Advancing Global Implementation of Electronic Methods for Fishery Monitoring and Enforcement

A SUPPLEMENT TO THE

CATCH SHARE DESIGN MANUAL

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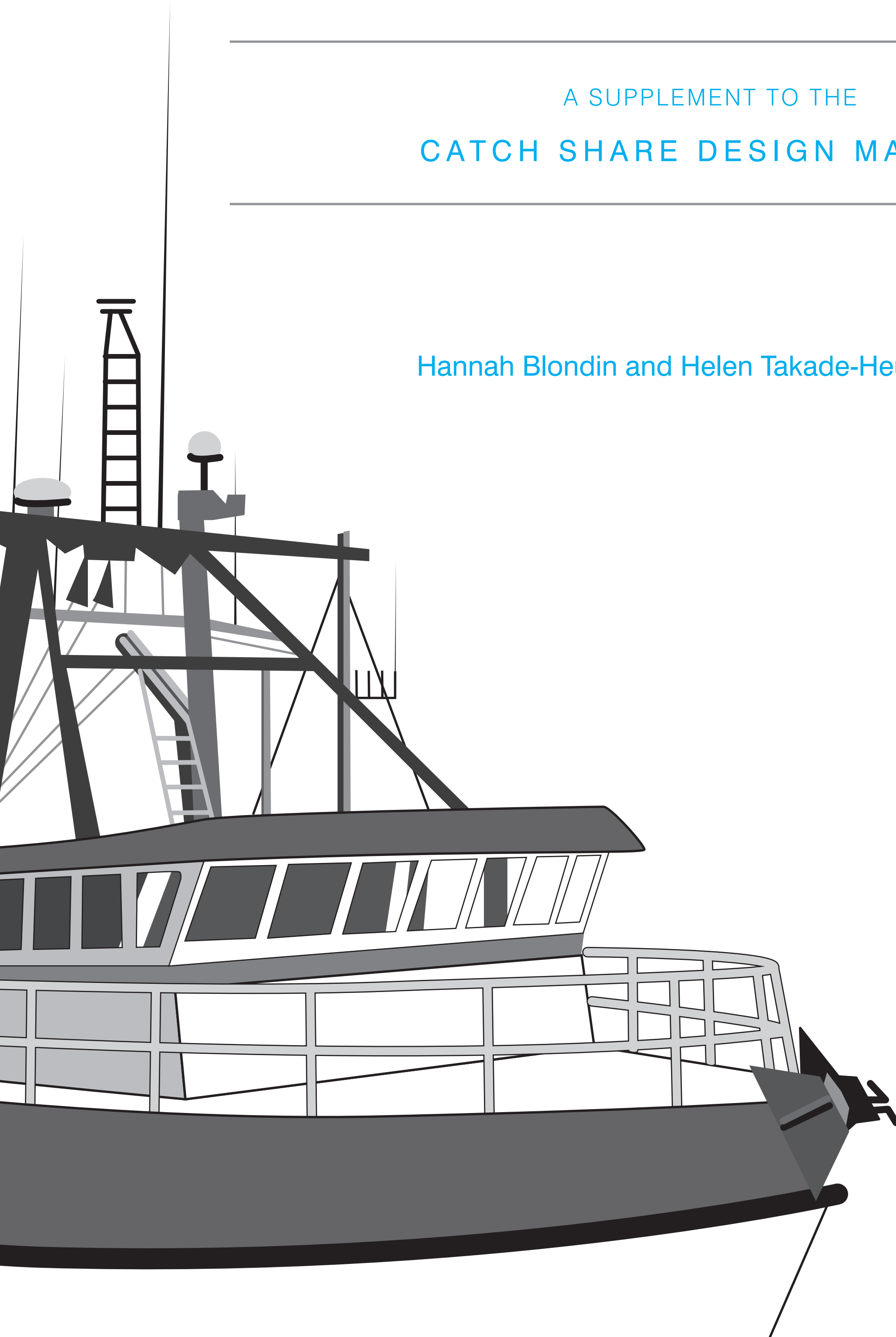

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Introduction

More than four million fishing vessels roam the seas, and they catch more than 90 million metric tons of marine and aquatic fish each year (FAO, 2016). Of the world's fish stocks that are formally assessed, 31% are fished at biologically unsustainable levels (FAO, 2016). Moreover, a much higher proportion of those stocks that are unassessed are thought to be overexploited or depleted (Costello et al., 2012). Adequate monitoring of a fishery is needed to set scientifically based sustainable catch limits, to ensure catch limits are not exceeded and to ensure adherence to other management rules designed to improve the economic and ecological performance of the fishery. However, the resources available for monitoring are typically inadequate or even dwindling; the cost of fishing is increasing, overall catch levels are declining or stagnant (FAO, 2016) and the number of vessels participating is on the rise, many of which may not be suitable for traditional, human-based monitoring methods. With these challenges in mind, there is a clear and present need for improved monitoring systems that are flexible, cost-effective, accurate, and reliable.

Many of the world's fisheries are monitored by fishermen reporting catch and other information in paper logbooks and/or through the use of human observers who are trained to collect data either on board or on shore when the vessel returns to port. However, self-reported data are prone to bias and transcription of paper logbooks into digital form can introduce errors into the dataset. Data collected by human observers can also suffer from bias and transcription errors if the overall monitoring system is not designed well, and human observers often come at a significant financial cost. The use of Electronic Monitoring (EM) systems in fisheries has increased significantly over the last several decades due to their potential to overcome a number of these monitoring challenges and to address some of the limitations of traditional monitoring systems.

EM systems utilize many different technologies to capture, store and transmit catch data, including, for example, digital cameras, electronic logbooks, hydraulic and motion sensors to monitor catch and the deployment of fishing gear, solid state removable hard drives to store large quantities of data onboard and satellite and cellular communications to transmit data to managers (NMFS, n.d.). EM systems typically include vessel-tracking technologies which enable officials to monitor spatial closures, track fishing effort and merge catch data with high resolution time and location information. Collecting data in electronic format can reduce human error and bias in the data collection process (although some level of human interface, such as through video analysis, is currently required). Another class of potential benefits of EM derives from the increased transparency and greater flexibility that EM systems provide. EM systems are able to be integrated into programs that maintain sustainability certifications or monitor for adherence to import regulations. This provides increased market access and related economic benefits to fishermen. Finally, in many cases the costs of maintaining an EM system are lower than those of utilizing human observers, although costs depend significantly on system components and program design.

The ability to successfully scale EM systems can result in an increase in the number of fisheries that are monitored, significant cost savings to existing systems, improvements to data accuracy, and expansion of the types and amounts of data that are collected relative to what is possible using a human-based monitoring system. However, most successful EM applications are currently limited to a handful of mainly industrial fisheries in developed countries, due to a combination of relatively high costs, needs for physical infrastructure and the requirement for a high degree of technical capacity to process, interpret and make use of EM data. Technological advances made in the last few years mean that many key EM technologies such as cameras and hard drives are becoming smaller, cheaper and more durable. Advances such as inexpensive solar-powered GPS trackers are making it possible to bring transparency and accountability to the thousands of smaller scale fisheries that suffer from lack of data, limited financial resources and a paucity of technical capacity. Implementing EM systems in a wider range of fisheries and then scaling them to increase monitoring coverage has the potential to protect fishery resources threatened by overfishing, resulting in improved food security for the 3.1 billion people who rely on fish as an important source of protein (FAO, 2016). Monitoring paired with effective management will ensure the conservation of some of the world's most vulnerable ocean ecosystems.

In this report we synthesize lessons taken from an analysis of 14 existing Electronic Monitoring (EM) programs in order to identify the main characteristics, drivers and design considerations associated with successful implementation and scaling of EM into an effective management regime. This guide is intended to help fishermen, fishery scientists, fishery managers, seafood buyers, technologists, data scientists and other stakeholders to evaluate opportunities and approaches for EM application and to identify and overcome barriers to successful scaling.

WHAT IS EM?

Broadly, EM can be defined as the use of electronic technology in order to monitor fishing activities. The case studies analyzed in this report all utilize camera-based technology to record fishing activity and satellite-based vessel monitoring systems to record vessel locations. Many also use an Electronic Reporting (ER) tool to report data. Satellite-based vessel monitoring systems include Automatic Identification Systems (AIS), which are primarily used for collision avoidance, and Vessel Monitoring Systems (VMS), a satellite communications system designed to monitor fishing vessel activities for enforcement purposes. This report focuses specifically on the use of cameras for EM, although systems that do not include cameras can fall into this EM classification. EM can be used to support a variety of fishery monitoring needs including catch volume and species composition estimation, fishing effort quantification, discard estimation and area-based monitoring. These functions are important for estimating the total amount of removals from a fishery, assessing fishery impact on marine mammals and seabirds, driving compliance with regulations and documenting spatial use as an input to marine spatial planning. Potential future uses of EM ranges from documenting marine pollution to human rights abuses.

WHERE HAS EM BEEN SUCCESSFULLY ADOPTED?

This guide draws from the EM implementation experiences of 14 case study fisheries from across the globe (Table 1) to identify factors for successful scaling of EM programs as well as barriers to EM implementation. All of the case studies represent industrial-scale fisheries located in developed countries. We define a "successful" EM program as one that is durable and scaled to be available to the entire fishery, where durability refers to the program being codified in long-term fishery rules or regulations with no specific end date.

Of the 14 case studies, three fisheries have "successfully" implemented an EM system and 11 represent test or pilot[1] implementations. A number of pilot implementations were planned to run for two to three years and have not yet been fully implemented at a fishery-wide scale, although discussions of full-scale implementation in these pilot programs are at various stages. For example, the U.S. Pacific groundfish fishery is nearing full EM implementation, with implementation in late 2018 for the fixed and whiting sectors, and in 2019 for the

1 Tests tend to be shorter in duration than pilots, and typically focus on single components, to determine if a single component will work in isolation. Pilots tend to be longer in duration and more complex, focusing on determining how the entire system (technology, fishing, and management) works together.

non-whiting bottom and midwater trawl sectors. New Zealand also anticipates implementing large-scale usage of EM in 2018. The management body for the U.S. New England groundfish fishery, the New England Fishery Management Council, has begun discussions on the implementation of a new monitoring program that may include large-scale use of EM.

The set of 14 EM case studies represents high governance, developed country contexts (e.g., the U.S., Canada, the European Union, New Zealand and Australia). Accordingly, the elements of success derived from the case studies are not inclusive of some of the broader fishery management challenges such as those pertaining to governance and infrastructure shortcomings that must be overcome in developing countries. In many developing country contexts, advancements in fishery monitoring have relied on more accessible, lower cost technologies such as low cost vessel trackers. Many of the elements of success in this guide will be relevant to developing country contexts, but should be considered alongside other relevant experiences and best practices.

To help foster thinking about how to increase widespread EM adoption, eight elements of success, drawn from 14 case studies of EM implementation, are presented below.

TABLE 1 | CASE STUDIES OF EM IMPLEMENTATION USED TO INFORM THIS GUIDE[2]

LOCATION	SPECIES TARGETED	GEAR	PROJECT TYPE[3]
BRITISH COLUMBIA, CANADA	Rockfishes (16 total species)	Trawl	Full Retention Catch Accounting
ATLANTIC OCEAN AND GULF OF MEXICO, UNITED STATES	Swordfish and yellowfin tuna	Pelagic Longline	Bycatch Accounting (Bluefin Tuna)
PACIFIC OCEAN, UNITED STATES	Rockfishes, Flatfishes, Sablefish, Whiting	Longline, Trap, Bottom Trawl, Mid-water Trawl	Discard Monitoring, Catch Accounting
PACIFIC OCEAN, UNITED STATES	Swordfish, Thresher Shark, Opah, some Tunas	Drift Gillnet	Protected Species Monitoring
NEW ENGLAND REGION, UNITED STATES	Cod, Haddock, Flounder	Trawl, Gillnet, Longline	Discard Monitoring
HAWAII, UNITED STATES	Swordfish, Tuna	Longline	Protected Species Monitoring
SOUTH ATLANTIC REGION, UNITED STATES	Snappers	Vertical Line	Discard Monitoring
ALASKA, UNITED STATES	Halibut, Sablefish	Longline, Pot	Catch Accounting
ALASKA, UNITED STATES	Rockfishes, Pacific cod, Pollock	Trawl	Discard Monitoring
AUSTRALIA	Yellowfin Tuna, Bigeye Tuna, Albacore Tuna, Broadbill Swordfish, Striped Marlin	Longline	Catch Accounting, Protected Species Monitoring
NORTH SEA, UNITED KINGDOM VESSELS	Cod, Dover Sole	Trawl, Gillnet, Longline	Catch Accounting
NEW ZEALAND	Snapper	Trawl	Seabird Monitoring
DENMARK, EUROPEAN UNION	Cod	Trawl, Seine, Gillnet	Catch Accounting
TROPICAL WATERS, PACIFIC OCEAN, INDIAN OCEAN, ATLANTIC OCEAN	Tuna	Purse Seine	Catch Accounting, Effort Estimation

2 The case studies include both pilots and scaled fisheries and gears. Not all case studies appear as snapshots.
3 See glossary for definitions.

Photo: Tim Briggs

1 Elements of Successful EM Programs

These elements emerged as consistent factors associated with successful implementation—or whose absence prevents successful implementation—of EM within a fishery management program:

1. Clearly identified goals with supporting objectives;
2. Stakeholder participation and support;
3. Planning for infrastructure needs;
4. Appropriate quantitative analysis of benefits and costs;
5. Transparency;
6. Clearly defined timeline;
7. Flexibility and adaptability;
8. Innovation.

Each element of success represents an important consideration at one of the broad stages of implementation of a fishery monitoring program (Lowman et al., 2013): 1) Assessment of Goals and Objectives, 2) Outreach and Program Design, 3) Pre-Implementation, 4) Initial Implementation and 5) Optimal Implementation. The following sections examine each element of success in turn, using case study summaries to illuminate how the particular element has supported a successful outcome.

1.1 CLEARLY IDENTIFY GOALS WITH SUPPORTING OBJECTIVES

Assuming that overall fishery management goals have been set[4], clearly defined *monitoring* goals that are nested in overarching *management* goals should be established. Consideration of an EM system should be framed as a means of achieving monitoring goals, which should be used to drive the decision making throughout the program planning process. Because EM can serve many purposes, ranging from the collection of catch data to the observation of infractions, the potential for "mission creep" is high unless the EM design and implementation process remains consistently focused on clear monitoring or enforcement goals. This does not mean that there should only be one goal supported by EM, but that these goals should be clearly defined and agreed upon from the start. The goals of the monitoring program should then be used to define measurable objectives by which system performance can be quantified, and should drive the design of the EM system (Snapshot 1). For example, a *management goal* of achieving Maximum Sustainable Yield (MSY) could guide a *monitoring goal* of 100% catch accountability. An *objective* that would support this goal could be to monitor 100% of fishing and discarding events (Snapshot 2).

EM system specifications and configurations[5] will vary depending on the goals and objectives of the program. For example, in a full retention fishery, the number of cameras, and their frame rate and resolution, need to be sufficient to monitor for any discards. The requirements will be

4 If the overall goals of fishery management have not been set, establish these first.

5 For more information on EM program design and the tradeoffs between different monitoring tools view the Fishery Monitoring Roadmap - https://www.edf.org/sites/default/files/FisheryMonitoringRoadmap_FINAL.pdf

SNAPSHOT 1 | Defining Clear Goals for EM in the Hawaii Longline Fishery

Fishery managers set clear goals for the Hawaii shallow set and deep set longline fishery, which targets swordfish and tunas respectively, when an EM pilot was conducted in 2010. The primary goal of the program was to decrease interactions with protected species, such as sea turtles and seabirds, which would prevent fishery closures. The monitoring objective was therefore to assess non-target species interactions, specifically with seabirds and sea turtles. A secondary monitoring objective was to count the number of hooks on each set. The pilot EM system consisted of four cameras, a GPS receiver, hydraulic pressure sensor, winch sensor, satellite modem and system control box on the vessels to determine if this configuration could accurately assess non-target species interactions (McElderry et al., 2010). Based on the pilot study, researchers found via review of video footage that EM was successful in identifying all protected species. The Pacific Islands Fishery Science Center moved forward with a phase-in of EM, starting with installation on six vessels with a proposal to review 35 longline trips from those vessels in 2017 (WPFMC, 2017) and the number of vessels equipped with EM continues to increase.

different if the fishery is allowed to discard certain species at sea, where it will then be necessary to place cameras to observe the sorting area or discard chute with fine enough resolution to identify species of fish. In addition, the particular attributes of the fishery that are conducive to the use of specific EM elements should drive decision making throughout the rest of the planning process, including the selection of the appropriate technologies for monitoring (Stanley et al., 2015). Fishery decision makers should also be aware that some systems and configurations may have limitations that prevent full achievement of the goals and objectives.

1.2 STAKEHOLDER PARTICIPATION AND SUPPORT

A transparent, participatory environment that fosters stakeholder participation is essential for identifying barriers and opposition to the adoption of EM systems. Participatory processes generally involve creating a forum for fishermen and fishery managers to share their needs and concerns. 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. Partnerships 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., 2015).

SNAPSHOT 2 | Defining Objectives for Each Component of the British Columbia Groundfish Fishery's EM Program

Between 1990 and 2006, an Individual Vessel Quota (IVQ) system was implemented in various sectors of the groundfish fishery in British Columbia, Canada. The IVQ system was implemented with the goal to rebuild the yelloweye rockfish stock (one of many target species in the fishery) to MSY and to increase economic vitality of the fishery. EM was implemented as a tool to provide adequate catch monitoring of all catch retrieval operations, a goal set forth for the fishery. The secondary supporting objective was to track all quota and non-quota species. In 2006, a comprehensive EM program was adopted for the six fishery sectors managed by IVQs, encompassing 16 species. When designing the monitoring system, managers assumed that the monitoring system designed for yelloweye rockfish would provide sufficient coverage of other quota species, given the low quota available (Stanley et al., 2015). To support the data collection needs of the IVQ, British Columbia created a specific monitoring objective for each component of the program, as shown in Table 2 (Stanley et al., 2015). The four key monitoring elements for the support of the IVQ include a hail system, harvester records (logbooks), a dockside monitoring program and the EM program (including sensor data and imagery). With this system, the groundfish fishery has successfully complied with annual quotas and increased the scientific certainty in the recent catch data (Stanley et al., 2015).

TABLE 2 | COMPONENTS OF THE GROUNDFISH HOOK-AND-LINE CATCH MONITORING PROGRAM SHOWING PROGRAM ELEMENTS, MONITORING OBJECTIVES AND COVERAGE LEVEL

ELEMENT	MONITORING OBJECTIVE	COVERAGE (%)
HAILS	Confirm valid fishing trips	100
LOGBOOKS	Create complete record of fishing operations	100
EM SENSOR	Collect complete sensor record of trip	100
	Verify logbooks	
	Confirm valid fishing locations	
EM IMAGERY	Collect complete image record of catch retrieval operations	100
	Random review to audit logbook catch record	10
DOCKSIDE MONITORING	Verify record of species and weights of landed catch	100
	Individual counts by species of landed catch	30–40 (of landed weight)

Adapted from Stanley et al. (2011). Hails refer to the hail-in and hail-out by harvesters as they provide notification of intent to leave for a fishing trip and return to unload from a fishing trip, respectively. EM refers to the EM component of the program.

Stakeholder participation and support is likely to be lacking in systems where stakeholders are excluded from the design and implementation processes (Ostrom, 1990; Olsson et al., 2004; Reed, 2008; Campbell et al., 2010). 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 the technology to scale 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 infrastructure that incorporates dialogue, feedback and compromise (Stanley et al., 2015). The support of fishermen relies on two-way communication with fishery managers (Snapshot 3). Fisheries that commonly use participatory processes to support decision making will likely find greater success due to leadership and established collaboration (Stanley et al., 2015). 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 outcomes will be applicable to their concerns (Johnson et al., 2004). For example, in the British Columbia groundfish fishery, fishermen supported EM partly because of an agreement to use fishermen-recorded logbooks as the main catch record, which are then checked using EM (Snapshot 4). 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.

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, etc.) may be necessary to create an environment conducive to the planning of a major change such as a transition to EM.

SNAPSHOT 3 | Communicating Results to Fishermen to Build Buy-in for EM in the Australia Eastern Tuna and Billfish Fishery

In 2015, Australian fishery managers implemented an EM program for the Eastern Tuna and Billfish Fishery after conducting a successful pilot. EM pilot studies completed prior to implementation found that the process would need early stage industry buy-in and process transparency so stakeholders would trust the resulting data. The program made use of the results of this pre-implementation study to inform the design of the EM program. The system was designed to be audit-based, meaning that data from only a random portion of the fishing trips was reviewed. The EM system 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 changes during the pilot 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 program was fully implemented in July 2015. 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).

SNAPSHOT 4 | Involving Industry in the Design of the British Columbia Groundfish Fishery's EM Program

The EM program that supports British Columbia's groundfish Individual Vessel Quota (IVQ) system has the confidence of the majority of the fishermen (Stanley et al, 2015). Industry members were involved throughout the entire planning process and helped to determine which components should be a part of the overall program. Fishermen and managers were a permanent part of the Electronic Monitoring Subcommittee that tested EM imagery review and prototyped equipment (Stanley et al., 2015). As a result, the industry is able to understand the purpose of each component and how it impacts the overall results relative to their needs and priorities (Johnson et al., 2004). The program provides flexibility, allowing fishermen to choose between the audit-based EM systems and carrying a human observer. A high percentage of the fishermen are receiving "passing scores" when their logbooks are randomly audited based on the comparison of EM imagery, meaning the logbooks and video match within an allotted tolerance. If a fisherman receives a failing score, he or she incurs the cost of a 100% review of the imagery from their fishing trip (Stanley et al., 2015). A retrospective study has found that the system has altered logbook incentive structure and led to higher accountability and accuracy in data logbooks; fishermen are now unlikely to bias their logbooks due to a combination of the EM imagery program and the existing dockside monitoring program (Stanley et al., 2015).

1.3 PLANNING FOR INFRASTRUCTURE NEEDS

Infrastructure related to EM implementation refers to: (a) equipment and operations (the physical EM equipment and software and the harmonization of fishing and/or catch handling behavior with monitoring operations), (b) the management framework (the legal and regulatory system) and (c) management capacity (the scientific and management support for the monitoring framework). The lack of appropriate infrastructure greatly reduces the likelihood and speed of uptake, as well as the effectiveness, of an EM program; ensuring that appropriate infrastructure exists in each of these categories is critical.

In some cases it may be possible to design new EM technologies or configurations to take advantage of existing scaled infrastructure, rather than requiring the creation or spread of new infrastructure systems. In these cases thinking outside the 'management box'—for example, thinking about how supply chain infrastructure could complement EM—can be important.

The design of the physical EM system design includes consideration of:

1. *Camera Specifications.* These include the number of cameras, their strategic placement, their resolution and recording frame rate, when they record and the design of a protocol for dealing with camera failure.
2. *Other Data Collection.* Types of data that are commonly collected include hydraulic sensor data, which can help to quantify fishing effort; positional data, including location and speed; and oceanographic and climatic variables such as temperature, salinity and wind speed. In many cases hydraulic sensor data is integrated into the operation of the EM system, triggering cameras to record when the sensor detects fishing activity.
3. *System Interface.* Designing a system by which fishermen can interact with the EM system is important. This often involves displaying camera

footage in real time on a dedicated computer monitor. In most cases fishermen are able to see the data being recorded but are not able to tamper with it.

4. *Data Storage and Transmission.* The storage and transmission of data are closely related and should be considered jointly. Storage considerations include the size and number of hard drives that record EM data, whether the hard drives are removable or not, if the cloud is being used for data storage and how long to store the data. Transmission considerations include whether removable hard drives should be sent to managers by fishermen, how these hard drives are transported, how often they are sent to managers and whether systems that use cellular or satellite transmission are more appropriate. Cellular and satellite transmission of data is becoming more accessible (both from a cost and technical perspective), and some work exploring wireless transmission of data in port is being conducted.

5. *Data Analysis and Link to Management.* 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 is generally conducted on a much shorter time scale than if they are used after the season ends. The amount of EM data that is collected and whether they form the main catch record (i.e., 100% of data are analyzed) or are used to audit a proportion of self-reported logbook records determines data analysis capacity (number of reviewers). It may also be useful to consider emerging machine learning capabilities for data analysis.

One of the most important components for the success of an EM program is the operations component, or the harmonization of the camera placements with fishermen's operations and behaviors and vice versa (Snapshot 5). Several EM pilots have failed as a result of inexperience with fleets and management procedures, resulting in equipment

SNAPSHOT 5 | Synchronizing and Automating EM Equipment to Achieve Monitoring Goals in the Hawaii Longline Fishery

The Hawaii longline fishery implemented an automated EM system in which various sensors are used to distinguish vessel activities and trigger image capture during fishing operations only. The benefits of this decision were twofold: (1) the automated system increased the fishing operation capture rate 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. In addition, as a result of the pilot, camera placement was improved so that multiple cameras provided synchronous imagery recording and were placed at angles that were harmonious with operations of longline retrievals. Multiple synchronous camera views ensured that more catch events were accurately recorded and provided enough coverage for reviewers to interpret hauling events for species identification. While comparative human observer data in a study of this system recorded 30 species, EM observers were able to record 25 species, as the EM system tended to use more general categories of identification and was not as specific as human observers. The EM system needed to be comparable to the human observers for it to be considered an option for monitoring this fishery. The fishery also has plans to develop and adopt standardized catch handling procedures to improve the ability of reviewers to observe and detect catch events (McElderry et al., 2010).

SNAPSHOT 6 | Defining Stakeholder Responsibilities for EM in the British Columbia Groundfish Fishery

Within the British Columbia groundfish fishery management program, the role of each party is clearly defined, including who is responsible for covering different program costs. The harvester is responsible for ensuring the function of the EM equipment throughout the entirety of each fishing trip during the season. If the system fails, the vessel is required to stop fishing immediately and return to port. This provides incentive for the harvesters to keep the system working at full capacity. The harvester is also responsible for arranging data recovery at the conclusion of each trip. An audit-based approach—reviewing a subset of recorded data—was also incorporated into the program. This allowed for more impartiality and much lower cost because a third party reviewer used the audited imagery to validate fishermen's logbooks. The fisheries manager set up an auditing system where for each vessel, a random selection of 10% of fishing events is reviewed, with the caveat that at least one fishing event per trip must be included in that selection. The responsibilities of each party are explicit and well defined (Table 3), and each party is well educated on their individual tasks (Stanley et al., 2009; Stanley et al., 2015).

TABLE 3 | RESPONSIBILITIES OF EACH PARTY WITHIN THE BRITISH COLUMBIA GROUNDFISH FISHERY

PARTY	RESPONSIBILITIES
HARVESTERS	Ensure accurate logbooks; ensure operation of EM system on vessel; make arrangements for data recovery post-trip; pay for 75% of EM program monitoring costs (with the exception of failure of audit, then pay for 100% of a full review)*
DEPARTMENT OF FISHERIES AND OCEANS (DFO)	Determine threshold for audit review; determine scoring system for audit review; pay for 25% of EM program monitoring costs
REVIEWERS	Review and analyze EM imagery data; provide audit score to fishermen

*Although fishermen on the west coast Canadian fisheries are typically 100% responsible for incurring monitoring costs, as a result of the new program, costs are shared between harvesters and the DFO.

that did not function optimally (e.g. McElderry et al., 2003). In the New Zealand longline fisheries, demersal longline vessels need camera coverage of the hauling station and the location where the longline emerges from the water, whereas pelagic longline vessels need cameras to cover the hauling station, the area where the catch is boarded and the area around the sea door where catch is maneuvered. 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 unforeseen barriers to effective monitoring are addressed.

The management framework infrastructure concerns the distribution of the responsibilities among the harvesters/fishermen, the management body and the video imagery reviewers/technical support. It is important that fishermen are educated on their responsibilities and the consequences of failing to fulfill them. For example, fishermen play a critical role in maintaining the function of the EM equipment; proper maintenance training is an important enabler of successful scaling (Battista et al., 2017), (Snapshot 7). Having technical support accessible to fishermen is also an important enabler of successful EM systems.

The video 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 established, prior to actual review. Ensuring that video reviewers are independent of both fishery managers and fishermen can improve program transparency. Deciding between an audit-based approach to video review (a proportion of video footage is randomly selected to audit self-reported logbooks for errors) or a census-based approach (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 level of trust in the system and the goals and objectives of the monitoring system.

SNAPSHOT 7 | Strengthening Capacity and Improving Upon Existing Infrastructure in the New Zealand Longline Fishery

Prior to EM program implementation, the New Zealand longline fishery identified elements of a successful long-term program based on lessons learned from several previously completed pilot studies. A vital part of the program was to increase industry awareness through outreach to familiarize fishermen with the technology and their specific responsibilities. New Zealand's Ministry for Primary Industries (MPI) contracted with a third party service to conduct video imagery analysis independent of industry and government. New Zealand also established data sharing agreements, aware that industry support would depend on the rules surrounding how and when information was collected and used. MPI ensures that the EM data will not be used for purposes outside of the management and monitoring objectives of observing interactions with marine cetaceans and seabirds (Guy, 2017). Finally, New Zealand was able to build off existing policy and infrastructure, which facilitated the introduction of the Integrated Electronic Monitoring and Reporting System (IEMRS). Through an amendment to existing fisheries regulations that required reporting and monitoring (by human observers), New Zealand was able to introduce IEMRS, which allows for more accurate, integrated and timely data to inform fishery management decisions and help ensure sustainable fishing (MPI, 2016).

1.4 APPROPRIATE QUANTITATIVE ANALYSIS OF BENEFITS AND COSTS

A central part of the conception, planning and research phase of an EM system is to estimate the costs and benefits of a range of systems that can achieve monitoring goals and compare these to the status quo scenario (McElderry et al., 2003). In cases where performance standards and objectives are clearly defined, cost-effectiveness analysis, which compares just the costs of alternative systems in achieving these objectives, can be conducted. These analyses can allow for more efficient and effective use of funds by quantifying tradeoffs among various management and monitoring systems (Snapshot 8).

A formal Cost-Benefit Analysis (CBA) compares the benefits of a management alternative to the costs of that alternative for a specified set of people with "standing" (i.e., those for whom impacts matter) (Stanley et al., 2015). If a CBA indicates a positive net benefit of adopting EM, successful implementation is more likely than if the overall net benefit is negative. Quantitative evaluations of benefits and costs can also help decision makers to decide which components of an EM system are necessary in order to achieve the management goals (Snapshot 9). This occurs by examining any preexisting ideas towards a particular technology—thus placing the focus of analysis on actual data needs—and then presenting this information to managers in an unbiased manner that is not clouded by personal judgements (Piasente et al., 2012; Stanley et al., 2015). CBAs also allow managers to balance incremental costs of data collection and analysis with the added complexity of fulfilling data needs (Stanley et al., 2015).

A cost-effectiveness analysis, which does not attempt to assign a monetary value to expected benefits, may be more appropriate than CBA during certain stages of the EM planning process or in the event that it is difficult to quantify benefits. Cost-effectiveness analysis takes the management objective as given and compares alternatives to determine which one achieves the objective at lowest cost.

SNAPSHOT 8 | Using CBA to Make the Case for EM in the Australian Eastern Tuna and Billfish Fishery

Australian fishery managers used CBA to compare a human observer program to two different EM configurations for the Eastern Tuna and Billfish Fishery. The Australian Fisheries Management Authority (AFMA) found it valuable to not only determine costs versus benefits of various EM systems, but also to compare these systems to the human observer status quo. Costs of the EM systems included initial implementation and long-term operational costs, while benefits included the reduced costs of using an EM system when compared to a human observer program. Piasante et al. (2012) reported that the quantifiable benefits of electronic monitoring, in the form of potential saved costs from reduced observer coverage, were $587,520 per year AUS, with an 80% uptake of EM in the 40-boat fleet. This 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 on-board 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).

SNAPSHOT 9 | Using CBA to Guide EM system Design Features in the British Columbia Groundfish Fishery

Within the British Columbia groundfish fishery, a CBA was used by the Department of Fisheries and Oceans (DFO) to weigh the costs of the EM data and capacity needs to achieve the management and monitoring goal against the benefits at each step of the process. DFO carefully considered the risks of each barrier to EM implementation, collaboratively brainstormed potential solutions to remove these barriers, estimated the costs of each potential solution and then weighed the costs against the risks to find the most efficient solution. This constant comparison led to the audit-based approach (i.e., reviewing a selection of footage) over the census-based approach (i.e., reviewing 100% of the footage). Benefits of the audit approach, in terms of human labor required for video review and the associated costs, heavily outweighed the benefits of the census approach for this 100% retention fishery. Rather than reviewing all the footage from every fishing trip, video footage from 10% of the fishing events of every fishing trip was reviewed and compared to fishermen logbooks. If the logbooks matched the results of the EM video review within a specified tolerance, they were accepted as valid and became the official record of catch counts. The audit approach proved to be more economically efficient in terms of data review, reducing fishermen's costs. Further, since the trips reviewed are chosen randomly, the mean catch rate within the reviewed sets can be extrapolated from the total number of sets to provide an unbiased catch estimate for the fishery (Stanley et al., 2009).

1.5 TRANSPARENCY

Transparency in all aspects of design and implementation of an EM program is an essential component of a successful monitoring program. EM deals with often new, unfamiliar and uncommon suites of technologies; keeping decisions transparent, including where, when and how data are being collected and how they will be used for management, fosters industry buy-in. 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 physical 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 needs to be transparent and understandable to fishermen and potentially other members of the supply chain (Snapshot 10). 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 on data ownership.

SNAPSHOT 10 | Designing British Columbia's Groundfish EM Program to Be Clearly Understood by Fishermen

The British Columbia groundfish fishery's EM system estimates catch using a process that is clearly understood by fishermen, so they know what may happen during the review, who conducts the review and expectations of the review. As previously described, the British Columbia groundfish fishery adopted the audit-based approach to video imagery review for monitoring assessments. A key component of the program, however, is that the review of imagery simply acts as a check for the fishermen's logbooks. The program continues to derive official catch estimates from the fishermen's own logbooks and offload records within the dockside monitoring program (Stanley et al., 2011). The catch estimation process remains familiar and intuitive to fishermen because it is based on their own records. The industry trusts the resulting data and takes precautions to ensure that their logbook recordings are accurate. This results in high compliance with the program, which has led to economic improvement and achievement of conservation goals (Stanley et al., 2015).

1.6 CLEARLY DEFINED TIMELINE

A clearly defined and transparent timeline for program implementation that outlines industry responsibilities at each step of the process can increase the chances of successful EM implementation (Snapshot 12). Several EM pilot studies have concluded that the technology used is capable of achieving monitoring objectives at the fishery-wide scale, but has failed to be fully implemented due to a lack of expectation that comes from a firm timeline for scaling.

A scaling strategy and timeline should be defined at an early stage with specific, achievable targets set for an implementation process at the scale of the entire fishery. An essential first step is defining a potential date by which full scale implementation should have occurred. Managers cannot assume that scaling will automatically occur at the conclusion of a successful pilot as has been widely demonstrated by numerous pilot projects that have concluded with successful results but without subsequent full scale implementation (Battista et al., 2017). In some programs where scaling is occurring, such as the U.S. Pacific groundfish fishery, full implementation is occurring at a slow pace, partly due to a lack of willingness to maintain a timeline to scale.

Failure to scale after a successful pilot often means that the opportunity to leverage the extensive time, effort and capital required for the pilot study in the full scale implementation process is wasted. This is an important opportunity as many of the processes developed during the pilot study are translatable to full scale implementation. 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 the agency to account (Snapshot 11).

SNAPSHOT 11 | Setting a Deadline for Effective Monitoring in U.S. Atlantic and Gulf of Mexico Bluefin Tuna Pelagic Longline Fishery

In 2012, the NMFS identified bluefin tuna discarding in the pelagic longline fleet as a significant issue to the overall U.S. Atlantic and Gulf of Mexico fishery, as mortality was poorly accounted for and difficult to track. To address the issue, the agency initiated Amendment 7 to the Highly Migratory Species (HMS) plan; among the objectives was to optimize the quota for all sectors and account for mortality (NMFS, 2014). One of the management measures targeted towards the pelagic longline fleet was the implementation of an individual bycatch quota system (IBQ) with mandatory EM implementation to support data collection. In the drafted Environmental Impact Statement, the agency generated a timeline of events and milestones that included an anticipated implementation date of late 2014 to early 2015 (NMFS, 2014). Even with extended comment periods due to the complexity of the issue and a government shutdown, EM became a fishery-wide requirement on June 1, 2015 (NOAA Fisheries, 2015).

1.7 FLEXIBILITY AND ADAPTABILITY

EM programs generally require the adoption of a combination of new, in some cases untested, technologies, and the potential for unforeseen impacts and implementation difficulties is significant. Technologies are changing rapidly and in ways that can have significant implications for EM program design. The highly disruptive nature of technological progress means that building flexibility into an adaptive EM program is an essential component of capturing the benefits that technologies can provide.

Adaptive management is a process by which program performance is evaluated against predefined criteria, then changes to program structure and measurable objectives are created to improve performance (Snapshot 12). This is an important lens through which to view EM implementation in fisheries and all parties should expect challenges that will require adaptation and innovation in an iterative implementation process. An adaptive iterative process also allows for risk management and requires leaders from all sectors (i.e., management, industry and science) to stay involved and proactive (Stanley et al., 2015). Ongoing evaluation allows managers to demonstrate the tangible results of the program—which can help to garner further industry buy-in and support—and to make adjustments to the EM program and develop and refine scaling strategies as needed (Battista et al., 2017).

SNAPSHOT 12 | Partnering with Fishermen to Develop a Comprehensive EM Program for the U.S. West Coast Groundfish Fishery

In 2011, the U.S. West Coast groundfish trawl sector transitioned to an Individual Fishing Quota (IFQ) program, which required 100% monitoring for catch accounting purposes. The cost of monitoring was subsidized by NOAA for the first three years, gradually transitioning full cost to industry by 2015. 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. With input from industry and others, they defined a purpose and need, and a set of EM objectives for the different gear sectors. Since there was not yet a functional EM model for a multi-species IFQ fishery, the PFMC solicited exempted fishing permits (EFPs) for industry to begin testing EM systems on the water. 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 NOAA, which included submitting logbooks on catch/discard 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), funding the purchase of seven EM camera systems, the 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, recording logbooks 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, 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.

1.8 INNOVATION

As technology evolves, allowing EM programs to integrate new and updated technologies can help drive successful outcomes. Camera systems are quickly becoming more advanced and cost-effective, and taking advantage of these changes can increase the feasibility of full-scale EM implementation. New technologies can help overcome the barriers and constraints that limit uptake of EM in a variety of fishery contexts, especially in small-scale fisheries and other cases where the resources required to implement existing EM systems are lacking. There are also an increasing number of emerging technologies (such as image recognition software) that may be able to help overcome barriers to full-scale implementation. The most effective monitoring systems are those that combine new technologies with monitoring methods that are already in place (Detsis et al., 2012; Chang and Yuan, 2014).

While the case studies in this guide are primarily focused on camera-based EM programs and pilots, there are a number of examples of other technologies that have been implemented as components of successful systems for monitoring or enforcement. These include VMS, global positioning systems (GPS), electronic tablets and phones, acoustic sensors, satellite imaging and many others. Many of these cases have benefited from increased functionality resulting from rapidly expanding access to the World Wide Web through cellular networks or satellite technology, which has expanded the areas where they may be implemented. Where camera-based EM remains impractical—such as in small-scale fisheries—innovative applications of other technologies have enabled improvements to fishery monitoring and accountability. Creative applications of VMS and GPS can support fishery accountability by monitoring the timing and location of fishing activity. Advances in technologies that provide unique identifiers—such as bar codes, QR codes or radio-frequency identification (RFID) transmitters—can be used to improve vessel registration and catch monitoring, as well as product traceability through the fishery supply chain. Innovative combinations of these and other accessible technologies can help create monitoring systems that achieve fishery goals without relying on complex or cost-prohibitive devices (Snapshot 13).

As technology continues to evolve and data becomes more accurate, it will become possible to engage in more dynamic fishery management, such as mapping hotspots of vulnerable fish or protected species, and improved bycatch avoidance programs. Advancements in automated image recognition have the potential to significantly streamline fishery monitoring. The video review process is typically the

SNAPSHOT 13 | Monitoring Vessel Activity and Catch Using Accessible Technology in Mexico's Gulf of California Curvina Fishery

The curvina fishery in Mexico's Upper Gulf of California occurs in large pulses based on spawning events and is targeted by fishermen aboard small skiffs. The Upper Gulf of California is home to the vaquita, a highly endangered porpoise; an illegal fishery focused on the harvest of swim bladders; and a legal curvina fishery important to the region. For the curvina fishery to be sustainable and prevent interactions with the vaquita, this fishery requires a high level of accountability. Ensuring adequate accountability in the fishery relies on systems that track the location of skiffs (to deter illegal fishing) and monitor catch by each vessel. An innovative system combines GPS devices and unique vessel identifiers to track fishing activity. A QR code system, a type of machine-readable barcode that contains information about the vessel, was adopted to simplify the catch recording process. QR codes affixed to each vessel contain information about the vessel and fisherman, such as vessel registration information and available quota (L. Rodriguez, personal communication). The QR code was taped to the side of skiffs and could be easily photographed via cell phone by monitors tracking individual quota amounts, or by enforcement as they tracked fishermen. In addition, a VMS-type system produced by Pelagic Data Systems was set up to monitor vessel compliance with no-fishing areas (L. Rodriguez, personal communication). The small skiffs used in the fishery lack on-board electricity, so tracking their locations requires an innovative approach. Small (approximately twice the size of a cell phone), solar powered and tamper-proof GPS trackers were used to overcome this barrier. The solution did require cellular coverage for upload, which is available in the region but may not be available in all rural areas. Because the system transmits data using 4G, the use of VMS systems could expand with the expansion of 4G.

most expensive aspect of an EM system (Sylvia et al., 2016) and ways of decreasing costs in this area can have major implications for EM uptake. Automated image recognition could eventually make it possible to identify fish species and measure individuals automatically. Initial trials of FishFace[6], a software developed by The Nature Conservancy and Refind Technologies that automatically identifies and measures catch, are promising.

Technological progress increases the potential for what can be done and decreases the costs of existing technology. For example, satellite communications capacity is increasing as new satellites are put into orbit; this is resulting in declining costs of satellite data transmission. This increased ability to receive and transmit data from the middle of the ocean combined with rapid improvements in onboard data processing and compression capability means that a new paradigm for fisheries monitoring is on the horizon. This will not only improve the timeliness of data transfer for fisheries management, but will also allow for new functionalities like improved connectivity to seafood markets, improved traceability, automated onboard data processing, and access to emerging markets, such as those for real-time oceanographic data. Another important benefit for fishermen derives from the improved accessibility of voice and internet communications at sea, which until recently has been rare for most vessels and their crews (J. Wiersma, personal communication).

6 For more information on FishFace see: https://www.nature.org/ourinitiative/urgentissues/oceans/providing-food-sustainably/fishface.xml

2 Common EM Barriers

Examination of the 14 case studies referenced in this report has provided valuable insights into common barriers to EM implementation that fishery stakeholders must overcome for EM to be scaled successfully to the fishery-wide level. While some barriers are economic or technical in nature, some are related to social and behavioral considerations. It is these that have the highest potential to be addressed through effective design of an implementation process. In this section we describe several major categories of common barriers to EM implementation and scaling.

2.1 COSTS

One of the most notable barriers to the widespread use of EM is the cost of acquiring, installing, using and maintaining the technology. These costs include the initial purchase price, ongoing operational costs and the cost of data processing and analysis. Deciding who should assume these costs 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, is a significant challenge (Sylvia et al., 2016).

The high upfront cost of the EM systems, including purchasing the camera and data management systems, is a common barrier to uptake. Human observers often come at a higher overall cost but the fact that these costs are spread out evenly throughout a fishing season makes this option attractive to many. Providing options for financing that allow fishermen to spread costs could help to overcome this issue.

In some cases initial costs are acceptable to fishermen but high operational costs inhibit EM uptake. The main source of operational costs is those associated with data processing and review, although data storage and equipment maintenance can also be significant sources of costs. Therefore, an important consideration during system design is whether to undertake review on an audit or census basis. While audit-based review is generally less costly than a census of all data collected, the goals and objectives of the monitoring program should drive this decision.

Where initial and operational costs are acceptable to stakeholders various cost-sharing arrangements have been made in response to differing points of view regarding appropriate roles, responsibilities and beneficiaries of the monitoring program. For example, monitoring program cost sharing is significantly different between fisheries on the East Coast and West Coast. On the East Coast, and particularly in New England, NOAA Fisheries has traditionally paid for the majority of monitoring costs. In contrast, on the West Coast fishermen have assumed greater responsibility for these costs. In both of these cases NOAA Fisheries and other government agencies continue to shoulder the costs of training, and federal grant programs are often used to fund pilot studies.

2.2 RESISTANCE TO CHANGE

Fishermen and managers can be resistant to change, often for different reasons. Learnings from social and behavioral science describe 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) and suggest 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. 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 under voluntary circumstances (Battista et al., 2017). 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). 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 an entirely rational opposition to being held accountable if no accountability measures have ever been in place in their fishery before. 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.

2.3 INADEQUATE INFRASTRUCTURE

A major barrier to implementation is inadequate infrastructure to support EM. In this case, infrastructure not only refers to the ability of individual vessels within the fleet to carry the EM equipment, but also the human capital to install and maintain systems and to collect, review, analyze, store, ensure and act upon EM data. There is no one-size-fits-all approach to design of an EM program. Many factors influence management and monitoring goals, and these goals and their supporting objectives determine the specific configuration of an EM system. The infrastructure to support the configuration may not exist; for example, there may not be sufficient cellular reception to transmit data. This would require the data to be stored on the vessel, and the vessel to have sufficient power supply to maintain the cameras and storage. Analysis of existing capacity as part of a larger cost-benefit analysis can paint an unbiased picture with which fishery managers can make decisions.

2.4 PRIVACY CONCERNS

Along with these new technologies, privacy concerns have emerged as a barrier to adoption. EM allows for a large quantity of data to be collected about individual vessels and their fishing activity. Considerations must be made to ensure objectivity and 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 the established fishery management objectives (Piasente et al., 2012). There may also be cultural or societal expectations around personal privacy that will need to be taken into account.

3 Summary

This analysis of 14 case studies of implementation of EM systems has illuminated eight common elements of success that should be considered when designing such a system.

These elements of success are applicable during at least one of the four broad phases of EM program implementation and are summarized in the table (4) below:

TABLE 4 | PHASES OF AN EM PROCESS, INCLUDING WHERE ELEMENTS OF SUCCESS SHOULD BE INCORPORATED AND EXAMPLE ACTIVITIES THAT SUPPORT THE ELEMENTS OF SUCCESS

PHASE	ELEMENT	EXAMPLE ACTION
ASSESSMENT OF GOALS AND OBJECTIVES	Clearly identified goals with supporting objectives	Nest monitoring goals within management goals for consistency of purpose
		Set measurable objectives so performance can be quantified
	Appropriate quantitative analysis of benefits and costs	Employ a formal process to compare alternatives such as a CBA
OUTREACH AND PROGRAM DESIGN	Stakeholder participation and support	Involve ALL stakeholders in all stages of implementation to identify potential barriers and unforeseen opposition, and ensure fair system design
		Treat fishermen as shareholders throughout the process
		Target negative preconceptions and create an inclusive environment to overcome barriers
	Planning for infrastructure needs	Clearly define responsibilities and provide training and support to ensure successful participation in the program
	Transparency	Be open about cost responsibility, which removes surprises and incentivizes fishermen to maximize system benefits while minimizing potential costs
		Be transparent throughout the entire process in order to increase buy-in and support fishermen with adequate outreach
		Clearly define data collection, data usages, payment responsibilities and rules of data ownership

(continued on next page)

TABLE 4 | CONTINUED

PHASE	ELEMENT	EXAMPLE ACTION
PRE-IMPLEMENTATION	Clearly defined timeline	Define the timeline at an early stage and include achievable objectives and targets
		Be explicit about scaling and set a deadline for full-scale implementation that is realistic and achievable
PRE-IMPLEMENTATION, INITIAL AND OPTIMAL IMPLEMENTATION	Flexibility and adaptability	Build flexibility into the system so management can adapt to technological advances and unforeseen barriers
		Evaluate the program regularly and frame in terms of pre-determined objectives and targets; evaluation is the basis for adaptation
	Innovation	Be willing to adopt new technologies that can provide benefits
		Structure regulations to avoid prescriptive mandates that might hamper uptake of new, more effective or cost-effective technologies
		Be prepared to redefine objective achievements when technology changes

4 Conclusion

With the pressure to ensure sustainable fishing globally and the increasing interest in improving traceability by markets and governments, EM is emerging as an adaptable approach to monitoring fisheries to achieve fishery management and market goals. When EM systems are thoughtfully designed to achieve clear fishery management goals, the technology has the potential to revolutionize the way in which fishing activity and catch are accounted for, which then leads to better compliance, more effective enforcement, greater transparency and improved scientific information. These improvements can then in turn ensure that sustainable fish stocks, fishing livelihoods and food security are maintained.

An EM system must address core management goals and all stakeholders must understand those goals. Timelines help drive the process to completion. A process that is collaborative amongst managers and stakeholders helps to directly and transparently address issues like infrastructure and costs. And managers, stakeholders and the management system itself should be flexible, adaptable and always looking for technological innovations that may ultimately be better solutions.

The barriers to global uptake of EM implementation include costs, social barriers around technology adoption, inadequate infrastructure, privacy concerns and failure to plan to scale. As we have explored in this guide, some of these barriers can be managed through a robust and transparent process that involves stakeholders from design through implementation to ensure goal and process alignment. Some barriers—for example, cost—can and are being addressed with the available technology through improvements that increase usability and reduce costs. Many of these barriers can be overcome through smart system design.

Continued innovation, collaboration among stakeholders and thoughtful planning to scale EM can help improve the effectiveness of fishery monitoring around the world to create sustainable fishery management systems that support healthy ecosystems and thriving fishing communities. Fishermen and managers can use technology alongside sound management to improve outcomes on the water; as technology continues to improve, that potential will grow exponentially.

Some technological innovations are tackling barriers to greater EM uptake, such as decreased costs of transmitting and receiving data at sea coupled with artificial intelligence/predictive algorithms and onboard image processing. These will allow fishing vessels to transmit large amounts of data to fishery managers while enjoying the benefits of broadband connectivity. EM that incorporates network connectivity and machine learning could fill an important niche in the rise of ocean conservation technology by providing a means for timely, cost-effective catch accounting; monitoring of bycatch/discards; and enforcement of closed areas. Inexpensive sensors mounted on autonomous platforms that can roam huge swaths of the ocean are already operational[7] and could be collecting valuable data for scientific fishery stock assessment. Scaling EM systems and bringing new technology to bear will yield massive benefits for ocean ecosystems and the fishermen and consumers who rely on them.

7 Example at http://www.sciencemag.org/news/2018/03/fleet-sailboat-drones-could-monitor-climate-change-s-effect-oceans

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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, n.d.).

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).