and lost revenue. However, the costs associated with human observers are linear over time—they depend more or less directly on how much time is spent onboard a vessel—and thus start off relatively low and increase constantly with fishing effort.

In contrast, while the overall costs of EM systems are often lower than those associated with human observers (McElderry et al., 2010; Kindt-Larsen et al., 2011; Bartholomew et al., 2018), EM comes with high upfront costs of purchasing the EM equipment and building the infrastructure needed to transmit, store and analyze EM data for management purposes. This often creates a perception that EM costs are too high, even when amortized costs are substantially lower than those of alternative monitoring systems capable of generating similar data (e.g., human observers). This perception is a common barrier to uptake.

Comprehensive reduction of monitoring costs (e.g., capital costs, operating costs and costs to fishermen associated with changes in fishing operations to accommodate the monitoring system) has been a significant driver of EM implementation in many fisheries including the U.S. West Coast groundfish trawl fishery (Snapshot 2), the U.S. New England and Mid-Atlantic mid-water trawl fishery (Snapshot 7), the Alaska halibut and sablefish fixed gear fishery (Snapshot 9), and Australia's ETBF (Snapshot 15).

In many fisheries, the logistical difficulties associated with deploying observers on small vessels spread over a large geographic area have been the main driver of EM adoption. For example, a mandate for monitoring by human observers in the U.S. Gulf of Mexico reef fishery was implemented in 2006. However, safety and logistical concerns have restricted the effective observer coverage rate to just 1% of fishing activity, far below the target rate (Snapshot 8). Safety and logistical concerns were also a main driver for the implementation of EM in the Canterbury set net fishery in New Zealand (Snapshot 17).

Cost concerns can also drive the design of particular components of an EM program, as in the British Columbia groundfish fishery. While the original idea in this program implementation was to review 100% of the video data for compliance, the high cost of doing so forced fishery managers and stakeholders to rethink this rule. Eventually, they decided to use the fishermen's own logbooks as the main catch record, which was then audited for accuracy using video data. This system was not only less expensive to operate due to lower review costs, but created fishermen buy-in to the data collection process, which in turn increased the accuracy of self-reported catch records (Snapshot 11).

Naturally, opposition to EM based on cost concerns can be reduced by shifting costs onto others—but deciding who should assume the costs of EM can create significant challenges, especially when scaling pilot projects up to fishery-wide implementation. Pilot project participants are often those fishermen that are most likely to benefit from the new technology. Expanding uptake to less willing participants, especially when costs are high and existing monitoring requirements are low, can be difficult (Sylvia et al., 2016).

Various cost-sharing arrangements have been made in response to the need to reduce costs of management entities and/or the industry, and to differing points of view regarding appropriate roles, responsibilities and beneficiaries of the monitoring program. For example, the way that monitoring costs are shared is significantly different between fisheries on the East Coast and West

Coast of the U.S. On the East Coast, and particularly in New England, NOAA Fisheries has traditionally paid for the majority of monitoring costs. In contrast, West Coast fishermen have assumed greater responsibility for monitoring costs. In both of these cases NOAA Fisheries and other government agencies continue to shoulder the costs of training observers, and federal grant programs are often used to fund EM pilot studies. In some fisheries, a strong case can be made that governments, acting on behalf of society at large, should share in the costs of EM to the extent that EM delivers social benefits. These benefits can be very significant, ranging from protecting endangered species to ensuring the sustainability of a nation's fishery resources.

Another way to reduce opposition to EM based on cost concerns is to provide government or NGO subsidies to cover the initial costs of EM system implementation. For example, full-scale implementation of EM was achieved in the US Atlantic pelagic longline fishery when the National Marine Fisheries Service procured funding to cover fishermen's costs of EM system installation (see Snapshot 6). Fishery managers are often keen to make fishermen responsible for their own monitoring costs but acknowledge that reducing this initial barrier to implementation is important. For example, in Australia's eastern tuna and billfish fishery (ETBF), the Australian Fisheries Management Agency (AFMA) covered the initial costs of EM system implementation, with ongoing costs of EM system operation slated to be recovered from industry (see Snapshot 15).

Element 7. Practical Learning Through Pilots

Almost all successful implementations of EM systems include equipment tests and pilot projects to ensure that the EM system is capable of achieving monitoring goals while not imposing onerous costs and inconveniences on the industry prior to fleet-wide adoption. Lessons learned from evaluating the pilots can then be applied to facilitate smooth implementation. Learning should occur throughout the EM implementation process, starting with a technical proof of concept to demonstrate that a particular EM system is feasible in the fishery and can achieve desirable results.

Pilot projects also play a significant role in building EM literacy among the fishermen who must use them (or at least interact with them). Even if a pilot project only involves a small portion of all fishery participants, experiences and lessons learned during the course of a pilot are often disseminated effectively as fishermen often communicate widely within a fleet.

Pilots must be designed to maximize learning, so it is important to include vessels with different infrastructure and operating conditions. Onboard observers, interviews and surveys can be used to gather feedback on how well the EM system is performing. The EM working group can then evaluate this feedback and make any necessary modifications to the EM system map or Vessel Monitoring Plans (VMPs) (see Elements 5 and 8).

Pilots are often implemented early on in the process when substantial investments in developing supporting infrastructure and institutional capacity have not yet been made. For example, the Ghanaian purse seine fleet participated in an EM pilot study in 2015 with the overarching goal of testing how EM could be used to monitor adherence to fishery regulations. While one of the goals of the pilot was to refine the system into a functioning EM system that could achieve monitoring goals in the fishery, another equally important goal was to design a legal framework under which continued use of the systems could be mandated (see Snapshot 19).

The EM program schematic (see Element 5) represents a theory of how the EM system could work in the fishery. The piloting process fits the theory to reality by installing EM equipment on a few vessels representative of the diversity of physical infrastructure in the fishery, and by making necessary modifications to the equipment or to how it is installed or operated. A particular EM tool (e.g., moveable cameras that reduce the need for multiple cameras) may look good on paper, but fail when actually placed on a working fishing vessel; thus testing of equipment, mountings and data transfer mechanisms is essential. The results of these tests can be used to develop VMPs that describe how EM equipment will be installed, maintained, repaired and used. Individual VMPs should result in the harmonization of the camera placements with fishermen's operations and behaviors, and vice versa.

It is important to note that a successful pilot project by itself is not a guarantee of success. For example, in the Atlantic haddock longline fishery, a successful pilot that indicated that EM was a feasible, less costly alternative to human observers did not translate into full-scale implementation. This was due to a lack of local infrastructure to support the EM program, a lack of fishermen's awareness of EM program requirements, and uncertainty regarding data-sharing agreements surrounding how data are collected and used (McElderry et al., 2004) (see Snapshot 5).

These examples and several other studies have found that EM results can be significantly improved when managers work with industry, particularly fishermen, to review catch and handling procedures to ensure that activity occurs within view of the placed cameras (Dalskov and Kindt-Larsen, 2009; McElderry et al., 2011; Piasente et al., 2012). As such, testing should occur well in advance of implementation and in a participatory manner to ensure that impact on fishing operations is minimized, and that barriers to effective monitoring that were unforeseen in the planning and design process are addressed.

Pilot projects often test only the obvious components of the EM program: onboard equipment that collect data, the removal of hard drives to transmit data to managers, and the video review process to determine data accuracy, for example. However, pilots should aim to test all program components, how they fit together, and how managers will use the data products. This can shed light on problems or opportunities to increase system efficiency that were unanticipated in the planning process.

While the costs of conducting pilot projects are non-trivial, pilots often enable participants to avoid costly errors during scaling and provide an opportunity to optimize equipment placements, catch handling procedures, data management and other program components prior to full scale implementation.

Element 8. Communication and Outreach

Participatory processes generally involve creating a variety of ways for fishermen and fishery managers to share their needs, concerns and knowledge. A participatory process that is transparent and engages all stakeholders is essential both for eliciting local knowledge critical to ensuring the effective design of the EM system, and for building support for it. A key component of undertaking a participatory process is to engage in an effective communications and outreach strategy.

Engaging Stakeholders

Stakeholder participation in the EM design and implementation process is critical for the overall success of EM, just as it is for any natural resource management program (Ostrom, 1990; Olsson et al., 2004; Reed, 2008; Campbell et al., 2010). Sometimes, participation is defined as consultation or attendance at a hearing. For EM program development, engagement and leadership that results in program acceptance, support and shared responsibilities are necessary. Stakeholders may be especially important for the identification of barriers to EM and developing ways to overcome them. When both internal barriers (e.g., deck operations that impede clear camera views) and external barriers (e.g., lack of industry buy-in) are identified and then managed or removed, successful programs result more frequently than when this is not the case (Battista et al., 2017). The process of bringing EM to scale (i.e., fleet-wide implementation) needs to be participatory to ensure that concerns are aired, heard and duly considered and that the design and implementation process is fair and inclusive.

Participation and leadership by multiple stakeholders, including fishermen, in the design and implementation process allows for a decision-making process that incorporates dialogue, feedback and compromise (Stanley et al., 2014). Fishermen's support for EM relies on two-way communication with fishery managers, and fisheries that commonly use participatory processes to support decision making will likely find that the resulting leadership and established collaboration patterns will facilitate EM adoption (Stanley et al., 2014).

If managers, industry and scientists are all at the same table to discuss priorities and tradeoffs, there is a higher probability that fishermen will take ownership of the process (Battista et al., 2017) and will continue to stay engaged, since the program will reflect and address their concerns (Johnson et al., 2004). For example, in the British Columbia groundfish fishery, fishermen supported EM partly because of an agreement to use logbooks filled out by fishermen as the main catch record, which are then checked using EM data (see Snapshot 11). Fishermen's participation in the design of the program ensured the system could achieve its goals while also aligning with fishermen's needs and preferences.

Changing behavior among fishery stakeholders is difficult, and good communication and processes that result in transparency and buy-in is key to providing managers and stakeholders with the knowledge, skills and motivation they will need to make the EM system successful. Fishermen and managers can be resistant to change, often for different reasons. Research in social and behavioral science sheds light on the mechanisms by which new innovations spread throughout a society or a group of people (Rogers, 1962; Granovetter, 1978; Prochaska and DiClemente, 1982; Moore, 2002). This body of research suggests that different individuals have varying "thresholds" in the number of their peers who must first adopt a new innovation or technology before they themselves will begin to use it. Different groups with different values, preferences and risk tolerances will look for different features in a new technology and will respond to different types of messaging about it (Rogers, 1962; Moore, 2002). Thus, a certain percentage of the population typically needs to adopt a new technology in order for it to take hold and become the norm when adoption is voluntary (Battista et al., 2017).

Stakeholders may be resistant to the adoption of a new technology, such as onboard cameras, due to a tendency toward tradition, firmly held perceptions and values, norms around being free while at sea, or due to opposition to being held accountable if no accountability measures have ever been previously in place in their fishery. They can also be concerned about confidentiality and how the data would be used if obtained by entities other than those for whom they are intended. Education that targets these perceptions, and outreach that strives to create an inclusive environment in which stakeholders can air concerns, can help to overcome these kinds of barriers. Where trust between fishermen and managers and/or scientists is low, efforts to rebuild trust (e.g., deeper dialogue about the reasons for distrust, consistent fulfillment of commitments, incorporation of fishermen's knowledge into assessments and rule-making processes) may be necessary to create an environment conducive to the planning of a major change such as a transition to EM.

Transparency in all aspects of design and implementation of an EM program is an essential feature of a successful monitoring program. EM may involve technologies and practices that are new and unfamiliar to fishermen and managers. Keeping decisions transparent, including where, when and how data are being collected and how they will be used for management, fosters buy-in and reduces fear of change. Historical issues with transparency have involved perceived "mission creep", where stakeholders believed that there was a push for more data than had been agreed to, and privacy concerns, where cameras were believed to record most or all aspects of living on the vessel (Sylvia et al., 2016). Resistance to EM implementation often stems from privacy concerns of fishermen who view EM tools as invasive. Often these opinions are based on incorrect assumptions about when and where camera imagery is recorded and who has access to the data (McElderry et al., 2003). To increase stakeholder buy-in and trust, the entire process of video review should be transparent and understandable to fishermen and potentially other members of the supply chain. To ensure transparency, EM plans should clearly define which, how much and when data are to be collected; how those data are to be used; who pays for which components of the system; and rules surrounding data ownership. A live stream of the video footage being gathered by the cameras that is viewable by fishermen (but cannot be tampered with) can also help alleviate these concerns.

An EM communications strategy developed by the EM working group (see Element 2), should identify the best means of communicating; this could involve sending out news or alerts via social media, email, text or other media that are checked regularly or used mainly for fisheries-related communications. Regular public workshops or webinars to educate the public and encourage stakeholder discourse can also be effective. For example, in the Atlantic pelagic longline fishery, public webinars were utilized during the successful fleet-wide implementation of EM and deemed essential for garnering stakeholder support (see Snapshot 6). The communications strategy should also spell out what information needs to be communicated and what topics require meetings or workshops. Topics can include EM terms and definitions, the benefits of EM, what would be lost if EM is not implemented or fails, what constitutes an infraction, how EM data will be used to detect infractions and other important points that are essential to communicate.

Vessel Level Communication

Once EM systems have been installed on vessels and are actively collecting data, regular two-way communication with captains and crew can help to improve system performance and strengthen fishermen's confidence in the monitoring system. Working with fishermen to troubleshoot potential problems (e.g., camera placements, lighting conditions, power supply) can lead to a more efficient implementation process and can improve data collection. If the EM program relies on fishermen's self-reported data, sharing fishermen's own performance (which may be checked using EM data) can help to motivate the collection of higher quality data.

Vessel Monitoring Plans

During pilot projects and initial implementation, EM service providers (see EM Resources) work with captains and crew to optimize the placement and use of EM equipment, as well as to figure out how best to operate the equipment on each vessel. This information is then described as part of a Vessel Monitoring Plan (VMP). However, VMPs do more than just detail these technical specifications—they often explicitly identify the specific responsibilities of vessel captains and crew; clearly define catch handling requirements; and provide a troubleshooting guide of "what to do if X happens". Several EM pilots have failed as a result of inexperience with fleets and management procedures, resulting in equipment that did not function optimally (McElderry et al., 2003). In an early pilot in the Alaska halibut fishery, 47% of EM trips experienced some or total data loss for a number of reasons, including poor camera placement and inadequate initial testing (McElderry et al., 2003).

Element 9. Implementation, Optimization, Evaluation and Adaptation

Much will be learned as fishermen, managers and EM service providers gain experience in a particular fishery. Moreover, certain conditions may change that have implications for the EM program. Regular evaluations of EM system performance with a focus on identifying problems and solutions will allow the EM system to remain effective. EM programs are difficult to design, and it is likely that the program will not achieve its full performance objectives at first. The implementation process is also a learning process; performance goals that were deemed achievable at the start may turn out to be very challenging. Alternatively, lofty goals may transform into smaller incremental objectives during the course of implementation. Ensuring that the process is iterative and adaptive from the start can help to maximize performance.

Adaptive management in this context is a process by which EM program performance is evaluated against predefined metrics of success, which drives changes to the program aimed at improving performance relative to these metrics. Adaptive management allows for risk management and requires leaders from all sectors (i.e., management, industry and science) to stay involved and proactive (Stanley et al., 2014). Ongoing program evaluation allows managers to demonstrate the tangible results of the program—which can help to garner further industry buy-in and support—and to develop and refine scaling strategies as needed (Battista et al., 2017). This can begin with something as straightforward as the testing process to determine optimal camera placement in order to ensure that EM coverage can be extended to all participating vessels, or determining whether regulations are too prescriptive and may slow or prevent the adoption of new technologies. An example of adaptive management unfolded over several years in the U.S. West Coast groundfish trawl fishery (see Snapshot 2). Exempted Fishing Permits (EFP) were granted for a variety of vessels in the fishery starting in 2004 and continuing up to the time of this writing. Fishermen partnered with various NGOs and service providers to develop an EM system for their fisheries. Throughout these partnerships, fishermen could focus on the business of installing equipment, fishing, recording data in logbooks and reporting back on the functionality of the EM systems. These "on-the-water" EFPs resulted in EM program design in situ, including the development of procedures for sorting catch, troubleshooting equipment and transmitting data. Additionally, the EFPs allowed managers and members of the Pacific Fishery Management Council to assess the feasibility of their scoping objectives, which informed the development of the regulatory program.

The adaptive management process requires metrics against which EM system performance can be evaluated, in order to drive adjustments. The metrics must be chosen carefully, as often "you get what you measure" rather than what you want. Metrics should be as closely related to EM system objectives as possible and include both process metrics (e.g., EM system architecture is completed and communicated, VMPs are completed, EM data are being transmitted to data users) and outcome metrics (e.g., bycatch, catch and discard limits are being complied with).

Building a Realistic but Motivating Timeline into the Process

A scaling strategy and timeline that specifies who is responsible for what and when should be defined at an early stage with specific, achievable targets; this can increase the chances of successful EM implementation. Several EM pilot studies have concluded that the technology used was capable of achieving monitoring objectives at the fishery-wide scale, but failed to result in full implementation due to a lack of a firm timeline for, and commitment to, scaling (see Snapshots 5, 8 and 13 for examples).

Defining a potential date by which full-scale implementation should occur can help to focus energy on the tasks necessary to achieve this, such as in the U.S. Atlantic pelagic longline fishery (see Snapshot 6). Managers cannot assume that scaling will automatically occur at the conclusion of a successful pilot (Battista et al., 2017), and a clearly defined, transparent timeline can act as a policy lever through which the regulatory agency can exert influence, and through which fishermen can hold fishery management entities accountable. In some programs, such as the U.S. Pacific groundfish fishery, EM implementation is occurring at a slow pace, partly due to a lack of willingness to maintain a timeline to scale up from the pilot studies.

While much will be learned about how to best install and operate EM equipment during the pilot study, still more will be learned as the entire fleet begins to use EM. Open communication channels for soliciting feedback and maintaining the capacity to efficiently authorize changes in VMPs, as well as in the EM system design itself in response to these changes, will be essential for optimizing the performance of the EM system.

EM DESIGN AND IMPLEMENTATION RESOURCES

The specific kinds of equipment and data processing methods that your EM system will require will depend on your fishery's goals, monitoring requirements and financial capacity, among other factors. This list of resources is intended to help you get started.

TABLE 4 | EM DESIGN AND IMPLEMENTATION RESOURCES

RESOURCE	DESCRIPTION	SOURCE
Archipelago Marine Research	A suite of EM tools including: EM Observe (video cameras, gear sensors and GPS create a profile of a vessel's fishing activity at sea); EM Record (data logging software that records key fishing operations – data is stored, no transmission); and EM Interpret (synchronizes all GPS, sensor and video data in a single timeline, designed for use by land-based reviewers).	Archipelago Marine Research: http://www.archipelago.ca/
Blackbox Video	EM system with cameras, hardware plus monitor, and Analyzer tool. System uses hard drives for primary and backup storage. Communication modules for 4G/LTE and WiFi are built into the main system and enable users of the Analyzer software to send messages to Black Box Video system.	Anchor Labs, Copenhagen: http://www.anchorlab.dk/BlackBox.aspx
Digital Observer Services	A fisheries consultancy and EM service provider that uses Satlink equipment, HD cameras and GPS systems. DOS analyzes the video information collected by the Satlink SeaTube system	http://digitalobserver.org/en/
Flywire EMS	EM camera system that is modular, easy to install and captures HD video, GPS and sensor data sets.	Flywire cameras: https://www.flywirecameras.com
Integrated Monitoring	EM camera system designed for wireless transmission of data (no removable hard drive capability).	https://integratedmonitoring.net/
Marine Monitoring	EM camera system that utilizes hydraulic sensors to activate video data collection. Offers bespoke solutions to individual fisheries.	Ecotrust Canada: http://ecotrust.ca/project/electronic-monitoring/
Saltwater inc.	Camera-based EM system provider based in Alaska.	www.saltwaterinc.com
Seatube	Camera-based EM system provider based in Spain.	Satlink: https://satlink.es/en/tracking-monitoring/satlink-seatube/
Shellcatch	Camera-based monitoring and electronic reporting capabilities through smart phone apps geared towards small-scale fishing vessels. Active in Latin America.	https://www.shellcatch.com/
Teem.fish	Camera-based EM system utilizing 360° cameras and a proprietary video review software program.	SnapIT HD: https://www.snapithd.com/

EM Cost Calculator Tool

In order to help fishery managers and stakeholders explore potential costs of monitoring in their fishery, EDF has created an EM cost calculator tool that categorizes potential costs of both camera-based EM and the use of human observers in a fishery. The tool reflects information collected for U.S. fisheries in 2017 and is not meant to provide an accurate estimate of monitoring costs, but rather to allow users to explore the impact of cost drivers on monitoring costs in their fishery. These cost drivers include physical fishery characteristics, such as number of vessels, geographic spread and isolation and gear types; as well as monitoring program standards such as video review rate, monitoring goals and storage requirements. The tool calculates, and allows comparison of, cost estimates for both a generic EM system and a human observer-based system.

The tool can be found at: http://fisherysolutionscenter.edf.org/resources

Figure 2 shows screenshots of: the main input page where fishery characteristics and program standards are inputted; a page that allows the user to decide who bears which types of cost; and a page of total cost estimates. All inputs and outputs in these screenshots are for illustrative purposes only and do not reflect the situation in any particular fishery.

FIGURE 2 | *Screenshots of EM Cost Calculator Tool*

Cost Drivers

Fishery Characteristics

Number of Fishing Vessels to be monitored in Fishery:	20	
Number of ports in fishery:	4	
Geographical Spread of Ports:	2	MEDIUM
Geographical Isolation of Ports:	2	MEDIUM
Number of Trips per Month	3	
Length of Each Trip (fishing days):	5	

Trawl Activity

Trawl Hauls per Fishing Day:	0
Length of each Trawl Deployment (Set to Haulback) (mins):	0
Length of Time from Haulback to All Catch in Hold (mins):	0

Longline Activity

Longline Hauls per Fishing Day:	0
Time Required for Longline Deployment per Set (mins):	0
Time Required to Retrieve each Longline Set (mins):	0

Pot Activity

Number of Pots per Fishing Day:	0
Time Required to Retrieve each Pot and Sort Catch (mins):	0

Gillnet Activity

Number of Gillnet Sets per Fishing Day:	1
Time Required to Retrieve each Set (mins):	240

Purse Seine Activity

Number of Purse Seine sets per fishing day:	0
Length of each Set (rings down to rings up) (mins):	0
Length of Time Required to Dump Catch (mins):	0

Program Standards

Monitoring Goals

Seabird / Marine Mammal Interactions	☑
Full Retention Compliance	☐
Protected Species Monitoring	☑
Catch + Discard Identification / Quantification	☐
Catch + Discard Length Measurements	☐

Observer Coverage

% of fishing days observed:	100

Electronic Monitoring

% of fishing activity recorded:	100
% of fishing activity ***recorded*** that is ***reviewed***	100

Data Storage

Number of years to store video data:	2
Accessible Storage Method:	☑ YES
Number of years to store raw observer data:	3
Observers on Federal Contract?	☑ YES
Video Data Chain of Custody Required?	☐ YES
Data Required After Each Trip?	☑ YES
Maintenance by Fishermen Permitted?	☐ YES
data generation per camera hour (GB)	0.25

Who Pays

At-Sea Observer Costs

Cost Category	Industry %	Government %
Program Management	0	100
Observer Deployment	100	0
Observer Gear Costs	0	100
Training and Certification	0	100
Data Transmission	100	0
Data Review/Processing	100	0
Data Storage	100	0
Vessel/Other Costs	100	0

Electronic Monitoring Costs

Cost Category	Industry %	Government %
Program Management	0	100
EM Equipment Purchase	100	0
EM Installation	100	0
EM Maintenance	100	0
EM Data Transmission	0	100
EM Data Review/Processing	0	100
EM Data Storage	0	100
Vessel/Other Costs	100	0

(Figure continued on next page)

FIGURE 2 | *Continued*

Cost Comparison (per vessel)

INTEREST RATE	5.00%								
EM COSTS	**Fleetwide Cost**	**Cost per Vessel**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**TOTAL 5yr COST**	**NPV of costs**
1. Program Management									
fee per vessel	42500	2125	2125	2125	2125	2125	2125	10625	11741.96641
2. Equipment Purchase									
a. base unit with 2 cameras	144000	7200	7200	0	0	0	0	7200	7200
b. extra camera	8000	400	400	0	0	0	0	400	400
c. power bank	16660	833	833	0	0	0	0	833	833
3. Equipment Installation									
a. labor	10000	500	500	0	0	0	0	500	500
b. travel	20000	1000	1000	0	0	0	0	1000	1000
c. lodging/per diem	5000	250	250	0	0	0	0	250	250
4. Equipment Maintenance									
a. labor	400	20	20	20	20	20	20	100	110.512625
b. travel	2000	100	100	100	100	100	100	500	552.563125
c. lodging/per diem	500	25	25	25	25	25	25	125	138.1407813
5. Data Transmission									
a. shipping costs	9792	489.6	489.6	489.6	489.6	489.6	489.6	2448	2705.34906
6. Data Review and Processing									
a. review hardware	3000	150	150	150	150	150	150	750	828.8446875
b. review software	12000	600	600	600	600	600	600	3000	3315.37875
c. training costs	4800	240	240	240	240	240	240	1200	1326.1515
d. reviewer time: seabird/marine mammal review	36000	1800	1800	1800	1800	1800	1800	9000	9946.13625
e. reviewer time:discard compliance review	0	0	0	0	0	0	0	0	0
f. reviewer time: protected species monitoring	144000	7200	7200	7200	7200	7200	7200	36000	39784.545
g. reviewer time: catch/discard identification/quantificatio	0	0	0	0	0	0	0	0	0
h. reviewer time: catch + discard length measurements	0	0	0	0	0	0	0	0	0
7. EM Data Storage									0
a. storage software/hardware/disks	5670	283.5	283.5	0	0	0	0	283.5	283.5
							TOTAL	**74214.5**	**80916.08819**

ASO COSTS	**Total Annual Cost**	**Cost per Vessel**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**TOTAL 5yr COST**	**NPV of costs**
1. Program Management									
b. briefing/in-season support	24555.44	1227.772	1227.772	1227.772	1227.772	1227.772	1227.772	6138.86	6784.215331
2. Observer Deployment									
a. deployment costs (inc. lodging/travel)	1930320	96516	96516	96516	96516	96516	96516	482580	533311.8257
b. gear costs	13000	650	650	650	650	650	650	3250	3591.660313
3. Observer Training + Certification									
a. personnel	18408	920.4	920.4	920.4	920.4	920.4	920.4	4602	5085.791003
4. Data Transmission									
a. satellite transmission costs	36000	1800	1800	1800	1800	1800	1800	9000	9946.13625
5. Data Review + Processing									
a. debriefing personnel	73666.58	3683.329	3683.329	3683.329	3683.329	3683.329	3683.329	18416.645	20352.71783
6. Data Storage									
Warehouse storage for observer forms	7200	360	360	360	360	360	360	1800	1989.22725
7. Vessel Costs									
a. value of missed fishing opportunity	24012	1200.6	1200.6	1200.6	1200.6	1200.6	1200.6	6003	6634.072879
							TOTAL	**531790.505**	**587695.6466**

SUMMARY AND CONCLUSIONS

Monitoring can dramatically improve the economic and conservation performance of almost any fishery; yet, only a small fraction of the world's fisheries is currently monitored. Among other reasons for this reality, many fisheries lack policy or regulatory drivers for monitoring; expertise in designing and implementing monitoring systems; and/or the resources to pay for monitoring.

Numerous pilot studies and fleet-wide implementations show that EM can generate high quality, cost-effective monitoring data for fisheries management in fisheries that have the requisite infrastructure and resources; still, they also illustrate the challenges that must be overcome. This guidebook is aimed at providing guidance on how to design and implement an EM system (summarized in Table 5), drawn from 20 case studies of EM testing and fleet-wide implementation (Appendix).

Fisheries that have successfully adopted EM have enjoyed significant benefits, including costs savings compared to existing monitoring systems (Snapshots 1,2,6,9,15,19); increased capacity to monitor fisheries (Snapshots 4,8); improved data streams for management (Snapshots 11, 18); greater stakeholder buy-in to the management process (Snapshot 11); and increased revenues (Snapshot 12). There is also potential for fishermen to use intensive monitoring to gain access to markets that are predicated on demonstrated performance against sustainability standards.

Successful EM systems are developed by fishery managers and stakeholders who are sufficiently motivated to collect high quality, high resolution data in order to satisfy statutory or regulatory mandates; achieve fishery management goals; increase compliance with regulations; or avoid high costs associated with failing to achieve management goals, such as a fishery closure. They are designed by cohesive groups of people with the requisite skills and perspectives to articulate clear monitoring goals, integrate the EM system with existing monitoring tools and make good choices about equipment and processes that keep costs reasonable while ensuring good system performance. These groups work to reduce costs without compromising performance, and develop a compelling business case showing that EM costs will be reasonable relative to alternatives and won't unduly interfere with fishing operations. They test EM equipment and work with the industry to figure out the best locations and method of installing cameras, lights, sensors and other hardware. They often pilot the EM system and evaluate its performance prior to fleet-wide implementation, in case any modifications are necessary, and continue to evaluate and adjust as necessary after implementation. Finally, they maintain communication with stakeholders from the beginning of the process by organizing participatory forums and using favored communication channels to make the EM design and implementation process transparent and trustworthy.

The specific challenges that must be overcome in order to implement an EM system will vary from fishery to fishery. However, our review of EM systems revealed some common challenges such as lack of sufficient motivating drivers for EM, high perceived costs, fear of changes that might be needed in fishing operations or in fishery management processes, and privacy concerns. Guidance on how to overcome these challenges is included in the design and implementation steps we articulate in this guide, in the hope that more fisheries can adopt EM or other monitoring systems (Fujita et al., 2018) and reach their full potential for producing food, revenue and livelihoods, while protecting ocean ecosystems and wildlife.

TABLE 5 | THE EM DESIGN AND IMPLEMENTATION PROCESS

ELEMENT	OUTPUTS/OUTCOMES	ACTIVITIES
1. Motivate EM Adoption	Informed and motivated stakeholders	Identify or create a social, regulatory or statutory commitment to EM
		Design communications and meetings to inform and motivate stakeholders
2. Assemble an EM Working Group	Cohesive working group with the right skills and perspectives for designing the EM system	Identify necessary skills and perspectives
		Recruit working group members
3. Set Clear Objectives	Clear objectives for the EM system	Review fishery management objectives
		Identify gaps in data streams necessary for achieving objectives
4. Establish Governance for the EM Program	Program delivery plan	Define roles and responsibilities for each aspect of the EM program
5. Design and Optimize the EM Program	EM system diagram showing the components of the EM system and how they relate to each other, and with other monitoring programs	Identify EM system components
		Articulate how existing monitoring elements will interact with the EM system
		Specify infrastructure requirements
	Initial specification of EM equipment, data management and rules for data use in making enforcement and management decisions	Review equipment options and make choices based on capabilities, cost, fit with fishery infrastructure and operations and other considerations
		Describe how data will be analyzed and used for decision making
		Develop service model specifying who will oversee the EM system and how EM services will be provided
6. Understand and Articulate the EM Value Proposition	Stakeholders understand the value of EM	Identify costs and benefits relative to other monitoring options
7. Practical Learning Through Pilots	EM equipment is tested and deemed feasible; gaps in the EM program are identified and filled	Install equipment on a few representative vessels
		Evaluate equipment performance and data processing; modify as needed
8. Communication and Outreach	Stakeholders are well informed about and support the EM system	Identify key audiences and favored communication modes
		Develop key messages
		Identify issues that will require workshops
9. Implementation, Optimization, Evaluation and Adaptation	EM equipment is installed fleet-wide and provides sufficient data for management and enforcement, with ongoing evaluation and adaptation	Retain vendors and personnel
		Install EM equipment
		Analyze and apply EM data

Appendix: EM Snapshots

1. U.S. HAWAII LONGLINE FISHERY

In the United States, the National Marine Fisheries Service (NMFS) is committed to the use of electronic technologies to collect timely, cost-efficient data that are needed to manage federal fisheries, with implementation plans for electronic technologies developed in all fishery management council regions.

The state of Hawaii is home to a valuable longline fishery that is made up of two distinct sectors: a shallow set longline fishery, which primarily targets swordfish, and a deep set longline fishery which targets tuna species. The longline fleet is composed of relatively small vessels (average 70ft in the shallow set sector; 76ft in the deep set sector) that go out for extended trips (17-20 days in the shallow set sector; 20-30 days in the deep set sector). These fisheries are highly monitored, with Vessel Monitoring Systems (VMS) required on all longline vessels, and a requirement for 100% observer coverage in the shallow set sector and 20% in the deep set sector. The main goals of the observer program in the longline fishery are to collect counts of target and non-target species captured, counts of hooks used, and to document interactions with seabirds, sea turtles and other protected species.

The observer monitoring program is expensive to operate and logistically difficult to maintain for both fishermen and managers. These factors, combined with strong political will to improve transparency in the fishery, led to a 2009 pilot project to determine whether camera based EM systems could be used to augment the observer program, increase the accuracy of data collected by both observers and fishermen, and replace some observers altogether. Project planning began in December 2008 with a conference call between call between Western Pacific Fishery Management Council members (WPFMC), the Hawaii Longline Association (HLA; a longline industry group) and Archipelago Marine Research (AMR). In this initial meeting participants discussed project goals and timeline, vessel technical requirements, observer coverage levels, communication strategy and goals, and availability of financial resources. With close assistance from the HLA, a pool of vessels volunteered to participate in a pilot, and the WPFMC identified a local partner that could provide technical support and otherwise service the EM system. In August, 2008 a Request for Proposals was issued by the WPFMC and AMR was selected as the project contractor by a steering committee appointed by the WPFMC.

In January 2009, AMR began installation of an EM system on two shallow set and one deep set vessel, consisting of four cameras, a GPS receiver, hydraulic pressure sensor, winch sensor, satellite modem and system control box. The winch and pressure sensors were used to distinguish vessel activities and trigger image capture during fishing operations only. The benefits of this decision were twofold: (1) it increased the percentage of fishing sets operations captured by video over that of a manual system that had to be turned on during each operation, and (2) fishermen felt more comfortable that the cameras recorded imagery only during fishing activity, rather than 100% of the time.

The goals of the pilot study were clearly defined from the outset: 1) to determine if this configuration could provide images of sufficient resolution and clarity to allow an EM image reviewer to accurately record counts of hooks, target species and non-target species; 2) determine if the EM system could allow an EM image reviewer to identify fishing interactions with sea turtles, marine mammals and seabirds, as well as hooking location and release condition; and 3) compare the results of the EM process to those generated by human observers onboard (McElderry et al., 2010). The pilot study was operational for a six-month period translating to a combined total of 320 days at sea, and collected 3000 hours of video data spanning 150 hauls. Overall results were positive, with the EM system able to determine the time and location of fishing more accurately than the human observers, generate hook counts that closely aligned with human counts, and perform just as well at identifying interactions between the longline gear and sea turtles and seabirds. The camera system was less able to generate accurate identifications of target and non-target catch species, as well as discards, which often happened out of camera view. Because implementation costs were not analyzed, and because it was not clear how the EM system could be integrated with the existing observer program, further implementation was not pursued at the time.

Recommendations that came out of the pilot study included improvements to camera placements, an increase in the number of cameras installed, and improvements in the design of structured catch handling protocol. Along with a 2015 analysis of monitoring costs, and taking into account these lessons from the initial pilot study, NMFS moved forward in June 2016 with a phase-in of EM, starting with installation of EM systems on six vessels and a proposal to review 35 longline trips from those vessels in 2017 (WPFMC, 2017). The observer program is working closely with the WPFMC to design the EM system to augment observer protocol; currently the EM system is installed on 19 vessels, and the number continues to increase.

2. U.S. WEST COAST GROUNDFISH TRAWL

The U.S West Coast groundfish fishery operates from ports in Washington, Oregon and California, and targets a range of groundfish species including Pacific whiting and pelagic rockfish species with pelagic trawl gear; a variety of rockfishes, flatfish species such as dover sole, and other demersal fish with bottom trawl gear; and sablefish with pot and longline gear. The fishery has historically been regulated by annual Total Allowable Catches (TACs) for many of the approximately 90 species in the fishery management plan, which required accurate accounting for landings and at-sea discards. Throughout the 1990s and early 2000s several stocks of rockfish were being overfished, which led to increasingly stringent management controls such as trip limits. This motivated fishery managers to monitor catch of specific species quite precisely. In the whiting fishery, this led to a prohibition of discarding at sea, as well as implementation of a human observer monitoring program to verify each vessel's compliance with retention regulations.

Concern over the potential for the fishery to be shut down due to overfished species interactions, combined with high costs of human observers and the challenge of synching observer capacity with monitoring requirements across six ports up and down the West Coast, led the 35 vessels that participated in the shoreside whiting fishery to turn to EM. In 2004, NMFS issued Exempted Fishing Permits (EFPs) to vessels in the shoreside whiting sector that exempted them from human observer coverage requirements if an EM system that could ensure compliance with regulations was utilized. The goal of the EFP program was to develop a cost-effective approach for at-sea monitoring in the shoreside whiting fishery that could: 1) verify maximized retention of catch; 2) confirm that fishing occurs only in permitted areas; and 3) verify catch records provided by vessel captains. Archipelago Marine Research (AMR) designed, installed and serviced the EM systems, which consisted of up to four video cameras; winch and hydraulic sensors; a GPS receiver and a control box. Data were reviewed by AMR reviewers and supplied to NMFS and industry on a regular basis. The program was funded primarily by industry at an average cost of approximately $180 per sea day, which corresponded to an approximately 50% cost savings. The EFP program was a resounding success from 2004-2010, with the successful profiling of over 96% of fishing activity, favorable comparisons to observer-based monitoring and a 90% reduction in discarding

However, in 2011, the U.S. West Coast groundfish trawl sector transitioned to an Individual Fishing Quota (IFQ) program, which included a requirement for 100% observer coverage of fishing activity. This brought an end to the

EFP program for EM in the whiting fishery and brought the use of human observers to the forefront in the larger trawl fishery. The cost of observer-based monitoring, which reached approximately $500/day/vessel in 2015, was subsidized by NOAA for the first three years, gradually transitioning full cost to industry by 2016.

In anticipation of transitioning monitoring costs to industry, the Pacific Fishery Management Council (PFMC) began a scoping process to develop an EM program starting in 2012, primarily to reduce high observer-based monitoring costs without compromising the quality and richness of monitoring data. In April 2013, the PFMC indicated that compliance monitoring (which could feasibly be done using EM technologies), rather than the collection of biological data (which would need to be collected by human observers), would be the primary focus of monitoring in the IFQ program.

In order to address the ballooning costs of human observers, the whiting industry, building on their previous experience with EM, began requesting that EM be permitted as a monitoring tool in the fishery. With input from industry and others, the PFMC defined a purpose and need, and a set of EM objectives, for the different gear sectors in the IFQ fishery (e.g., whiting, fixed gear and bottom trawl). In September 2014, the PFMC approved four EFP applications for the 2015-2018 fishing seasons that would allow vessels to use EM as the compliance monitoring tool while fishing in lieu of a human compliance monitor. The EFP process was implemented, as there was not yet a functional EM model for a multi-species IFQ fishery. A total of four industry groups (whiting, fixed gear, and two bottom trawl) submitted EFP applications and were approved for EM testing during the 2015-18 fishing seasons. These groups used a basic framework for EM as agreed upon in their EFP contract with NMFS, which included submitting logbooks on catch and discard that that were then verified by review of video footage. EDF partnered with The Nature Conservancy (TNC) and a group of trawlers and fixed gear vessels from the California Groundfish Collective (CGC) to fund the purchase of seven EM camera systems, contract with an EM service provider for installation and work with NOAA on the terms of the EFP. Through this partnership, fishermen could focus on the business of installing equipment, fishing, making logbook entries and reporting back on the functionality of the EM systems. The result of these "on-the-water" EM EFPs was a functional design of EM systems in situ, and the implementation of procedures for sorting catch, troubleshooting equipment and data transmission. Additionally, the EFPs allowed managers and members of the PFMC to assess the feasibility of their scoping objectives, which fed into developing the regulatory program. The EFPs also established a process for providing feedback between skippers and the reviewer to improve accuracy and review time. As of this writing, the EFP vessels are preparing to transition from the EFPs to the EM regulatory program, which is set to be implemented in 2018 for fixed and whiting sectors, and in 2019 for the non-whiting bottom and midwater trawl sectors.

3. U.S. PACIFIC DRIFT GILLNET FISHERY

The Pacific drift gillnet fishery, which targets swordfish, suffers from high bycatch issues and was recently the subject of hard caps on individual animals that can be injured or killed before a fishery closure is implemented. In 2016, the PFMC voted to require 100% monitoring of fisheries operations and included a provision that would allow the use of EM systems as an alternative to human observers. The stated monitoring need is to document bycatch and protected species interactions in the drift gillnet fishery.

Even with the mandate for 100% monitoring in the fishery and the engagement of a large NGO in EM implementation—The Nature Conservancy (TNC) received a federal grant to conduct EM research in the fishery in 2016—industry support for EM has been virtually nonexistent. A proposed EFP to engage industry in the development of EM, coupled with funds provided to TNC to advance EM in the fishery, has seen a lack of interest, with TNC unable to secure any participants. Testing of EM in the fishery is needed to determine whether monitoring goals can be achieved at reasonable cost, but without industry buy-in, little progress has been made to date.[1] In August 2018, the California State Legislature passed a law banning the use of large (more than 900ft) drift gillnets in this fishery, due mainly to pressure from environmental groups that protested the high bycatch rates of sea turtles and marine mammals. Federal legislation to ban these gears off the coast of California was also introduced in 2018.

4. U.S. NEW ENGLAND GROUNDFISH TRAWL AND GILLNET

The New England groundfish fishery targets bottom-dwelling species (e.g., cod, haddock, flounder) using trawls and gillnets, among other gear. In 2010, the New England Fisheries Management Council (NEFMC) implemented a system of "sector" management which allocated shares of the TAC for a variety of species to groups of fishermen, and instituted new accountability measures to ensure that catch limits are not exceeded. Fishermen in sectors are required to self-report the amounts and species of all fish that are kept and discarded, and are also subject to onboard monitoring by fishery observers. Vessels in New England vary greatly in size, operate out of a variety of ports that are spread out over a large geographic area, and conduct trips that last between a few hours and several days. These characteristics of the fishery, in addition to an entrenched mentality on the part of fishermen that have a long history in the region, have contributed to a relatively low observer target coverage percentage of 14% in recent years; actual coverage is much less than this in practice. To compound this low coverage rate issue, and due mainly to fishermen's reluctance to carry observers, NMFS has paid for the costs of observer coverage since 2010, although they have recently started to transfer responsibility for a portion of monitoring costs to fishermen. These considerations have accelerated the consideration of EM as a monitoring tool in New England fisheries.

From 2010-2013, NOAA conducted a feasibility study in conjunction with Archipelago Marine Research (AMR) to test the suitability of EM systems for providing an independent estimate of catch and fishing effort in the New England fishery. This project was designed to be applied in a variety of ports and on a variety of fishing vessels to account for the wide range of these characteristics in New England. This pilot study was successful, showing that EM could be used to provide comprehensive and cost-effective monitoring.[2]

This pilot study was followed up in 2013 by a three-year collaborative project between The Nature Conservancy (TNC), the Maine Coast Fishermen's Association (MCFA), the Gulf of Maine Research Institute (GMRI) and Ecotrust Canada. The overarching goal of this project was to determine if EM could be used to collect information on catch and discards that would achieve monitoring goals cost-effectively, and in a way that did not interfere with fishing operations. Two primary objectives that derived from this overarching goal were to assess the feasibility of identifying groundfish species using EM, and make accurate length estimates of individual fish discarded at sea. To achieve these objectives, EM systems were installed on three trawl and five gillnet vessels, and video footage was collected on more than 150 fishing trips. Trained video reviewers analyzed a percentage of hauls completed on these trips each year to verify the accuracy of self-reported discard estimates; this "audit" approach is potentially more cost-effective than making a census of all video data.

The collaborative nature of the pilot project ensured that many of the project objectives were met, even in as

1 https://usa.oceana.org/blog/fishery-managers-move-clean-california-swordfish-drift-gillnet-fishery

2 http://blogs.edf.org/edfish/2013/09/27/effective-monitoring-is-critical-for-the-new-england-groundfish-fishery/

challenging an environment as New England. The success of this project encouraged NMFS and the NEFMC in 2016 to approve an Exempted Fishing Permit (EFP) that authorized up to 20 fishermen in groundfish sectors to utilize EM systems in lieu of human monitors. This project came about due to a setback in early 2016 when industry interest in supporting EM—and monitoring in general—decreased, resulting in a significant reduction in industry participants. Project partners adapted and requested a shift to an EFP where participating vessels would use EM instead of at-sea observers for those trips on which they had been selected for observer coverage. The project is now focused on key issues that have been identified by project partners, which include creating incentives for fishermen to participate in monitoring programs, improving integration of EM data into NMFS databases and reducing the cost of video review by developing mechanisms for an audit-based review process. However, a low observer coverage target level has resulted in a mere six vessels participating in the EM project, with fewer than 20 trips monitored using EM. The lack of mandatory EM requirements and an ambivalence towards EM in the larger fishing community, have been identified as contributing factors to this modest participation level.

5. U.S. NEW ENGLAND LONGLINE

The Cape Cod Commercial Hook Fishermen's Association (CCCHFA) is a nonprofit industry group that works to promote sustainable fishing initiatives. In the early 2000s, there was significant interest in developing a longline haddock fishery on Georges Bank that minimizes the bycatch of cod, which are highly regulated in the North Atlantic. Fishery managers identified a 50% observer coverage rate as a target that could achieve a monitoring goal of demonstrating low rates of cod capture in the new fishery. While the CCCHFA recognized the need for adequate monitoring of the haddock fishery, there were substantial industry concerns about accommodating the proposed rate of observer monitoring, due to logistics and cost issues. Many of the vessels in the fishery are small day boats with limited space to accommodate a non-crewman.

In response, the CCCHFA contracted Archipelago Marine Research (AMR) to test EM as a method of monitoring catch in the haddock fishery. EM systems were tested onboard four fishing vessels over a three-week trial period, and consisted of two cameras, a hydraulic pressure sensor, a GPS receiver and a control box. Observers were placed on most EM trips and performance of the two systems was compared; the EM system was found to provide sufficient temporal and spatial information on fishing activity, and broadly comparable catch data, with EM catch estimates within 5% of observer estimates.

Although the pilot study's positive results indicated that EM could be a feasible alternative to human observers, a lack of local infrastructure to support the EM program, a lack of fisherman awareness surrounding program requirements, and uncertainty around data sharing agreements that address how data are collected and used have hindered full-scale implementation (McElderry et al., 2004).

6. U.S. ATLANTIC PELAGIC LONGLINE FISHERY

The Atlantic Highly Migratory Species (AHMS) fishery management program spans five distinct fishery management council regions from Maine to Texas, and the Caribbean. The AHMS program strives to maximize resource sustainability and fishing opportunities while minimizing adverse socioeconomic impacts, and is also responsible for implementing management actions deriving from the International Commission for the Conservation of Atlantic Tuna. The trans-boundary nature of the management program was designed to address difficulties in coordinating management actions among five different management councils. The fishery is managed under the Highly Migratory Species (HMS) fisheries management plan, which, as required by the Magnuson Stevens Act, is designed to stop overfishing of all species in the plan.

The Atlantic pelagic longline fishery is composed of 136 vessels (110 of which are currently active) that operate over a large geographic area, targeting swordfish and tuna species. Accounting for fishing mortality of all species in the fishery has been a significant issue with limited monitoring protocol in place until recently. In 2012, however, concerns surrounding tracking bluefin tuna mortality, which were considered overfished at the time, spurred NMFS to initiate Amendment 7 of the HMS plan. This amendment included a mandate for the creation of an individual bycatch quota system (including for bluefin tuna) and mandatory EM system implementation to support data collection for the system (Atlantic HMS, 2014). The Environmental Impact Statement (EIS) accompanying the proposed amendment presented a clear timeline of events and milestones, including an implementation date of late 2014 (NMFS, 2014). Even though the timeline was relatively short, NMFS extended the comments period due to the complexity of the issue, and a government shutdown notwithstanding, NMFS published the final rule to implement Amendment 7; EM became a fishery-wide requirement on June 1, 2015 (NOAA Fisheries, 2015). This represented the first fleet-wide implementation of EM in the United States.

When Amendment 7 was initiated in 2012, the goal of the EM program was to provide an effective and efficient way to monitor and verify Atlantic bluefin tuna catches in the pelagic longline fishery. To accomplish this goal an audit approach was selected, where EM review would verify the accuracy of counts and identification of bluefin tuna reported in logbooks by the vessel captain. A long-term goal is to improve the estimation of fishing effort and catch data in the fishery.

Major challenges were identified by NMFS and the AHMS program; among them a limited willingness on the part of the fishermen to have the system installed on their vessels, and concerns regarding the potentially high cost of purchasing and installing the system. To address the first challenge, in late 2014, NMFS conducted a series of very effective informational webinars that were designed to educate industry and the public on Amendment 7 requirements and what the practical implications were to industry. The second challenge was overcome by NMFS procuring funding for the installation of EM systems on all 136 qualifying vessels (estimated to cost approximately $2 million), as well as EM data storage and analysis for the initial years of the program. During the educational webinars, it was made clear to vessel owners that they would be responsible for the costs of installing a hydraulic sensor component of the EM system, as well as the ongoing costs of shipping hard drives to NMFS for analysis.

While Amendment 7 came into effect in early 2015, the EM requirements were activated in June, which allowed time for EM to be installed on vessels at 12 different ports along the eastern seaboard, and to allow fishermen and managers to become familiar with the system. This focus on flexibility and adaptability has been a common theme in the first three years of the program.

7. NEW ENGLAND AND MID-ATLANTIC MID-WATER TRAWL

In 2014, the New England Fishery Management Council (NEFMC) and the Mid-Atlantic Fishery Management Council (MAFMC) initiated action on an Industry Funded Monitoring (IFM) amendment designed to shift a portion of monitoring costs onto industry. As part of this omnibus amendment, particular interest has been shown in developing a monitoring program for the Mid-Water Trawl (MWT) fishery that targets herring and mackerel on the east coast of the United States. The fishery catches high volumes of herring and mackerel as well as bycatch of haddock, river herring and shad, which are subject to "hard" catch limits. Catch accounting of Atlantic herring and these sensitive bycatch species is limited.

Due to the perception that observers are expensive and logistically difficult to accommodate, and may not be the most cost-effective method of monitoring fisheries that retain and land the vast majority of their catch, there was widespread industry and environmental advocate support for exploring new, cost-effective monitoring systems, including EM. In response, NMFS contracted with Saltwater Inc. on a pilot project designed to evaluate the utility of a combination of EM and port samplers to monitor catch retention, identify at-sea discard events and perform catch accounting in the MWT fishery from August 2016-January 2018.

Twelve MWT vessels, comprising almost the entire fleet, volunteered to participate in this study and have EM systems installed The monitoring plan involved video footage being recorded throughout the duration of the trip with all video data being reviewed manually. While this initial plan was relatively resource intensive, the stated goal of the program was to allow for refinement and adjustment of monitoring protocol. Indeed, this pilot project has helped to identify the critical factors needed to support an operational EM program in the MWT fishery and has provided a reference case on which to base system improvements. For example, some issues with cameras not being able to reliably identify discard events were identified and are being addressed in future implementations by the adaptive design of catch handling protocol and individualized vessel monitoring plans. Early collaboration between all data users was identified as an essential component of planning.

Another outcome of the pilot was the development of industry interest in understanding ways of avoiding species that are not desirable. This has led to the development of a further project that utilizes echo-sounders to better identify species composition before the trawl net is deployed. This new project, which involves three additional vessels and is slated to commence in 2019, is utilizing catch composition estimated by the EM monitoring system as an input.[3] Overall, the successful pilot project indicates that EM and port sampling can achieve monitoring goals in the MWT fishery. At a larger management scale, experience from the pilot will help to inform further development of EM in the region and the refinement of the IFM Amendment.

8. U.S. GULF OF MEXICO REEF FISHERY

The commercial reef fishery in the Gulf of Mexico (GOM) consists of approximately 890 permitted vessels. Main target species are groupers and snappers, caught with bottom longline, vertical line, and modified buoy gear. There has been concern regarding the stock status of many species for several decades, and in November 1984, a fishery management plan was implemented, in part to rebuild declining fish stocks. Regulations have grown increasingly stringent in the intervening decades, with size and landing restrictions implemented on various reef fish species and TACs on grouper species. Following Amendment 22 to this fishery management plan that dictates mandatory observer coverage of fishing activity, NMFS, in collaboration with the Gulf of Mexico Fishery Management Council (GMFMC), implemented an observer program for the fishery in 2006.

The overarching goal of this observer program is to provide quantitative fishing effort and biological information on the fishery which can be used for the management of the fishery. Specific objectives are to: 1) provide fishery bycatch characterization of finfish species, 2) estimate finfish discard and release mortalities, and 3) estimate protected species bycatch quantities. Due to the small size of most vessels, which has led to observer safety concerns, the realized observer coverage percentage in the fishery

3 https://www.fisheries.noaa.gov/feature-story/electronic-monitoring-tech-applications-mid-water-trawl-herring-fishery

is approximately 1%. This, along with a limited logbook system where only 20% of fishermen are selected to report information on discarded catch, has led to NMFS exploring EM as a possible monitoring tool in the southeast region (Pria et al., 2008).

In 2008, a pilot project to investigate the use of EM in the longline fishery was conducted. EM systems were installed on six vessels over 148 days at sea and consisted of three cameras, a GPS receiver, a hydraulic pressure sensor, a winch sensor and a control box. The goal of the pilot study was to assess whether EM could provide sufficient monitoring capabilities to fulfill the goals of the observer program. Observers were deployed on study vessels and EM data were compared to observer data for a total of 218 fishing events. While the overall performance of the EM systems was positive and showed potential, institutional funds to expand the program are limited; given that the fishery does not generate sufficient income for industry to feasibly self-fund the program, further EM implementations were not explored.

9. U.S. ALASKA FIXED GEAR HALIBUT AND SABLEFISH

The North Pacific fishery for halibut and sablefish is a highly regulated, extremely valuable fishery composed of relatively small (40-60ft) boats using longlines and pots to catch high value halibut and sablefish. There are limited sustainability concerns in the fishery, but monitoring levels have historically been relatively low due to observers only being required on vessels of more than 60ft in length. This changed in 2010 when the North Pacific Fishery Management Council (NPFMC) voted to restructure the observer program, mandating vessels as small as 40ft to carry observers, and requiring that observer costs be paid by the industry. This implementation was scheduled to begin in early 2013. At the same time, and in response to effective and motivated stakeholder testimony, a motion was approved to develop EM as a tool for fulfilling observer requirements in the halibut and sablefish fixed gear fisheries.

A coalition of industry associations representing small vessels from a range of communities across Alaska worked together to ensure that EM would be available as a viable alternative by the time the new observer rules were scheduled to be implemented. In 2011, these industry associations, in collaboration with the Alaska Fisheries Science Center (AFSC) and Archipelago Marine Research (AMR) and funding from the National Fish and Wildlife Foundation (NFWF), launched a two-year pilot program to develop EM. The role of the AFSC was to provide project design advice, and at their request the primary objective of the pilot program was to use EM to provide an independent estimate of catch amounts and composition, and particularly at-sea discards, on small (less than 60ft) longline vessels. This initial pilot program was a resounding success, with data collected through the program assessed to have met the overarching project goal of providing a reliable independent estimate of total catch. In addition, the EM system was tested on a wide range of vessels and fishing behaviors, and was estimated to be more cost-effective than the use of human observers.

In 2015, various stakeholders, led by the Alaska Longline Fisherman's Association, received funding from NFWF to operationalize and fully implement EM in North Pacific fixed gear (pot and longline) fisheries. The main consideration for this phase was to build industry consensus on vessel responsibilities when carrying an EM system. Funding has been secured to help vessels with the initial implementation costs, and a funding model has been designed to ensure a smooth transition to industry funded monitoring in the future. The original project partners, including the Pacific States Marine Fisheries Commission (PSMFC), which is involved in testing and refinement of video review practices for the fishery, are again working together to achieve their common goals. This collaborative, well-planned process has led to NMFS publishing a proposed rule to integrate EM into the North Pacific Observer Program, which after the initial comment period, is due to become fully implemented in 2018.

10. U.S. ALASKA CATCHER PROCESSORS COMPLIANCE MONITORING

Examples of a purely regulatory driven implementation of EM exist in the Alaska groundfish fishery. Fishery regulators have implemented EM on catcher processor vessels to verify compliance with regulations for catch sorting and weighing. EM has been implemented in the American Fisheries Act (AFA) pollock fishery, Gulf of Alaska (GOA) rockfish fishery, Amendment 80 flatfish fishery, and the Pacific cod freezer longline fishery in the Bering Sea. All vessels that participate in these fisheries are subject to 100% observer coverage and electronic reporting requirements for in-season management.

Even though vessels are already subject to high levels of monitoring, EM is being used as a tool to ensure the effectiveness of observer sampling. In the AFA pollock fishery, cameras are being used to verify that salmon bycatch have been sorted and stored properly to enable observer sampling. In the GOA rockfish fishery and Amendment 80 fishery, EM is being used to ensure that catch is not sorted before observer sampling. In the Pacific cod longline fishery, EM is being used to ensure that all cod caught (and only cod) are passed over a motion compensated flow scale. All of the vessels participating in these fisheries are highly profitable and business-oriented, and have a long history of monitoring in the fishery. In these cases, EM implementation can be mandated by regulators and the main consideration in implementation is ensuring that the EM process is well integrated into catch handling and sorting behavior.

11. BRITISH COLUMBIA GROUNDFISH FISHERY

Between 1990 and 2006, Individual Vessel Quota (IVQ) systems were implemented in various sectors of the groundfish fishery in British Columbia, Canada, eventually resulting in the integration of all groundfish sectors under a single management plan. The main driving force behind this effort was the need to rebuild the overfished yelloweye rockfish stock and improve the waning economic performance of most sectors of the fishery. A key component of this program was the design of a monitoring system that could generate accurate catch data that could be used for in-season management. The monitoring program also had to be designed in a way that instilled confidence that other fishermen could not cheat the system, thereby solidifying quota value.

When designing the monitoring program for the integrated management plan, a consultative infrastructure for its design and implementation was created as a first step. The provincial government, the Department of Fisheries and Oceans (DFO), tribal entities, environmental groups and industry representatives formed a powerful coalition that carried out the program's vision. This led to a mature leadership structure that incentivized industry participation, as fishermen were involved from the very beginning in problem formulation and resolution.

Industry members and managers were a permanent part of the EM sub-committee (of the monitoring program committee) that tested EM video review protocols and prototyped equipment (Stanley et al., 2014). In this way, fishermen were involved throughout the entire monitoring program planning process and their feedback was used to determine which monitoring components should be a part of the overall program. This helped industry to understand the purpose of each monitoring component and how it related to monitoring goals (Johnson et al., 2004).

The four key monitoring elements for the support of the IVQ system were: 1) a hail system, 2) harvester records (logbooks), 3) a dockside monitoring program, and 4) the EM system. Fishermen were required to call in, or "hail", to fishery managers when they were departing for a fishing trip and again when they were planning on delivering; this initiated a trip record. During fishing operations fishermen were required to fill out a logbook which detailed fishing times, locations and durations, as well as a record of catch and discards of all species. Dockside monitors were utilized at landing sites to verify fishermen's records of species landed by weight. The EM system was utilized in two ways: first, the hydraulic sensor data, which indicated when fishing was occurring, was used in conjunction with the GPS receiver to generate an independent record of haul times and locations. Second, the EM video data were used to provide the possibility of generating a complete independent record of catch by species (Stanley et al., 2011).

When designing the EM review component of the monitoring program, the Department of Fisheries and Oceans (DFO) conducted an economic cost-benefit analysis (CBA) to analyze the costs of various configurations of the EM system, including video review requirements, against the benefits of these configurations in terms of their ability to achieve monitoring goals. This rigorous quantitative analysis led to a recommendation that fishermen's logbook records be considered the default catch record, and that this catch record be verified using review of video imagery. This led to an audit-based approach to video review which, rather than requiring that all video data be reviewed, permitted review of a subset of footage.

The audit approach involved reviewing a target of 10% of the fishing events from each fishing trip and comparing these results to fishermen-reported data. If the logbooks matched the video review results to within a specified tolerance, the fisherman received a passing score and the logbook data were accepted as the official data record. If the logbook data did not match the video review results, fishermen received a failing score and 100% of the video data from that fishing trip was reviewed; the costs of this additional review were passed onto the fishermen. If fishermen continued to receive failing scores they could be required to carry human observers for future fishing trips (Stanley et al., 2014).

There are several direct and indirect benefits of this audit approach. First, the partial review of video data is less expensive than a census approach and passes costs of additional review (in the case of inaccurate logbook records) onto fishermen. This incentivizes fishermen to record catch data diligently and to ensure that their logbook records are accurate. The fact that the fishermen's own records are the basis for catch estimation and accounting creates trust between fishermen and managers (Stanley et al., 2011), and has led to improved economic performance and achievement of conservation goals in the fishery (Stanley et al., 2014). Further, since the fishing events that are reviewed are chosen randomly, the mean catch rate within the reviewed sets can be extrapolated out to the total number of sets to provide an unbiased catch estimate for the fishery (Stanley et al., 2009).

The responsibilities of each party in the fishery are well defined and communicated, including who is responsible for paying for specific program costs (Stanley et al., 2009; Stanley et al., 2014). This monitoring system has been a resounding success and a model for stakeholder participation and buy-in. The fishery as a whole has successfully complied with annual quotas and other management measures and improved the scientific certainty of management measure implementation.

12. BRITISH COLUMBIA AND U.S. WEST COAST DUNGENESS CRAB FISHERY

The Area 'A' crab fishery in northern British Columbia consists of a fleet of approximately 50 vessels that use crab pots to harvest Dungeness crab. This valuable fishery has a history of conflict between fishermen due to a dramatic increase in fishing effort in the 1990s, which resulted in highly concentrated gear set on the fishing grounds. Concerns arose that fishermen were removing catch from other fishermen's traps, or destroying gear that interfered with their own operations. Some fishermen estimated that these behaviors were costing them as much as CDN $100,000 per year. In response, fishery managers implemented a trap limit program in 2000 that reduced the amount of gear on the fishing ground, and a monitoring program was developed with the objective of monitoring trap limits and preventing theft of catch.

For most fishermen the value proposition for adopting a monitoring system was clear, as gear vandalism and crab theft were direct economic costs that monitoring could potentially reduce. This resulted in widespread acceptance that the industry would be responsible for paying for the costs of the system. The Area 'A' crab association worked closely with Archipelago Marine Research (AMR) to develop a cost-effective EM program that could achieve these objectives. The EM system included cameras, hydraulic winch sensors, a GPS receiver, a control box and a Radio Frequency Identification (RFID) scanner. Every vessel in the fishery marked their crab pot buoys with both a unique visual identifier and a RFID tag. The hydraulic sensors indicated when pots were hauled, and when this occurred the buoy was passed across the RFID scanner to identify that the pot was legally registered. Cameras recorded fishing activity and the GPS receiver identified the location of fishing activity to within a few meters. After approximately 15 days of fishing, hydraulic, RFID and video data were retrieved from the vessel and analyzed to ensure compliance with the regulations.

After the first three years of EM implementation, support for the program was very high, with the overwhelming majority of crab license holders voicing their support for EM in the fishery. The feeling among the fleet was that the system, which cost about $10 per trap per year, paid for itself through higher catch rates and lower gear loss rates. In addition, the program has created a level playing field in the fishery with a sense that all fishermen are respecting the rules and being treated equally.

Building on this experience, and in response to concerns surrounding theft of crab pots and catch, the Quinault Indian Nation (QIN) began to require the use of RFID tags to identify crab pot gear. QIN partnered with Ecotrust Canada to insert RFID tags, which are registered to individual vessels, into crab pot buoys. When crab pots are pulled aboard, the fishermen run the tags over a sensor that identifies the gear. A camera onboard identifies when all pots are pulled aboard and is integrated with RFID data to identify any illegal pots that may be inadvertently, or otherwise, pulled. This system ensures that QIN fishermen are fishing the correct pots and in the correct area, and is designed to lessen the theft of gear and catch.

While the QIN are the vanguard for these EM systems in U.S. fisheries, the systems are potentially applicable to the entire West Coast Dungeness crab fishery where gear theft is an endemic problem. In addition, cameras used are of high enough quality (resolution and frame rate) that they can potentially be used in the future to drive improved management in the fishery by documenting discarded crab sizes and sexes, and improving the quality of effort data.

13. BRITISH COLUMBIA SALMON TROLL

In 2002, an association of fishermen in British Columbia set out to explore individual quota allocation as an alternative approach to management in the salmon troll fishery. Archipelago Marine Research (AMR) was contracted to develop an EM system that could collect the data needed to operationalize a quota system. EM systems were installed on four fishing vessels to collect data on fishing times and locations, as well as the documentation of catch by species. Although the monitoring program was successful, the small scale of the fishery meant that there was no clear positive value proposition for full-scale implementation.

14. WCPFC TROPICAL WATERS PURSE SEINE FOR TUNA

The South Pacific Tuna Treaty (SPTT) is a multi-lateral treaty that provides 45 U.S. flagged purse seine vessels with fishing access to the Exclusive Economic Zones (EEZs) of 16 Pacific Island Countries and Territories (PICTs). Part of this treaty are a number of reporting requirements imposed by individual PICTs, as well as RFMOs such as the Western and Central Pacific Fisheries Commission (WCPFC). These reporting requirements include the collection of data around vessel registry and fishing effort, catch amounts, species compositions and length frequency.

For the last 25 years these reporting requirements have been fulfilled by human observers and monitoring officials based in American Samoa, which was the landing site for most of the U.S. fleet. However, in 2010, some fishermen started to develop a new fishing model that involved transshipping of catch to vessels in other ports that would then transport catch to canneries based in Thailand. This came about partly due to a shift in fishing patterns towards the Western part of the treaty area, and resulted in a need for a different method of monitoring the fishery that could operate over a wider and more diverse geographical area. This made the case for EM in the fishery more compelling, which was noted by fishery participants and managers.

In the spring of 2014, a workshop was held by a diverse group of stakeholders to identify the main obstacles and challenges to EM implementation in the fishery. The challenges ranged from practical issues, such as installation and maintenance logistics on individual vessels and how to transmit data from vessels to managers; to considerations such as increasing the technical capacity of industry to support EM implementation; reviewing and refining national and multi-lateral legal frameworks; and deciding how to fund the EM program. During this workshop, participants acknowledged the need for a working group to develop the standards and procedures needed for the development of an EM system by diverse stakeholders. This method of establishing standards for EM systems in the region is designed to ensure that data are collected in a timely and accurate manner that allows for stakeholder integration into the management decision-making process.

15. AUSTRALIA EASTERN TUNA AND BILLFISH

Australia's Eastern Tuna and Billfish Fishery (ETBF) utilizes primarily pelagic longline gear and targets a range of different species including various tunas, swordfish and marlin. The major monitoring needs in the fishery include collecting data on fishing effort and total catch and discards of all species, and the monitoring of fishery interactions with protected species. Until recently, human observers were used to collect this range of data, but the high costs of observer monitoring led to an industry-led initiative to explore EM as a monitoring tool. This led to the initiation of a pilot study in 2008 for the use of EM to collect high quality data that could be used to make fishery management decisions.

The pilot process commenced with project planning meetings between the Australian Fisheries Management Agency (AFMA) and Archipelago Marine Research (AMR) in April 2008. These meetings defined project goals, tasks, coordination procedures, project timelines and practical vessel requirements. In February 2009, AFMA issued a call to ETBF vessels for expressions of interest to participate in an EM trial. The vessel operators that responded to this call were invited to a one-day informational meeting in August 2009 to discuss project design, including EM system components, installation on the vessels, equipment servicing and data processing. A contract between the EM service provider, AMR and AFMA was agreed to for a pilot field study and covered leasing of EM equipment, installation costs and responsibilities, data analysis, communications and the use of AMR's data review software (Piasente et al., 2012).

EM systems were installed on 10 vessels in the ETBF, and between October 2009 and August 2010 EM systems collected data on almost all fishing activity undertaken by these vessels. The system during the pilot was designed to be audit-based, meaning that data from only a random portion of the fishing trips were reviewed. The process included a comparison of the audits to the fishermen's own logbook data, giving the fishermen responsibility and accountability that prompted improved logbook reporting, which in turn resulted in improved catch data overall. This drove behavioral change, as fishermen were able to receive real-time feedback from logbook outputs, as well as clear consequences for poor reporting and protected species interactions (Piasente et al., 2012). The trial was considered a success, with some issues identified, such as difficulties with scheduling system servicing. The pilot study also found that if full-scale implementation was to be attempted, early stage industry buy-in and transparency throughout the entire process would be key considerations.

Another key component of this initial trial was the collection of cost data to provide input into an economic cost-benefit analysis (CBA) which compared several EM system configurations to the status quo of observer monitoring. Piasante et al. (2012) reported that the quantifiable benefits of electronic monitoring, in the form of potential saved costs from reduced observer coverage, were AUS $587,520 per year, assuming an 80% uptake of EM in the 40-boat fleet. The CBA also proved that although the initial costs of implementation were relatively high, the long-term costs of EM were significantly lower than those of the status quo, due to the higher cost overall of onboard human observer coverage; further, the benefits of EM significantly outweighed overall costs. The various scenarios compared to the status quo provided fishermen with tangible, realistic results so that they could better understand the justification for implementing the monitoring program, leading to higher levels of industry buy-in (Piasente et al., 2012).

An EM program was fully implemented in July 2015 and made use of the results of the pilot study, including the CBA, to inform the design of the EM program. The costs of this initial implementation, including the purchase of EM equipment and installation, were funded by AFMA, with ongoing costs slated to be recovered from industry. The key objectives of the EM program are to:

- reduce overall monitoring cost;
- increase confidence in data quality via cross-validation of EM data with observer data and logbook records;
- increase the level of monitoring that occurs in the fishery;
- reduce the regulatory burden of monitoring on fishermen by allowing for individual accountability;
- reduce workplace health and safety risks to observers; and
- document sustainable fishing practices, which may lead to higher ex-vessel prices.

EM systems are now compulsory for most commercial fishing boats in the ETBF, the Western Tuna and Billfish Fishery (WTBF), and the Gillnet Hook and Trap (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF). The electronic monitoring of 100% of fishing activity complements existing observer coverage that is used to collect required biological data from that area. In 2016, the Australian Bureau of Agricultural and Resource Economics and Sciences concluded that an observed increase in net economic return in 2015 may have been a result of the individual transferable quotas, and that the EM system is a critical element to ensuring a high performing ITQ system (ABARES, 2016). Australia is planning to expand the program to more domestic fisheries.

16. NEW ZEALAND SNA1 TRAWL

New Zealand's snapper (*Pagrus auratus*) fishery in quota management area 1 (SNA1) is the country's most valuable inshore finfish fishery. However, during a management review in 2013, wastage of undersize snapper was identified as an area of particular concern (Pria et al., 2016). The main issue was a lack of monitoring of undersized (i.e., below the minimum size limit) snapper discarded at sea. To address these issues, the fishing industry, led by the SNA1 commercial group, worked with the Ministry of Primary Industries (MPI) to develop a monitoring system for the SNA1 fishery. MPI (2016) contracted Archipelago Marine Research (AMR) to conduct a pilot to explore the feasibility of EM as part of an effective monitoring system, with an overall goal of estimating the amount of at-sea discards of snapper in the inshore trawl fleet.

The planning process began in January 2014 with a series of meetings between MPI, the SNA1 commercial group and AMR to discuss the objectives of the trial, and how these objectives could be achieved. Specific objectives were developed by the group and included: 1) summarizing the performance (i.e., cost, accuracy and effectiveness) of the EM system, and 2) developing onboard EM configurations for the fishery. A methodology was collaboratively developed which involved all catch being brought onboard (and within camera view) before sorting occurs, all sub-legal size snapper being placed into a specific bin before discarding, and all discarding occurring at predetermined points on the vessel, which were to be individually tailored to each vessel's configuration and catch handling preferences. Vessel operators were also required to record an estimate of snapper discard weight in their catch effort returns for comparison with EM estimates. One of the outputs from this series of meetings was a Memorandum of Understanding (MoU), which described the operational terms and procedures agreed to by all parties.

EM systems were installed on five vessels starting in early 2014, and the trial ended successfully in August 2014. A basic methodology for equipment configuration and catch handling requirements was developed during the trial.

EM has been tested in a series of pilot projects in New Zealand over the past 15 years; these pilots have been instrumental in demonstrating the effectiveness of EM for monitoring a diverse range of fisheries with a diverse range of monitoring goals. In 2017, the Minister for Primary Industries announced that the entire commercial fishing fleet (approximately 1200 vessels) would be monitored electronically as part of a new Integrated Electronic Monitoring and Reporting system starting in 2018.[4] Commercial fishing permit holders will be required to acquire, install and operate EM equipment, including onboard cameras.

17. NEW ZEALAND SET NET FISHERY

The Canterbury inshore set net fishery in New Zealand consists of approximately 15 vessels that target a diverse range of species including rig (*Mustelus lenticulatus*) and elephant fish (*Callorhinchus milii*). The fishery is located in the distribution of Hector's dolphin, which is the world's smallest cetacean and classified as nationally endangered with a population estimated to be approximately 7300. In 1997-98, at-sea monitoring recorded six Hector's dolphin mortalities in the commercial set net fishery, which equated to a mortality rate of 3% for observed sets. In 2002, the Ministry of Fisheries set a maximum allowable take of three Hector's dolphins per year in the Canterbury set net area, and stated that fishing would be prohibited if this limit was reached.

4 http://eminformation.com/1725/em-confirmed-part-new-zealands-fishing-future

The Canterbury set net fishery has historically been monitored using human observers, although this system has proved problematic—from 1998-2001 the target coverage of 150 fishing days per year was achieved only once. This was probably due to the small size of the vessels, many of which cannot physically accommodate an observer, and the difficulty of scheduling observer trips when trips are short, and occur at short notice to take advantage of weather windows.

To try and improve monitoring for interactions with the Hector's dolphin in the set net fishery the ministry of fisheries explored EM as a monitoring option. A pilot study was conducted between October 2003 and January 2004 in order to test the effectiveness of EM for identifying interactions between the Canterbury set net fleet and the Hector's dolphin. The EM system consisted of two cameras, a GPS receiver, hydraulic and rotation sensors, and a control box, and was found to operate reliably. Specific objectives of the pilot included assessing the suitability of EM for clearly identifying marine mammal interactions, fostering industry education about EM systems, and testing the suitability of EM system installation on various components of the fleet. The pilot study demonstrated that EM could be an effective method for monitoring retrieval operations and documenting interactions with protected species in the fishery (McElderry et al., 2007). In October 2008, however, commercial set net fishing was banned within four nautical miles of the coast in an effort to mitigate accidental fishing mortality of the Hector's dolphin. Observers were also placed on vessels that operated outside of the four mile boundary, but observer targets have not been met due to safety and other concerns.

For the 2012-2013 season the MPI commissioned AMR to conduct another trial in the fishery that built upon the lessons learned from the 2003 pilot project. While the overall goal of this second trial was the same as in the first trial—namely, to test the feasibility of the EM system for monitoring protected species interactions in this fleet—specific objectives were set with an eye towards full-scale implementation. These objectives included quantifying the effectiveness of EM in estimating the mortality rate of the Hector's dolphin and other protected species in the fishery; and testing protocols, frameworks and other infrastructure necessary for the implementation of EM. A total of 160 fishing trips across six vessels were monitored as part of the trial. Due to operating issues, such as vessel captains not operating the EM system for the full duration of the fishing trip, a complete EM record of fishing activity was only collected for 26% of trips, but 87% of hauls. However, the trial demonstrated that EM could potentially be used to monitor protected species interactions as effectively as could human observers, if vessel captains could be incentivized to ensure that equipment was operating for all fishing activity. New Zealand is slated to implement EM requirements for most commercial fisheries in 2019.

18. E.U. DENMARK FULLY DOCUMENTED FISHERY

The Common Fisheries Policy (CFP) of the European Union (EU) includes a mandate for the limitation of catches to a Total Allowable Catch (TAC) level for many species, including cod. However, until recently, only landed catch was counted against the cod TAC, resulting in widespread discarding of undersized or over-quota catches of cod, and estimates of only about half of actual cod removal counted against the TAC (Kindt-Larsen et al., 2011). The uncertainty surrounding the total amount of removals led to lower cod quotas in following years (Ulrich et al., 2015).

In response to this, in 2008 the Danish government proposed a Catch Quota Management System (CQMS) that would require fishers to report all catches of cod, including undersized catch. In order to support this level of catch documentation the National Institute of Aquatic Resources in Denmark started exploring the possibility of the use of EM to monitor Danish cod fisheries. In 2008, a feasibility study was conducted to understand the technical requirements of the EM system developed by Archipelago Marine Research (AMR). This was followed by a pilot project to test AMR's EM system in the fishery from May 2008 to September 2009 (Kindt-Larsen et al., 2011). The EM system was deployed on six Danish fishing vessels representing a variety of gear types (four trawlers, a gillnetter and a seiner), all of which targeted demersal species, including cod. These fishing vessels volunteered to participate in the pilot but were incentivized by being awarded additional cod quota. The EM system recorded 608 total trips and 2330 fishing events and was considered a success, as estimates of cod discards made by the EM system were similar to those self-reported by vessel captains. Overall, the trial demonstrated that EM could provide the catch and discard documentation required to support the implementation of the CQMS. Further, the presence of an EM system incentivized fishermen to avoid discarding cod, as these discards were counted against available quotas.

The positive results of the feasibility study and pilot generated significant political support; a joint statement was signed in October 2009 by fishery authorities from Denmark, U.K. and Germany to explore a new management scheme for cod in the North Sea, Skagerrak and Eastern Baltic Channel. In 2010, the EU officially made provisions for a CQMS in these areas, including a provision that vessels participating in the scheme could harvest an additional 5% of quota allocated to that member state. One of the requirements of this provision was that vessels make use of an EM system to record all onboard fishing and processing activities. From 2010-2015, a variety of EM trials have been implemented annually in Denmark. A recent analysis shows that while some uncertainties regarding data validity and accuracy remain—and should be addressed prior to full-scale implementation—there has been a marked improvement in discard reporting in logbooks and an overall reduction in discards (Ulrich et al., 2015).

In 2013, the Common Fisheries Policy (CFP) was implemented, which includes a mandate to end discarding in EU fisheries by 2019. This obligation to land all catch has crystallized the need for the spread of Catch Quota Management Schemes across Europe and effective monitoring programs to support them. To date, EM systems have also been tested in the U.K., the Netherlands and Germany, with an overall acceptance of this method of monitoring among fishery stakeholders that have had experience using it (Plet-Hansen et al., 2017).

The European Union CFP also includes a mandate for the limitation of catches to a Total Allowable Catch (TAC) level. However, until recently, in many fisheries only landed catch was counted against the TAC, and at-sea discards remained an issue. In Denmark, the cod fishery's self-reported catches of cod included only landed catches and did not account for discarding of undersized cod, high-grading for quality purposes, and other discards at sea. Some estimates were that only about half of the actual cod removal was counted against the TAC. In response, the Danish government proposed a Catch Quota Management System (CQMS) that would require fishers to report their total catches (including discards). To support this objective, a pilot project to evaluate the use of EM was conducted. The results showed that the EM system could provide the necessary documentation for supporting the CQMS, and that the presence of an EM system incentivized fishermen to avoid discarding cod, as these discards were counted against available quotas.

19. GHANA TUNA PURSE SEINE

The purse seine fleet in Ghana is composed of 14 vessels that target tuna species in the Atlantic Ocean. These large purse seine vessels that are certified by the International Seafood Sustainability Foundation (ISSF) adhere to harvest limits and have a commitment to mandatory 100% observer coverage to ensure that these limits are not exceeded. On the west coast of Africa, however, a lack of reliable observer data has long been a problem; this has made compliance with International Commission for the Conservation of Atlantic Tunas (ICCAT) rules uncertain. In 2015, a pilot project was initiated for the Ghanaian purse seine fleet with the overarching goal of testing how EM could complement observer-based monitoring and improve adherence to ICCAT regulations. The project was funded by a coalition of international organizations including the government of Ghana, FAO, WWF and ISSF, as well as the Ghanaian tuna industry.

The EM system, which includes six cameras on each of the 14 vessels in the fleet, along with VMS and a satellite modem for the transmission of data, is designed to collect data on when and where each boat is fishing, and the type and quantity of species caught. While one of the goals of the pilot is to refine the system into a functional EM system that can achieve monitoring goals in the fishery, another equally important goal is to design a legal framework under which continued use of the systems can be mandated.

The project has been a success, and potential barriers to full-scale implementation (such as inefficient data review processes) have been identified.[5] In addition, the EM pilot project has improved the tuna industry's image in Ghana and increased adherence to ICCAT regulations.[6]

20. SOUTHERN OCEAN PATAGONIAN TOOTHFISH

The Southern Ocean Patagonian Toothfish fishery uses deep water demersal longlines to target Patagonian toothfish (*Dissostichus eleginoides*)—also known by the market name of Chilean Sea Bass—in the Southern Ocean.

Fishing vessels from several nations participate in these fisheries; because of the highly valued catch and largely remote offshore location of fishing operations, the fisheries were regarded as poorly monitored and subject to IUU fishing practices as far back as the 1990s. While efforts to manage IUU have been successful, there are many fully legal toothfish fishing operations taking place, and these fleets are anxious to further differentiate themselves from the poor practices of the past. Fishing companies from the UK, New Zealand, Chile and Uruguay see EM as a tool to demonstrate legitimacy of fishing practices and increase product traceability from capture event to consumer. These vessels fish in South Georgia territorial waters and carry observers for scientific research, but EM offers the additional benefit of continuous coverage of both setting and retrieval operations. The primary objectives for EM are to monitor compliance with night time setting requirements, monitor seabird interactions with both setting and hauling operations, and to gather more precise data on fishing effort.

Starting in 2013, EM systems were installed on two UK Argos Froyanes Ltd. vessels fishing in the South Georgia EEZ. Since then, six vessels have incorporated continuous use of EM systems for all areas of operation. These vessels are equipped with cameras to monitor retrieval operations, including bird avoidance devices; and setting operations, including streamer line deployment and efficacy. Infrared cameras monitor compliance with night time setting requirements, including seabird activity during gear deployment. Sensors provide accurate information about vessel position, proximity of gear setting and retrieval, streamer line deployment, counts of hooks set, and ambient light levels. EM systems are remotely monitored via hourly synoptic reports transmitted by satellite "system health" reports. Technical support via email communication has enabled the vessels to maintain continuous monitoring with EM while at sea, often for months at a time.

These EM programs were proactively instigated by the companies involved; the governments of South Georgia and the South Sandwich Islands have recognized the benefit of EM to the fishery and have deemed it a regulatory requirement. For further information, please contact info@archipelago.ca.

5 https://mofad.gov.gh/wp-content/uploads/2017/07/Ghana-ABNJ-Project.pdf

6 http://www.fao.org/in-action/commonoceans/news/detail-events/en/c/1106184/

Glossary

Glossary

Automatic Identification System (AIS) – Automatic identification system is a satellite-based fisheries surveillance program that can provide consistent information on a vessel's position and activity. Used in areas beyond national jurisdiction (i.e., outside of exclusive economic zones).

Bycatch (*syns.*: Incidental catch, Non-target catch/species) – Fish other than the primary target species that are caught incidental to the harvest of those species. Bycatch may be retained or discarded. Discards may occur for regulatory or economic reasons (NRC, 1999).

Catch (*syn.*: Harvest) – The total number (or weight) of fish caught by fishing operations. Catch includes all fish killed by the act of fishing, not just those landed (FAO, n.d.).

Catch accounting – The tracking of fishermen's catch, including landings and discards.

Closed-circuit television (CCTV) – (i.e., video surveillance) Video cameras are used to send a signal to a specific location on a limited set of monitors (Dempsey, 2008).

Cost-benefit analysis (CBA) – A systematic approach to determining the strength and weakness of various options to calculate options that achieve the best benefits while saving money (David et al., 2013).

Discard (*syns.:* Regulatory discard, Economic discard) – To release or return a portion of the catch—dead or alive—before offloading, often due to regulatory constraints or a lack of economic value (FAO, n.d.).

Effort (*syn.*: Fishing effort) – The amount of time and fishing power used to harvest fish; effort units include gear size, boat size and horsepower (Blackhart et al., 2006).

Electronic monitoring (EM) – Technologies such as onboard cameras, tablets and electronic logbooks used to monitor and capture information on fishing activity including fishing location, catch, bycatch, discards, gear usage and interactions with protected species (NMFS, 2017).

Enforcement – Measures to ensure compliance with fishery regulations, including catch limits, gear use and fishing behavior.

Human observer (*syns.*: Onboard observers, Observers) – A certified person onboard fishing vessels who collects scientific and technical information on the fishing operations and the catch. Observer programs can be used for monitoring fishing operations (e.g., areas fished, fishing effort deployed, gear characteristics, catches and species caught, discards, collecting tag returns, etc.) (FAO, n.d.).

Individual Fishing Quota (IFQ) – A type of catch share program in which shares are allocated to individuals or individual entities. Recipients are generally fishermen and shares may or may not be transferable.

Individual Vessel Quota (IVQ) – A type of catch share in which shares are allocated to an individual vessel. Shares are attached to the vessel rather than the vessel owner and may or may not be transferable. This has been used most commonly in Canada.

Infrastructure – For the purpose of this report, infrastructure not only applies to the physical structures (i.e., vessels) and facilities, but also the organizational structure (i.e., management framework) of the fishery necessary for operation.

Logbook (*syn.*: Logsheet) – A detailed, usually official, record of a vessel's fishing activity registered systematically onboard the fishing vessel. It usually includes information on catch and species composition, the corresponding fishing effort and location (FAO, n.d.).

Monitoring (*syn.*: Catch control) – The collection of fishery information for the purposes of science, including setting catch limits and assessing stocks, and ensuring accountability, including catch accounting and enforcing fishery regulations.

Monitoring, control and surveillance (MCS) – The continuous requirement for the measurement of fishing effort characteristics and resource yields, regulator conditions under which the exploration of the resource may be conducted, and the degree and types of observations required to maintain compliance with the regulatory controls imposed on fishing activities (FAO).

Remote monitoring – Use of a technology to monitor fishing activity. The review of the data that results from these technologies does not take place onboard a fishing vessel (i.e., not by human observers).

Reporting – Reports of fishing trip data by fishermen, as well as catch, landings and purchase data by dealers or processors (NMFS, 2017).

Scaling – An increase in the adoption of an innovation from a small number (e.g., pilot study) to the whole (e.g., an entire fishery within a national jurisdiction).

Vessel Monitoring System (VMS) – A satellite communications system used to monitor fishing activities (e.g., to ensure that vessels stay out of prohibited areas). The system is based on electronic devices which are installed onboard vessels. These devices automatically send data to a shore-based satellite monitoring system (Blackhart et al., 2006).

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