# Technologies for Improving Fisheries Monitoring

Rod Fujita, Christopher Cusack, Rachel Karasik,
Helen Takade-Heumacher and Colleen Baker

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## Contributors

Emilie Litsinger, Wiro Wirandi, Erica Cunningham, Layla Osman, Samuel Amoros Kohn, Aristoteles Stavrinaky - Environmental Defense Fund

Shah Selbe, Fellow of the National Geographic Society and Founder, Conservify

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## FISHERIES MONITORING

The world's marine fisheries produce healthy food for billions of people, provide jobs for tens of millions and contribute importantly to economic development in many countries (FAO, 2018a). However, wild fishery production seems to have leveled off or declined (FAO, 2018a), even as it becomes clear that more seafood and more livelihoods will be needed as global population grows to improve food security and lift people out of poverty (Thilsted et al., 2016).

Recent studies suggest that if catches in all of the world's fisheries could be adjusted to meet scientifically determined targets, and if fishery economics could be optimized, fisheries could produce much more food and profits while at the same time increasing the amount of fish left in the water for keeping ocean ecosystems healthy (Costello et al., 2012; Costello et al., 2016; Gaines et al., 2018). Managing fisheries such that they reach this potential can be a key approach for achieving many of the United Nations Sustainable Development Goals: ending poverty and hunger, protecting vulnerable populations, creating sustainable livelihoods and protecting ocean ecosystems.

One of the key barriers to achieving this potential is the widespread lack of fisheries monitoring. Improving fishery performance with respect to seafood production, profits, livelihoods and conservation will require that more fisheries are monitored, scientifically assessed and managed based on data and science. It will also require good fisheries governance that generates incentives for compliance with science-based regulations. Unfortunately, the large majority of the world's fisheries are most likely not monitored or managed in this way; approximately 600 fisheries are scientifically assessed and managed, and the catch of about 7000 is monitored to some degree—but there are at least 10,000 fisheries in the world.

While the number of fisheries that are monitored in some way is increasing as a result of a variety of domestic statutes and international agreements (OECD, 2017), monitoring is often limited to location tracking via Vessel Monitoring Systems (VMS) or Automatic Identification Systems (AIS). Many fisheries do not monitor compliance with fishery regulations, such as catch limits that are essential for sustainability. Thousands of fisheries are not even managed, let alone monitored (Costello et al., 2012). This lack of management and monitoring, combined with other factors—such as weak prosecutorial and enforcement systems (Hillborn et al., 2005; Beddington et al., 2007; Beddington and Kirkwood, 2007; Hanich and Tsamenyi, 2009; Sundström, 2013)—results in widespread illegal fishing (Agnew et al., 2009). Illegal fishing results in the draining of billions of dollars in revenue from legitimate fishers; overfishing; habitat damage; and the deaths of untold millions of seabirds, sharks, turtles and other ocean wildlife (Jensen and Vestergaard, 2002; Agnew et al., 2009).

The good news is that technology is increasingly being deployed to improve fisheries monitoring in all kinds of fisheries. The use of camera-based Electronic Monitoring (EM) systems in industrialized fisheries is described by

Michelin et al. (2018). EM systems use cameras, gear sensors and sophisticated data analysis to provide full accountability for fishing activities; this generates several benefits, including high levels of compliance, documentation of sustainable fishing practices and access to markets that demand high levels of transparency and sustainability. However, less than 1% of the world's fishing vessels are subject to EM (Michelin et al., 2018) due to a number of constraints, including lack of infrastructure; costs; and lack of capacity to analyze and use EM data. Michelin et al (2018) provide more detail on these constraints, and Fujita et al (2018) provide guidance on how to design and implement EM systems by overcoming these obstacles.

The purpose of this report is to describe other kinds of monitoring technologies that can be especially useful in fisheries that do not have sufficient infrastructure, revenue or capacity for conventional EM systems, and to show how monitoring programs using technologies can be designed for any fishery. We focus on technologies that are useful for monitoring compliance with fishery regulations such as catch limits, effort limits and the use of closed areas to improve fishery yields, profits and conservation performance.

To this end, we reviewed the global experience of the use of technologies in fisheries. Some of the technologies that we describe in this report can serve as components of EM systems (e.g., small wide-view, seaworthy cameras); there are now some relatively low-cost systems that include most of the elements of an EM system (e.g., Shellcatch and Flywire; see section on catch and effort monitoring). We also drew on a literature review and our experience working with such fisheries around the world to articulate the conditions necessary for high levels of compliance, and how to overcome barriers to widespread adoption of technologies to improve compliance.

It is important to note that there is no magic bullet for enforcing fishery regulations. We cannot assume that the use of technology will result in high levels of compliance in every fishery, because compliance relies not only on surveillance and monitoring data, but also on people with the integrity, skills and resources to use the data to actually enforce the regulations, as well as on the perceptions and attitudes of fishers. Moreover, certain enabling conditions must be present for technology to be useful in enforcement—notably, legal mandates and data management systems.

In this report, we describe some of the major fishery enforcement challenges that can be addressed with current or soon-to-be available technology (summarized in Table 1). We also discuss barriers to the uptake of monitoring technology, and describe a human-centered design process intended to identify and address these barriers in specific fisheries, increasing the likelihood that monitoring and enforcement programs will be adopted more widely. We illustrate how this process can be used to design a monitoring program through four desk exercises conducted with regional experts for a shellfish fishery in Mexico, a finfish fishery in Chile, an artisanal hake and tuna fishery in Peru, and a blue swimming crab fishery in Indonesia. Finally, we provide a summary and discussion of lessons learned from global experience with monitoring technologies to date.

## GLOBAL EXPERIENCE WITH USING TECHNOLOGY TO IMPROVE FISHERY COMPLIANCE

Various kinds of technologies—defined broadly to include both hardware and software for analyzing and visualizing data—have been used to improve compliance with fishery regulations. Some of them simply allow fishermen to self-report catch, effort and other data, resulting in a data stream that may or may not be reliable, often necessitating an audit by observers or on-board cameras. Monitoring goals vary considerably from fishery to fishery; hence the technologies used to achieve them will also vary. For example, if monitoring data are to be used to prosecute illegal fishing activities, technologies must be chosen that can generate data capable of meeting standards of evidence in court.

Despite the fact that fisheries will vary widely in their monitoring needs and capacities, we have identified some generic compliance challenges and describe some technologies that may be useful for addressing them. This is for illustrative purposes only; each fishery should use the design process outlined in this report to choose appropriate technologies. We have described technologies that are currently available on the market, but many other technologies are under development and may soon be available. This is why it is important to consult with a technology expert when designing any monitoring system that uses technology.

In this section, we added to a list of technologies compiled by The Databranch (www.thedatabranch.org) and drew on a literature review and consultation with technology experts to describe technologies for improving compliance with catch and effort limits, bycatch and discard limits, spatial and temporal restrictions on fishing, transhipment regulations and regulations concerning the accurate labeling of seafood products. We also describe systems that combine sensors, data storage devices, data transmission devices and software to monitor compliance with a number of different regulations, as well as innovations for tracking legal fishermen and permitted vessels; generating incentives for the collection of monitoring data; and managing the increase in data generated by these new technologies. Generic enforcement challenges and the technologies that can help address them are described below, and summarized in Table 1.

### *Catch and effort monitoring*

Catch limits are one of the best ways to manage fishing mortality such that fish stocks are maintained at levels capable of supporting high and sustainable yields. However, they are difficult to set and impossible to enforce without catch data, which are often lacking in small-scale fisheries and newly developing industrial fisheries. Total catch (i.e., landed catch plus discards) must be monitored in fisheries with significant discard rates to avoid unintentional overfishing.

Monitoring the incidental take of non-targeted species of fish and ocean wildlife, such as sea turtles, dolphins or seabirds (i.e., bycatch), is essential for reducing these impacts. Bycatch is a widespread challenge with ecosystem-wide impacts. A 2009 study estimated bycatch to be 40% of global catch (Davies et al., 2009), and more recent studies suggest that 10-20% of global catch is discarded (either as bycatch or for other reasons), adding up to some 10 million tons per year (FAO, 2018a; Zeller et al., 2018). In multispecies fisheries with catch limits, bycatch that results in discards at sea can result in overfishing. In fisheries with weak stock management, wherein the entire fishery is shut down when the lowest catch limit is reached if the fleet cannot avoid further fishing mortality on that stock, bycatch can severely limit fishing opportunity and profits. Bycatch also results in the deaths of millions of sharks, rays, sea turtles, seabirds and marine mammals each year (Davies et al., 2009; Wallace et al., 2010; Anderson et al., 2011; Žydelis et al., 2013; Lewison et al., 2014).

Monitoring fishing effort is necessary to ensure compliance with effort limits such as days at sea, gear limits or seasonal restrictions. Effort data are also essential for computing catch per unit effort, an important indicator for both stock assessment and for evaluating the economic performance of fisheries.

Compliance with catch, bycatch, discard and effort limits is usually monitored by fishermen who record their catch in logbooks; with surveys conducted by enumerators at ports where fish are landed; or in a small proportion of fisheries by human observers or EM systems capable of measuring and identifying catch or effort (Fujita et al., 2018; Michelin, 2018). Each of these methods has its limitations.

Logbooks have the potential for quantifying total catch and bycatch (including discards) but are often inaccurate or incomplete, and more errors are introduced when they are transcribed into electronic form for analysis (Girard and Du Payrat, 2017; Guillot et al., 2017; Stop Illegal Fishing, 2018,).

Enumerators at ports can collect reliable data on landings, but cannot quantify total catch, as they cannot account for discards at sea. Moreover, some portion of actual landings will be missed if there are unmonitored landing sites.

In some recreational fisheries, catch is monitored via surveying a portion of the fishermen, as well as random checks to ensure compliance with recreational regulations. It has been challenging to use these data to effectively manage recreational fisheries, particularly at finer scales, temporally or geographically. Enforcement can be difficult due to limited enforcement resources and the large number of individual fishers.

While human observers and EM systems generate very high quality, rich catch data that usually result in high compliance (Fujita et al., 2018; Michelin, 2018), they require infrastructure, resources and a degree of governance lacking in most of the world's fisheries.

A number of other technologies for monitoring catch that have potential for reducing costs and other barriers to implementation have been tested, and a few have been adopted at the fleet-wide scale. Electronic logbooks, smartphone apps and low-cost camera systems are now in use at the pilot or fishery scale, albeit in only a few fisheries at this time, many of which are recreational (Garvy, 2015; Girard and Du Payrat, 2017).

**Smartphone and tablet apps**

Because smartphones and feature phones are quite widespread among fishermen, even in many small-scale fisheries, a number of mobile apps have been developed for catch monitoring.

**Deckhand** - An electronic logbook app that collects catch and effort data from fishers and uses it to fill out required forms. This logbook is available for iPad, iPad mini and iPhone and takes advantage of the built-in GPS function of those devices to verify and supplement inputted information about catch, effort, bycatch and other data points that users can customize. The app protects against incomplete logging, refusing to shut down or submit until all fields are complete. Once complete, forms are submitted to a secure server using cellular networks. If fishers are out of cellular range, the app will continue to collect GPS data and can store months of activity until it is within cellular range again. Almost exclusively used in Australia by commercial fishers, the app can also keep a running balance for fishers of the catch quota left on their licenses. Some fisheries have been able to incorporate geofencing into the app so that vessels are notified when they enter marine protected areas or exclusive fishing zones. As of 2013, the manufacturer was still lobbying the Australian government to accept forms created with Deckhand.

http://deckhandapp.com/

**AST iCatch** - A catch reporting smartphone app designed for Android and iOS smartphones. Designed by AST Marine Sciences, this smartphone app is meant for inshore fleets, as it requires a cellular network to transmit data. The app is customized for each fishery and offers dropdown menus that collect data for target species, gears deployed and bycatch. The dropdown menus reduce input error and time spent filling out forms. The app can also collect location of catch by having fishers select areas on a digital map. As it collects more and more data, the app is able to show fishers their own catch trends and other indicators that are useful for business planning, such as fishing effort expended and areas fished.

http://www.ast-msl.com/solutions/icatch-smart-phone-catch-reporting-app/

**Abalobi**—A suite of five smartphone (Android) apps that facilitate self-reporting of catch data into an electronic logbook, port monitoring, community-based monitoring along the shore (for non-port landing sites), data visualization and marketing. Abalobi also includes analytics for management, a “fish with a story” feature to improve seafood value, and a fishery communications feature.

http://abalobi.info/

**OurFish** - An Android tablet or smartphone app that helps fishers monitor and log catch information such as quantity, type, weight and location. Developed by Rare, the app links easily with fisher registration cards that have QR codes on the back. Fishers scan their code when they start fishing; when they return, they use the mostly picture-based interface to enter catch information and again scan their QR code. The information is submitted to and collected on a data cloud using cellular networks. The app has been launched in Honduras, Belize and Myanmar, and there is a small pilot in Indonesia. The platform continues to be improved and updated, including improved sharing of data insights and marketplace information.

https://www.rare.org/stories/tracing-fish-and-finances#.W9SKOxNKjoA

**mFish** - This app is available from Google Play and Facebook Free Basics, and as a mobile website that allows fishermen to enter catch data and gain access to information on weather, price and fishing best practices. mFish is designed to minimize data use costs and can be used for free on Facebook Free Basics or with a mobile browser, either on a smartphone or a feature phone. In Indonesia, mFish was launched in partnership with the Indonesian Ministry of Marine Affairs & Fisheries (KKP). This partnership made it possible to provide average prices to users at more than 40 ports. Fishers generally value this information, as it may improve their negotiating power. Access to this kind of market power can potentially incentivize further uptake and use of the app for catch reporting. Within a month, more than 14,000 monthly users were accessing the platform on both smartphones and feature phones.

https://eachmile.co/state-department

https://mfish.co/

**VeriCatch** - This system is comprised of two integrated apps: FisheriesApp for self-reporting catch and biological information, and KnowYour.Fish for creating a traceable supply chain. FisheriesApp allows the user to create custom forms for capturing whatever data are deemed necessary; for example, total catch or sustainability information important for accessing certain markets. KnowYour.Fish uses FisheriesApp data as inputs and transfers catch and other information to buyers and consumers. It also provides information on the sustainability of the catch according to programs like Monterey Bay Aquarium Seafood Watch and Ocean Wise.

https://vericatch.com/about/

**FACTS—**The Fishery Activity and Catch Tracking System (FACTS) is an electronic logbook that can run on multiple devices and operating systems for self-reporting catch and hail in/hail out data. In addition, it tracks fishing license information and how close a fisher is to attaining his or her catch quota or other catch limits. FACTS is being used in the U.S. in Michigan and Maryland, and by several Northeast groundfish fishery sectors.

https://www.fisheryfacts.com/

**Odaku** - This is a smartphone app that links to GPS devices to allow vessel tracking. The app includes an electronic logbook for recording catch; e-commerce for selling fish; supply chain traceability with blockchain technology to provide for secure transactions; information on fishing regulations; alerts that go off when the vessel is approaching an international border; and weather information for fishermen. About 500 fishers in India are currently using Odaku.

https://www.f6s.com/odakufisheryplatform/about

**FishAngler, FishBrain, MyFishCount and Tails n' Scales** - These are all smartphone apps for recording recreational catch. They provide fishing forecasts and allow fishermen to share photos of their catch; in addition, FishAngler has a social media interface. FishBrain allows fishers to track their fishing methods and spots so they can learn how to fish better from their own experiences. Apps like MyFishCount and Tails n' Scales have been developed to integrate self-reported data into federal (U.S.) management. MyFishCount is being used in the U.S. South Atlantic region to supplement the available scientific information. Tails n' Scales was developed by the state of Mississippi for mandatory red snapper catch accounting.

https://www.fishangler.com/
https://fishbrain.com/
https://www.myfishcount.com/
https://tailsnscales.org/

**Fishface** - This is an app that uses facial recognition software to identify fish species from photos. The Nature Conservancy (TNC) is in the process of fully developing this app, but the goal is a smartphone application that fishers across the globe can use to more accurately and efficiently identify and sort catch. An early pilot of this program was deployed in Indonesia at a processing plant, but new iterations focus on mobility and onboard use. Micronesia has used Fishface to lower the cost of onboard monitoring of tuna vessels. Eventually, having an app that can conduct an instant taxonomy of catch should lead to better data and more informed fisheries management. In particular, it could make it possible to quickly identify and document prohibited species in the catch, and help advance the automation of catch accounting from video recordings made with low-cost camera systems suitable for small-scale fisheries.

https://www.nature.org/en-us/about-us/where-we-work/asia-pacific/indonesia/stories-in-indonesia/indonesia-fisheries/

### *Low-cost camera based systems*

While electronic logbooks and smartphone apps for catch reporting have the potential to increase the amount and quality of catch data, they are subject to the challenges associated with all self-reported data: accuracy and reliability. Some fisheries may have sufficient social capital, trust and norms, such that self-reported data are highly accurate. However, other fisheries will likely require catch and effort monitoring that does not depend entirely on self reporting. Low-cost cameras coupled with image analysis may make independent catch monitoring possible in fisheries that lack the requisite resources and analytical capacity for EM systems.

**FlyWire**—Combines video cameras and other sensors to generate data that are analyzed with AI (Artificial Intelligence) software. A single camera can be mounted on a boom to monitor a small vessel (Figure 1), or multiple cameras can be mounted on larger vessels. The system can be plugged into a vessel's power supply or run off of a rechargeable battery that can be recharged either while running with solar panels or onshore. The company claims that installation can be completed in less than four hours, and that the equipment is easy to maintain even at sea. Several pilots are underway with the aim of developing an EM system that costs less than $1000 for artisanal fisheries (NOAA, 2017). In the Upper Gulf of California, Mexico, data from the FlyWire system are being compared to data from human observers in the gillnet fishery. In the Peru nearshore fishery and the Indonesian coastal gillnet fishery, FlyWire data are being integrated into data management systems and also being tested for use in monitoring sea turtle catch.

**FIGURE 1** A FlyWire camera system mounted on a small fishing vessel in the Gulf of California, Mexico. Source: FlyWire.com

**Shellcatch** - The Shellcatch system is similar to FlyWire (Figure 2). The company claims that Shellcatch cameras have been deployed on more than 250 vessels in Latin America so far. The system is comprised of a small video camera (Figure 3) that can be recharged with a solar charger, and a smartphone app that captures the video and location data from a separate GPS device (not included) and then transmits the data automatically as soon as it is in range of a cell tower or WiFi network. The company claims that because the smartphone

**FIGURE 2** A Shellcatch system installed on a small hookah diving vessel in Chile. Divers use an air compressor and a long air hose to allow them to harvest valuable benthic resources such as the loco (Concholepas concholepas) Credit: Marco Antonio


**FIGURE 3** A Shellcatch camera mounted on an artisanal fishing boat. Source: Bloomberg.com

app is intuitive, no special training is required. They also provide support to users and can analyze video data within 48-72 hours. Costs are relatively high (US$2,000/monitoring unit, plus a monthly service fee for analytical services of US$150) but may be feasible for high-value fisheries with high potential for poaching or incidental catch of prohibited species.

**GoPro** - These inexpensive, widely available cameras offer an interesting opportunity for enhancing monitoring programs. GoPros have extremely wide lenses, allowing a comprehensive view that is valuable for monitoring, and are waterproof (though it is not clear how they might stand up to extended exposure). Unfortunately, cameras can only record even the lowest quality video for a maximum of two-and-a-half hours before running out of battery. For fisheries with longer trips than two hours, this poses a problem. The cameras can be set to record at intervals (e.g., eight minutes every hour) to extend their useful time onboard, but this dilutes the efficacy of an onboard monitoring system. Another approach may be to connect the GoPro to another type of sensor that can detect when a relevant fishing event is happening (e.g., gear is being hauled) which would turn the camera on. GoPros also offer a variety of mounting options; they can be mounted directly on the hull of a boat and are small enough to be worn by fishers themselves. These mounting accessories will add to the total, but GoPros are available for $150 and up, which is more affordable than other EM camera systems. Instead of a traditional memory card, new models push data to smartphones via the GoPro app, which downloads data from the cameras using cellular signal or WiFi.

https://gopro.com/

**DIY smart cameras** - It is now possible to build a smart camera for onboard monitoring using easily available components. For $90, Google's AIY Vision Kit includes a plug-and-play circuit board that provides the included Raspberry

Pi camera with computer vision that does not require an Internet connection. There is also a company called Naturbytes that sells cameras with the Raspberry Pi (without the AI circuit board) for $45. A fully waterproof camera case can be created from transparent polycarbonate IP67 enclosures found online for around $15. These smart camera kits can run off batteries, solar power or wired power. To use Google's AI software, a training set of imagery would need to be created and then used to build algorithms for automatic detection. These images can be collected as part of the project or can be leveraged from other projects that have collected similar images.

**Shore-based remote camera monitoring** - Onshore cameras can be used to monitor intertidal or very nearshore fisheries, such as Chilean TURFs. High-definition "trail cameras" (small battery powered cameras that blend in with their surroundings and thus are hard to find; Figure 4) were used to monitor compliance with fishing bans in coastal rockfish conservation areas (RCAs) in the Salish Sea, Canada (Lancaster et al., 2017). Six cameras were used to monitor 42 locations, and the data suggest that fishing effort was about the same inside and outside of the RCAs, with illegal fishing occurring in 79% of the RCAs; these estimated rates of non-compliance are similar to those estimated from aerial fly-overs. Trail cameras can be purchased for $40 and up.

**FIGURE 4** A small camouflaged trail camera. Source: WildgameInnovations.com

### Software for camera systems

Some camera systems are designed specifically for fisheries monitoring (e.g., FlyWire and Shellcatch) and include analytical services that use AI to process images and flag fishing events to facilitate the review of video data. It is also possible to purchase software to perform these functions if cameras are purchased separately, such as a GoPro, or if a service provider is not retained.

**Camio** - A cloud-based software system that analyzes video footage, flags events (e.g, the hauling of fishing gear) and can be configured to provide alerts when a specific, user-defined event occurs in the video footage. Costs for this service are variable, depending on usage rates. If sufficient technical expertise is available within the fishery to use such software systems with inexpensive cameras (see sections on GoPro and Naturebytes cameras), costs could potentially be reduced.

https://camio.com/

**CVision Consulting** - This company aims to enhance and improve video monitoring data analysis through the use of artificial intelligence. CVision recognizes that collecting vast quantities of data will improve fisheries management, but often the result is mountains of information and not enough human capacity to analyze it. Therefore, CVision is developing artificial intelligence tools that can study videos and run their own analyses, whether it is identifying action points (e.g., flagging video that humans should review), enumerating fish by species and labeling bycatch, or even estimating the length measurements of fish caught. The tool "OpenEM" provides users with an open platform for adapting CVision's AI algorithm to their own fishery without requiring an in-house data scientist. These types of tools can lower costs, reduce errors and speed up data collection.

http://cvisionai.com/

### *Compliance with size limits*

Size limits are used in many fisheries to prevent growth and recruitment overfishing, by protecting juveniles and spawning adults respectively. They are generally easy to set; often, minimum size limits correspond to the length at which 50% of the individuals reach maturity. Size limits are also relatively easy for fishers to understand; it makes sense to allow juveniles to live long enough to spawn. However, size limits are notoriously difficult to monitor and enforce. Strong port monitoring can induce discards at sea, obviating the purpose of the regulation. Gear restrictions such as mesh size may be more effective, but gears and fishing practices can be modified at sea outside the view of port monitors. At-sea inspections require patrol boats and must be sufficiently frequent to deter violations, increasing costs.

**Poseidon** - This is a mobile app that quantifies fish lengths from geo-tagged digital photos uploaded by harvesters. Initially, Poseidon was only for use on red abalone, but TNC aims to adapt it for other species, like spiny lobster and possibly some finfish, by the end of 2018.

https://news.bloombergenvironment.com/environment-and-energy/plenty-of-fish-in-the-sea-for-big-data-ai-to-tackle

**The Nature Conservancy's Smart Weighing Measuring System** - This is a comprehensive system for use in processing plants. TNC piloted the Smart Weighing Measuring System (SWMS) in Indonesia, in partnership with Indotropic (a seafood processing company) and an IT company that helped develop the components. Fish that are brought to the processing plant are first sorted by type, sometimes with the assistance of software like FishFace, and barcoded. Then the fish are weighed and passed onto a measuring board where fish length is quickly quantified. A new barcode is printed that combines weight, measurement, species and GPS tracking information, which is integrated into a database. These barcodes then follow fish through packaging and to the buyer, creating an extremely detailed profile for the catch. SWMS requires a touchscreen computer, a barcode printer and scanner, digital scale and a measuring board. If full retention of the catch can be ensured (especially with respect to discarding fish in certain length categories that may be of lower value or sold to other buyers prior to landing at the processing plant) this system may provide a way to check compliance with size limits and estimate length-frequency composition; this data can be used to compute fishing mortality and spawning potential ratio, both important indicators of overfishing.

https://www.nature.or.id/en/blog/ensuring-traceability-of-marine-product-all-the-way-to-the-source.xml

### *Compliance with spatial and time restrictions*

Spatial restrictions (i.e., restrictions on where fishing can take place) are often put into place with the intent of protecting spawning aggregations, fragile habitats and marine biodiversity. However, only a small fraction of marine reserves (where fishing is banned) are enforced due to the cost of using patrol boats, the failure of prosecutorial systems to take violations seriously, the remoteness of certain zones or dispersal areas, and more (Campbell et al., 2012; Edgar et al., 2014; Yamazaki et al., 2018). Restrictions on when fishing can take place (i.e., time restrictions) are used in many fisheries to protect spawning activity, aggregations or other features that make a stock especially vulnerable to overfishing, and sometimes to simply reduce fishing pressure.

**Conservify FieldKit** - FieldKit is an open-source software and hardware platform (including environmental sensors, app, and FieldKit.org website) that allows individuals and organizations to collect and share data, and to tell stories using data through interactive visualizations. The modular aspects of FieldKit make it useful for many different kinds of applications. One such application would be in serving as a low-cost fisheries monitoring device. The core FieldKit circuit board contains all of the components and circuitry to support coastal VMS for tracking compliance with spatial restrictions: a GPS, solar charging circuitry, expandable data storage through SD cards, WiFi module for smartphone connection, and free data downloading through an onboard LoRa radio module (supporting commonplace Internet of Things radio networks deployed across the globe). The advantage to using LoRa radio for downloading the GPS tracks of vehicles is that it costs less than transmission through cellular networks but still has impressive range and coverage. This effort is currently being piloted with a team at Scripps Institution of Oceanography.

https://www.dropbox.com/s/tvjl6uv42ifulex/FK_Fisheries.pptx?dl=0

**Argos CLS Transmitters** - Vessel tracking system designed for small-scale fisheries vessels. Using the Argos satellite constellation, these trackers collect both GPS data and Doppler location (based on the change in frequency that occurs as objects move toward or away from the receiver). While GPS locations can be spoofed or interfered with, Doppler locations cannot be falsified. The transmitters can be installed by the fishers themselves and include an assistance button for emergency situations. The data are compiled in a CLS-designed interface that displays location, speed and directions of vessels on a mapping system. Authorities can also see if a transmitter has been turned off. CLS often assists with building up the technical expertise required to make use of their data, but the amount of technical expertise required to utilize data can often be a barrier.

https://fisheries.cls.fr/governments/protect-small-scale-fisheries/

**Pelagic Data System (PDS) Vessel Tracking System** - This affordable device ($150 for the tracker and $20 per month for data service) is a little bigger than the average smartphone, solar-powered and easy to install. It records vessel position every few seconds and uploads the information automatically, using cellular networks, to a secure data cloud. If necessary, the device can even store up to a year's worth of data directly onboard, allowing data to upload whenever a cellular network is available. The devices can be customized for other data needs, by adding on gear sensors or temperature loggers which integrate into the system. The device is enclosed in a durable case so that there is nothing to turn on or off, open, break or replace, which leads to the claim that the device is "tamper proof." After data are collected, PDS compiles the vessel activity in an online dashboard, where it is possible to view individual and multiple vessel tracks; sort track data by permit status; and detect landing sites, incursions into protected zones and other fishing behavior patterns. PDS also offers more complex data analytics, depending on the context and other data available. For example, catch logs can be integrated with vessel tracking to map the most productive fishing grounds. Fifteen different countries have already launched programs using PDS, which has received the NatGeo Marine Protection Prize and the Seafood Champion Award for Innovation.

http://www.pelagicdata.com/

**Satlink VMS Artisanal** - Solar powered VMS device that is self-contained and self-powered and thus does not require any installation; it is simply secured to the vessel. The device is comprised of a satellite transceiver with an integrated GPS receiver, allowing it to leverage Satlink's satellite network coverage to send GPS retrieved information on vessel location and movements. There is an emergency beacon function that automatically sends a notification to authorities and also emits a flash to make the vessel easier to locate. Satlink also offers different software interfaces to leverage VMS data, such as an electronic reporting system that automatically integrates VMS information with reporting statements. There are also more straightforward interfaces like "TrackIT," which is PC and smartphone compatible and displays the location of the fleet in 10-minute intervals. It is even possible to set update alerts, for example if a vessel stops reporting its location or enters a new zone.

https://satlink.es/en/tracking-monitoring/satlink-vms-artesanal/

**Remora** - This is a vessel tracking device paired with a web platform that improves the traceability of fish catch and vessel monitoring. Device users can define restricted areas and set up alerts to notify them by text or e-mail when they approach these areas. Further, Remora examines vessel fuel use in order to increase fuel subsidy accountability and incentivize government interest. Remora began its first field tests in Cabuya, Costa Rica in October 2018, but hopes to expand geographically. While devices are not currently for sale, the creators hope that each tracker would cost no more than $150.

https://www.imaginexyz.com/projects/remora

**Global Fishing Watch (GFW)** - This data platform detects illegal fishing independent of fishery-specific monitoring efforts by collecting and integrating a tremendous amount of information about fishing activity from around the globe. This is a big advantage for fisheries that are unwilling or unable to carry any monitoring equipment except VMS or AIS. Primarily, GFW analyzes publicly available AIS data, but it is supplemented by infrared imaging, which uses light to identify vessels fishing at night, as well as radar systems. A growing number of countries provide GFW with their fleet's VMS data. These data inputs, which are all different ways of tracking vessel location, are then run through Google-designed algorithms. This step ensures the vessels included are fishing vessels, not cargo ships or sailboats, and allows for additional analysis (e.g. type of gear, vessel size). The information is then displayed on a free, public map that can show information from as recent as three days prior. The map can be overlaid with marine protected areas, narrowed down to one specific vessel, or indicate heat maps of activities. Currently, most of the information is from and about large commercial fishing vessels. However, these data can benefit small-scale fisheries by enabling governments to detect illegal fishing, interdict illegal vessels and deter illegal fishing—particularly in the form of encroachment into areas set aside for artisanal or small-scale fisheries, or into protected areas. GFW is committed to finding ways to integrate more small-scale fishing into its data, as evidenced by a recent partnership with Pelagic Data Systems.

http://globalfishingwatch.org/

**FishSpektrum** - This is not a service or a monitoring system but rather a resource for stakeholders interested in tracking vessels. FiskSpektrum is a multi-disciplinary big-data project that has developed a publicly available global, up-to-date database of fishing vessels, including gear type, flag state and regions of fishing pressure. As of October 2018, FishSpektrum has almost 1.7 million fishing units (vessels) in its database, though not all of them are active. These data are collected and standardized from public records from IMO, FRV-EU, FAO, RFMOs, ITU, national ship registers, ship classification societies and IUU red lists, among others. The majority of these are registered in Europe. While the service is intended for all stakeholders, the entire database is restricted and only accessible to those with a password, who may be paying users. To date, the team at FishSpektrum has engaged in large-scale projects focused on global bluefin tuna trade, illegal fishing in West Africa, discards in Europe and a review of data on transhipments from Global Fishing Watch. The practical utility of FishSpektrum for smaller-scale fisheries remains unclear.

http://fishspektrum.com

**OceanMind** - OceanMind is a non-profit that works with clients to compile and analyze data for vessel monitoring, improving supply chain traceability, fisheries monitoring in EEZs and marine reserves monitoring. OceanMind uses publicly available data from VMS, AIS and other sources and corroborates the accuracy of data transmitted by vessels of interest, which allows them to identify likely illicit and unlicensed behavior in a particular area. For example, in a project within the Chilean EEZ, OceanMind was able to provide enforcement agencies with timely evidence of illegal fishing, which increased their chances of catching rule breakers. The services provided by OceanMind, if accessible to smaller scale fisheries, would likely alleviate some capacity constraints associated with analyzing monitoring data.

http://www.oceanmind.global

**Navama** - A for-profit company that partners with NGOs to monitor protected areas and fishery management zones using satellite AIS data, VMS and other GPS data. Navama has developed several pilot programs and devices that they have deployed across the globe. One tool they have developed is called seeOcean, a spatial and analytical platform that consolidates available vessel tracking data with other relevant data such as bathymetry, seamounts, coral reefs, protected areas, wave, wind, chlorophyll, ports, EEZ and RFMO boundaries to allow the large-scale analysis of marine fishing activities. Navama claim to pair these data with a full supply chain traceability program called Smartfish that certifies a product's provenance using the seeOcean platform. While such a service has utility for fisheries concerned with traceability, it may be costly and inaccessible for fisheries with low capacity. In addition, Navama provides a platform whereby fishermen with a tracking device can voluntarily register their vessel onto a public-facing database, which would demonstrate their compliance with regulation and be useful for analysis. This platform was developed in partnership with World Wildlife Fund (WWF).

http://navama.com/

**Trygg MatTracking (TMT)** - TMT collects vessel information tracking data with the explicit purpose of identifying illegal fishing operations and notifying relevant stakeholders. TMT compiles and updates a global public registry of IUU vessels, normally kept by RFMOs and certain agencies like INTERPOL. In addition, it is building a tool (Fisheries Analytical Capacity Tool) similar to FishSpektrum that intends to identify every active vessel on the global fishing fleet and the companies that operate it, using the vessel as the unit of analysis. TMT has supported initiatives in West Africa to combat illegal fishing, mainly by identifying and tracking fishing vessels, analyzing their movement patterns, defining ownership structures of fishing fleets and investigating fishing crimes. This system therefore has the most utility after a fishery has adopted some sort of functional tracking program.

https://www.tm-tracking.org/

**Synthetic Aperture Radar (SAR)** - This technology is most commonly used to map ground features and terrain. There are only a few satellites equipped with SAR, making SAR data hard to come by. However, because SAR images come in a large range of resolutions, and because they are not impacted by weather (e.g., cloud cover) or darkness, SAR can provide a way to monitor fishing vessels even if AIS or VMS systems are turned off. SAR does not depend on cooperation or collaboration with the fishing fleet. Unfortunately, at this time SAR is difficult to miniaturize for use on drones or planes.

**Planet Images** - Earth-imaging company that creates satellite images that can supplement AIS and VMS information, or monitor areas where AIS signals have been turned off or lost; however, satellite images are impacted by weather and darkness. These images can be crucial for open-ocean area monitoring and for directed, sustained study of traffic in certain ports. Resolution of these images may vary, including 3-meter, 5-meter and 80-centimeter. Customers can pay per image, requesting pictures of certain areas, or enter into a subscription agreement to monitor areas over time. Planet also sells its extensive image dataset to academics for research purposes, and research accounts are also available. Currently, Planet emphasizes its satellite images for open-ocean study, rather than nearshore studies. The lack of highly accurate directional controls on the small satellites that take Planet images may pose a challenge for geo-referencing the photos, making the use of these images for monitoring MPAs or other relatively small areas problematic.

https://www.planet.com/markets/maritime/

**Marine Monitor (M2)** - Low-cost software that pairs with a shore-based radar to monitor nearshore marine protected areas (MPAs). M2 specifies its use for marine protected areas because radar cannot distinguish between permitted and illegal vessels; thus it is simplest to use radar when all vessels are subject to the same rules. M2 software requires the purchase of "off-the-shelf" radar hardware that is then fitted with M2's custom open-source software solution that displays boat tracks and integrates site-specific areas of concern. Alerts can be set up so that M2 notifies users when a vessel has entered a MPA or its duration in a MPA. M2 software can integrate data from an AIS sensor or a shore-based HD camera. Including the price of software, tech support, radar hardware and possible site-specific costs, M2 estimates the deployment cost of the system to be $80,000; this may seem costly, but may be cost-effective for some fleets as it can monitor up to 30 vessels. M2 has been deployed in the Philippines, Mexico and California, with projects pending in further locations.

https://protectedseas.net/marine-monitor-m2/

**SA Instrumentation** - Manufacturer of systems of passive acoustic monitoring for marine mammals. By using hydrophones and acoustic processing systems, these technologies can detect the presence of marine mammals through the sounds they emit. The technology has been designed to withstand harsh conditions, so there is a range of ways it can be deployed, whether in a fixed terrestrial or marine mount, on buoys, or included as a payload on a drone. SA Instrumentation's systems are able to transmit their data wirelessly, most often utilizing cellular networks—minimizing operation costs and allowing for long-term autonomous deployment—and can be powered by batteries or solar panels. Additionally, SA Instrumentation can customize systems to meet user needs, such as its new mobile system that is more transportable.

http://www.sa-instrumentation.com/.

**Soundtraps** - It may be possible to use lower cost passive acoustic technology such as battery powered underwater microphones (approximately $3000) with built-in data loggers to detect and deter illegal incursions into protected areas or territorial use rights for fishing (TURF) areas. For example, if night fishing is illegal, enforcement authorities can compare recordings made at night with a library of sounds associated with fishing activities to detect fishing at night.

http://www.oceaninstruments.co.nz/

### *Compliance with transhipment regulations*

Transhipment, which is the transfer of fishing supplies and seafood products at sea, has become a vital part of the seafood industry. Transhipment saves fuel, labor and time associated with having large fishing vessels return to port after each fishing trip to deliver fish and resupply. However, it is often used to launder illegally caught fish by mixing the illegal catch with legal catch on a fishing vessel, or by transferring illegally caught fish from the fishing vessel to artisanal fishermen who are not regulated.

**Global Fishing Watch** - The Global Fishing Watch (GFW) program uses vessel movement patterns based on AIS and VMS data to detect potential illegal transhipment activity. See section on compliance with spatial restrictions for more details on GFW.

**Project Eyes on the Seas –** A partnership between Pew Charitable Trusts and Satellite Applications Catapult that uses satellite monitoring, along with other data, to detect "suspicious fishing activity." Among other scenarios, suspicious activity can consist of two or more vessels in close proximity (a transhipment indicator) or a vessel that stops signaling its position. When an activity is deemed suspicious, Eyes on the Seas analysts research vessel history. Once they make a determination, an automated system notifies authorities of suspected illegal behavior in their domain. Authorities are then able to pursue vessels, investigate them and possibly prosecute them. As of 2015, the system was geographically focused on marine reserves in the southern Pacific, directly working with Palau, the Cook Islands, Samoa and others.

https://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2015/03/project-eyes-on-the-seas

**Autonomous vehicles** - Autonomous vehicles are powered by wave and/or solar energy, navigated by remote control and can carry a variety of sensors such as microphones and cameras. In concept, such vehicles could detect illegal activity and transmit data to enforcement entities; however, they are quite expensive at present, preventing routine use in most fisheries. A considerable amount of research is being conducted on the development of inexpensive autonomous vehicles that may be practical for use in enforcing spatial fishing restrictions.

## *Reducing fish fraud*

Seafood certification and ranking systems such as the Marine Stewardship Council and Monterey Bay Aquarium's Seafood Watch Program depend on supply chain transparency and traceability. If seafood buyers cannot be sure of the provenance of seafood or how it was caught, price premiums or market access that reward sustainable fishing behavior cannot be assured. Unfortunately, seafood fraud is rampant. Though few investigations have been carried out, there are many documented cases of seafood purveyors selling lower value fish as more highly valued species, either knowingly or unknowingly (Buck, 2010; Warner et al., 2013; Wagner, 2015).

**FIGURE 5** A prototype Conservation X labs DNA scanner. These portable scanners could be used to identify seafood to species level and help to reduce seafood fraud. Credit: Conservation X

**Conservation X DNA barcode scanner** - This small hand-held DNA scanner is still under development, but has been piloted with customs enforcement officials in Washington. Fish samples are ground up and solutions are added to free the DNA from cells (Figure 5). The device then analyzes the DNA in the sample and compares it to the Barcode of Life DNA library to make an identification. It can be pre-programmed to indicate whether or not the sample matches the DNA of a protected species, and a built-in camera takes a screenshot to serve as evidence. Currently, each test takes about 30 minutes and each sample costs about $15 to process with the scanner (Gewin, 2018).

**Legit Fish** - This is a supply chain validation system which compares seafood provenance claims with government records; hence, it requires credible government data.

http://legitfishinc.com/

**Tracking devices** - Vessel tracking devices such as the Pelagic Data Systems (PDS) tracker can be used to establish locations in which fish are caught and landed. These data can serve as part of a digital record of seafood provenance.

**Supply chain tracking software** - A number of software systems are now available for tracking fish through the supply chain in order to reduce fish fraud and reliably transmit information about the seafood to buyers. First, the fish must be labeled with a unique identifier. For high value products, a QR code, barcode or NFC-enabled labels (small passive electronic disks that encode information and are activated by the magnetic fields produced by smartphones) might be required to ensure sufficient security. For other products, text messages or app input fields that include information on where the fish was caught, how it was caught, how it was handled, where it was landed and other information can be validated by trusted entities, such as local NGOs with no financial stake in the fishery. These attribute data can then be transmitted to buyers via standard forms of communication; the problem remains that fishermen or buyers could alter the information and thereby make false claims about the seafood in order to secure higher prices or access to more markets. A pilot study conducted by the non-profit collective Provenance has shown that tuna caught by fishermen using poles and lines in small boats could be tracked through the supply chain using text messages validated by trusted local NGOs and blockchain technology, which is essentially an encrypted electronic ledger maintained on a large network of computers to reduce the risk of hacking posed by large centralized databases (Provenance, 2016). Blockchain also requires each transaction to be authenticated with highly encrypted digital keys, which prevents anyone from altering the attribute data associated with a shipment of seafood. In the Provenance tracking system, the attribute data are organized into a story about the seafood which can be accessed by hovering smartphones over NFC-enabled stickers on seafood packages.

### *Improving governance conditions for compliance*

Fisheries enforcement depends on reliable methods for identifying fishermen and vessels which are eligible to participate in a fishery, and the nature of their fishing privileges or rights (e.g., validity of their fishing permit or quota). Many governments maintain fisher and vessel registries for this purpose. However, there are thousands of fisheries that are conducted by fishermen and vessels that are not registered, making enforcement of eligibility requirements impossible.

The lack of basic demographic information on artisanal fishers makes it difficult to formulate sound policy on human and health services, let alone fisheries management for this large sector of society. However, this is changing with the use of mobile phone technologies. For example, in the Philippines, the National Program for Municipal Fisherfolk Registration (FishR) allows fishers to register themselves and their fishing activities in a centralized database using a computer or mobile device. Previously, the process required fishers to report in person to a local government office. Prior to FishR, only 5% of the estimated two million small-scale fishers were registered, leaving the rest of the small-scale fishing sector largely unaccounted for. Within just two years, that number increased to more than 80%, or 1.5 million fishers. A major reason for the program's success is that registration comes with an incentive: access to certain government services such as health insurance and alternative livelihood opportunities (Gorospe et al., 2016).

**FINNZ ELEMENTS –** A comprehensive web-based fisheries management software platform that can support all aspects of fisheries administration. Accessible on tablets, smartphones and computers, this platform offers modules that assist with fishing registers, licensing, catch quotas, reporting, trading and even financial management activities. Users can choose from among these modules to customize a system to meet their needs. Centralizing a fishery's data in one cloud-based platform can improve diagnostics and reduce redundancies. FINNZ is third-party friendly, meaning it can integrate with outside data streams (e.g., VMS tracking) or, if a fishery chooses not to use FINNZ for catch monitoring, electronic logbooks. It can easily be scaled to thousands of users or kept at the small-scale level.

http://www.finnz.com/products/fisheries-management-solution/

**FishTrax** - A customizable, web-based system for fisheries data management. Each FishTrax system can be configured for a fishery's needs, from a simple single purpose like fisher-reported catch information, to a comprehensive collection of scientific information, traceability information, administrative information and more. These portals utilize an import login for data entry, and an export login for others to access the information. This allows for the control of data input and access. In fact, depending on the stakeholder, FishTrax takes the same information and displays it differently to emphasize the trends most important to that stakeholder group. There can even be a public portal that educates the general populace about the fishery.

http://fishtrax.org/

### *Data management*

Many aspects of fisheries need to be monitored for enforcement to be effective. Because monitoring systems often develop in a piecemeal, unplanned fashion, many fisheries store monitoring and surveillance data in different forms of varying utility. For example, logbooks and fish landing receipts are often kept on paper, while catch data may be transcribed from paper forms into electronic spreadsheets for analysis. Registration and permit data are often kept in a separate database. Differences in data formats can make quality control and analysis—and therefore, enforcement—difficult or even impossible.

A number of integrated platforms are now available to fisheries willing to invest in unifying data formats. These platforms often consist of data loggers that can receive input from a variety of different sensors, databases and user interfaces that allow for quality control, analysis and visualization.

**Nautilus** - A cloud-based content manager that works on iOS or Android platforms and can also be accessed on the web. Users can upload files of all types (e.g. PDF, audio, video, etc.) to Nautilus, and the information is then distributed to authorized users who are members of the administrator-defined groups. In a mobile setting, the Nautilus application synchronizes and stores appropriate content on users' devices, which allows them offline access to the information. When users are within WiFi or cellular network range again, the information will automatically update.

http://www.elementalmethods.com/nautilus/

**Olrac Dynamic Data tools** - Described as an electronic logbook solution, this tool is comprised of two components: the Olrac Dynamic Data Manager (DDM) and the Olrac Dynamic Data Logger (DDL). The DDM is a web-based tool that can store and manage numerous types of fishery-related data and reports like vessel movements, port departure and entry, fishing activity, catch and others. Access to the DDM is controlled by user logins, with different levels of access assigned to different titles (e.g., fisher, administrator, inspector). The application features a map interface and can run analyses to provide key information. The DDM tool is paired with the DDL, which can collect information for compliance, environmental or scientific data reporting purposes. It can send the collected data in any format, whether numeric, text or even video. DDL can be installed on waterproof, ruggedized tablets for use on vessels or outdoor landing sites. Information is transmitted using satellite, cellular, or WiFi networks, depending on what is available. Available from OLSPS Marine, initial price will vary based on the level of customization required. Users also must pay an annual licensing fee, which will be around 20-30% of the initial price.

https://marine.olsps.com/

**Akvo** - This organization aims to increase transparency and data sharing in the international development sector by providing services, such as trainings or design consultations, through their open-source data platforms. Operating on a "not for profit, not for loss" basis, Akvo offers assistance at the "design" stage (i.e., deciding what data to collect), "capture" stage (i.e., training data collectors), "understand" stage (i.e., cleaning and analyzing data) and finally, the "act" stage (i.e. sharing insights with relevant people). Open-source tools such as AkvoLumen or AkvoRSR encourage the consolidation of data from numerous sources and in different formats, allowing for the import of multiple file types and the construction of specialized survey forms so that fisheries can collect the data they need.

https://akvo.org/

**SMART Marine** - The Spatial Monitoring and Reporting Tool is a conservation software that aims to improve enforcement efficiency. The software is a project of the SMART Partnership, which consists of nine global conservation agencies. By collecting, storing and analyzing information collected by enforcement officials or local people, SMART can inform agencies where their efforts can best be focused. Data collection can also be used to evaluate ranger job performance, which has proven to motivate improved performance and encourage those already performing well. The software is free and open-source, and is compatible with MIST, CyberTracker and CITES-MIKE databases. A permanent computer, such as a laptop, is required to install the software, and data must be referenced using GPS coordinates. While a GPS-enabled smartphone can be an efficient way of collecting data for input into SMART, paper forms may also be used as long as data are geo-referenced using a GPS device.

http://smartconservationtools.org/

### *Incentivizing data collection and sharing*

Many fisheries lack strong statutory or regulatory mandates to collect data that can be used to enforce catch limits, size limits, spatial restrictions and other regulations; for such fisheries it will be especially important to incentivize data collection. In some cases, buyers who want reliable information about the seafood can simply pay fishers and/or port enumerators to collect this information, or demand it as a condition of purchase. Periodic audits for accuracy might suffice, as well as electronic reporting technologies that not only collect information, but provide insights to fishers. In developing country contexts, providing access to up-to-date weather or sea condition information within collection apps can also increase enthusiasm among fishers for using monitoring technology. However, in other cases where trust is low, transferring valuable tokens via smart contracts for data stored on a blockchain may be useful.

**FishCoin** - This technology is still in the development phase but has the potential to incentivize data collection and to reliably transfer information about seafood through the entire supply chain (FishCoin, 2018). Fishers or port enumerators would use a smartphone or tablet app like mFish (developed by Eachmile, the same team behind FishCoin) to capture information on where the fish was caught, how it was caught, where it was landed, how it was handled and other information that might be valuable to seafood buyers and consumers (i.e. Key Data Elements, which vary among buyers and regulatory entities as they have different data needs). As the seafood is transferred from harvesters to the first buyer, and then to the next, on through the supply chain, this digital information is transferred in parallel through a blockchain to keep the information secure. Participants in the FishCoin ecosystem would "purchase" the digital record with tokens, thus incentivizing the collection of accurate data: inaccurate data could prevent transfer of the digital record to the next buyer, or perhaps the sale of the seafood itself. The digital record could be validated by government inspectors or trusted NGOs without a stake in fishery profits at the point of harvest, upon entry into another country, or at other points in the chain. Because many fishers are unlikely to value tokens that would be listed on cryptocurrency exchanges, FishCoin would make it easy for fishers to exchange FishCoin for mobile phone airtime or cash.

### *Predicting illegal behavior*

While technologies such as shore-based radar can effectively monitor fishing activity in nearshore areas, and vessel tracking devices can monitor the activity of registered vessels, illegal fishing activity often occurs by unregistered, untracked vessels, and far from shore. As enforcement resources such as patrol boats and port monitors are scarce, and the potential areas in which illegal fishing can take place are many and large, the ability to predict where illegal fishing is likely to take place can increase the effectiveness of enforcement efforts. Moreover, some illegal fishing activities, such as blast-fishing (where fishers use dynamite to kill mainly reef fish), are so destructive that preventing them is of paramount importance.

A recent emphasis is therefore being made on data analysis techniques that can be used to better predict fishing behavior; existing VMS and AIS data have formed the main basis of these efforts. For example, de Souza et al (2016) utilized satellite-AIS data to detect and map global fishing activity using a global, four-year data set. The authors developed three different procedures—including data filtering, a statistical model and a data mining approach—to characterize and predict fishing activity for the three major gear types in use on the world's oceans: seine, longline and trawl. VMS and AIS data analyzed using machine learning techniques are also being used to characterize transhipments at sea, which often enable illegally obtained catch to be transferred to a market-bound vessel outside of the jurisdiction of enforcement agents (Miller, 2018).

Recently this big-data analysis approach has been amended to include environmental variables to enable better prediction of fishing behavior. For example, Kroodsma et al. (2018) explored the impact of oceanographic variables, such as primary productivity estimates and sea surface temperatures, to predict the intensity of fishing effort in areas of the world's oceans. Additionally, Ortuno Crespo et al. (2018) developed a predictive model for longline fishing that incorporates 14 environmental variables, such as sea surface temperature, salinity and estimates of primary productivity, to better understand the environmental preferences of longline fishermen and thus predict the occurrence and distribution of longline fishing effort.

Image Sat International (ISI) has developed Kingfisher, a multi-sensor intelligence system that uses a combination of information sources to expose illegal fishing, including satellite-AIS, VMS, SAR, infrared imagery and coastal radar. For example, if a vessel's AIS system is turned off but the vessel is detected using other imagery techniques, this is a good indicator that illegal fishing may be occurring. A good example of Kingfisher's capabilities occurred in the jurisdiction of a South American country when a fishing vessel approached the EEZ boundary and switched off its AIS system. Kingfisher's predictive algorithm determined where they expected the vessel to be, the country dispatched patrol vessels, and the illegal fishing vessel's crew were apprehended.

https://www.imagesatintl.com/solutions-services/maritime-situational-awareness/

This emphasis on statistical prediction of illegal behavior is rapidly gaining traction. In theory, the occurrence of any illegal activity can be related to explanatory variables, such as environmental factors and the characteristics of the fishermen, and economic variables, such as price. For example, Aghilinejhad et al. (2018) conducted a range of field surveys around the southern Caspian Sea in Iran to determine the factors that contributed to the occurrence of illegal fishing of the sturgeon stock. The authors used a statistical model to show that several social, economic and other variables could predict the occurrence of illegal fishing. These variables included fish price, fishermen's awareness of penalties and vessel ownership structures.

Once a statistical model has been formulated, risk scores that reflect the probability that a particular vessel will engage in illegal activity, or that illegal activity will occur in a particular area at a particular time, can be developed. For example, if enough cases of blast-fishing in a region are available, along with data on equipment and supplies purchased in support of each trip (e.g., fertilizers, blasting caps, or pipes to make bombs), it would be possible to construct a "training set" that would enable the use of machine learning techniques to learn which attributes are highly correlated with actual

**TABLE 1** Fishery Enforcement Challenges that Can Be Addressed with Existing or Soon-to-be Available Technology

| CHALLENGE/NEED | TECHNOLOGICAL SOLUTIONS | SPECIFICS |
|---|---|---|
| IUU fishing of highly migratory species and transboundary stocks | Satellite imagery<br>VMS data<br>AIS data | Global Fishing Watch, Eyes on the Sea, Camio, Data Science for Social Good |
| Catch limit compliance - self reported | Electronic logbooks on tablets<br>Smartphone apps | TNC e-Catch, DeckHand<br>Apps: Abalobi, mFish, FACTS, FishBrain, iSnapper, FishAngler |
| Catch limit compliance - monitored | Low-cost cameras with data loggers | Flywire, ShellCatch |
| Effort limit compliance | Electronic logbooks on tablets<br>Smartphone apps<br>GPS trackers<br>Low-cost VMS | TNC e-Catch, DeckHand<br>Apps: Abalobi, mFish, FACTS, FishBrain, iSnapper, FishAngler<br>PDS trackers, Remora trackers, SatLink artesanal VMS |
| Compliance with spatial restrictions (MPAs, TURFs, SPAG closures, etc) | GPS trackers<br>Low-cost VMS | PDS trackers, SatLink artesanal VMS, Data Science for Social Good tracking and alert software, Camio tracking and alert software |
| Compliance with seasonal restrictions | GPS trackers<br>VMS | PDS trackers, Remora trackers, SatLink artesanal VMS |
| Reducing bycatch of ocean wildlife | Cameras<br>Satellite imagery<br>AI for detecting wildlife in images<br>Acoustic monitoring of marine mammals | Flywire, ShellCatch, GoPro<br>Planet Images, CVision<br>SA Instrumentation |
| Illegal access to fishery | Radar<br>GPS trackers<br>VMS | Marine Monitor (M2) radar<br>PDS trackers, Remora trackers, SatLink artesanal VMS |
| Seafood fraud | DNA scanning<br>Blockchain ledgers | Conservation X DNA scanner, FishCoin |
| Fisher ID and vessel registry | Electronic registries | FINNS, FishTrax (web-based) |
| Compliance with size limits | Cameras<br>AI software for image processing<br>Web-based length quantification | Flywire, Shellcatch, TNC system, CVision, Poseidon |
| Data management | Hardware to integrate data from multiple sensors<br>Databases with user friendly interfaces | Nautilus, Olrac<br>Akvo, Hydroswarm |
| Predicting illegal activity | Machine learning | Google TensorFlow |
| Incentivizing data collection and sharing | Blockchain ledger | FishCoin |

blast-fishing events. These attributes would then be used to assign a blast-fishing risk score based on the monitoring of those attribute data in advance of fishing trips. One such project conducted by researchers as part of the Data Science for Social Good (DSSG) initiative is to create an open-source risk tool which would use machine learning techniques to analyze satellite data and create a "DSSG Risk Score". This risk score, which would apply to individual vessels as well as fishing areas, would help to inform fishery managers and enforcement agents of the appropriate allocation of surveillance and enforcement resources. The outputs from these analyses, including risk scores, would enable enforcement authorities to focus inspection or interdiction efforts.

https://dssg.uchicago.edu/project/fishingriskframework/

## SERVICE MODELS

Technologies can generate data, but it takes people to make sense of and use the data to deter illegal fishing. It also takes people to find the right technology and purchase, install, test, maintain and repair it. We refer to all these functions as the "service model". One model for providing these services entails a community-based approach, in which local fishery managers, fishermen and perhaps NGO personnel perform all of these functions. Another model is for local managers and stakeholders to design the monitoring system and use the data, relying on technology vendors to install and maintain the equipment. Yet another model is to retain a service provider who can provide all of the necessary equipment, install and maintain it; and even analyze the data to produce data products that local managers and stakeholders can use for enforcement purposes.

## BARRIERS TO UPTAKE

Just because technologies to enhance fisheries surveillance and monitoring are available does not mean that they will be adopted. And even when technologies are adopted, the data they produce are not always used for management. The specific barriers to the uptake and use of technology will vary from fishery to fishery; the design process outlined later is aimed at identifying and overcoming these barriers. In this section, we describe common barriers to increased uptake of surveillance and monitoring technologies and the enabling conditions necessary for their use in effective fisheries management and enforcement.

### *Insufficient drivers for monitoring and enforcement*

All fisheries need drivers for monitoring; it does not happen spontaneously. Some fisheries engage in monitoring in response to social or ethical commitments to resource stewardship. Others monitor for encroachments or infractions by "outsiders"—but not within the fishery itself—in response to perceived losses. Often, fisheries need a legal or regulatory mandate to monitor, usually coupled with a rationale for monitoring, such as the need to sustain yields, prevent illegal fishing or protect habitat. To be effective, such mandates must include deadlines and consequences for failing to implement monitoring and surveillance programs.

To be sure, there are many cases where small-scale fisheries without a statutory or regulatory mandate for monitoring have incorporated, or made attempts to incorporate, technology into monitoring programs through NGO, industry and government interventions. These are often driven by inter-governmental agreements, NGO initiatives and/or funding opportunities. One example is FISH-i Africa, a task force uniting eight Eastern African countries committed to using monitoring and market forces to deter illegal fishing and fisheries crime (including fraud, forgery, corruption and slavery) in the Western Indian Ocean (Stop Illegal Fishing, 2018). While FISH-i does not finance and deploy EM systems, it does promote and encourage the use of AIS and VMS systems to track and identify vessels to catch illegal activity. FISH-i has used information supplied by monitoring programs to deny port access to known illegal vessels, to uncover vessels without licenses or with false licenses, and to locate vessels fleeing enforcement officers. These successes were supported to some extent by the use and availability of technologies such as VMS and AIS (Gutierrez et al., 2018).

Some monitoring programs that reveal illegal activity arise for surprising reasons. For example, when fishing was banned in the Upper Gulf of California, many fishermen worked with scientists to place PDS trackers on their vessels. The trackers would demonstrate to the government that their landings were legal and compliant with spatial and temporal regulations (Blust, 2018) and much higher than records suggested. The motivation was to qualify for larger compensation payments for not fishing, which were tied to previous landings.

For some fisheries, even strong drivers for monitoring are not enough to overcome barriers such as high perceived costs; fear of having to change fishing practices; concerns about being held accountable; privacy concerns; infrastructure gaps; social and cultural barriers; and low fisheries governance. These concerns can impede or even completely block progress toward fisheries monitoring (Mangi, 2015; Sylvia et al., 2016; Bartholomew, 2018; Stop Illegal Fishing, 2018). We discuss these barriers to monitoring in the next sections.

### *High perceived costs*

While the use of monitoring technologies can reduce monitoring costs relative to other methods, such as onboard or dockside observers, costs may be perceived as relatively high because of the need to purchase equipment and the psychological tendency to subconsciously downplay savings or other benefits that accrue over longer timeframes. Moreover, while the costs of monitoring are typically distributed in some way among individual vessels, fleets, governments and other stakeholders, there is not always clarity and consensus on which actors will pay for what, how long this arrangement will last and under what conditions. In some cases, governments pay for monitoring programs, while in other cases governments partner with industry or NGOs to finance them. For example, a pilot program for monitoring the curvina fishery in Mexico was financed by two state governments and an NGO (Rafael Ortiz, pers. comm.). In other cases, outside actors, such as governments of other countries and donors, pay for VMS and AIS programs. The government of Norway, for example, finances VMS and AIS tracking services from Trygg Mat Tracking (TMT) for the FISH-i project and the West African Task Force (Gutierrez et al., 2018). In both of these examples, the source of outside funding does not guarantee permanence or stability in the long term. In addition, funders of the programs may have different goals for monitoring than those more intimately involved with the fishery itself.

In other cases, management authorities reimburse vessels for their monitoring costs, which can be a burden to fisheries with less upfront capital. For example, in 2017, NOAA Fisheries indicated they would reimburse a percentage of the cost of at-sea monitoring of the Northeast groundfish fishery, though the exact amount was not made explicit: "We expect to again be able to reimburse sectors for a portion of their eligible ASM expenses. At this time, we do not know what the reimbursement rate will be, but expect it will be less than the fishing year 2016 rate of 85 percent" (GARFO, 2017). Therefore, these costs can be too high, or be perceived as too high or uncertain, for fishermen and those working on vessels to facilitate strong buy-in and support for EM programs.

### *Resistance to change and distrust in government*

Fishers, management authorities and other stakeholders are resistant to many kinds of change, including new technologies (Eayrs et al., 2014; Mangi et al., 2015; Doddema et al., 2018). In some cases, resistance to change is associated with skepticism about the government or what the use of data would mean for their ability to remain in the fishery (Mangi et al., 2015).

### *Privacy concerns*

On fishing vessels, privacy can be rare and highly valued, especially when vessels are small and lack private rooms. Tracking devices and cameras are often seen by fishermen as invasions of privacy that make their fishing activities and locations—sometimes regarded as proprietary—transparent to managers, buyers, academics and others. This can serve as a deterrent for many fishers to participate in EM programs.

### *Accountability*

Fishery participants vary widely in their willingness to be held accountable to regulations. In pilot projects, fishermen who engaged in questionable fishing activity and could have been held accountable have tampered with fishery devices by covering solar panelled devices, putting devices on defunct boats or discarding devices into the ocean (FAO, 2018b).

### *Infrastructure*

Pilot programs and reports focusing on the implementation of monitoring programs in developing economies have noted various infrastructure barriers (pers comm: Laura Rodriguez, Layla Osman; AU-IBAR, 2015; Bartholomew, 2018). Fisheries with limited electricity, internet connectivity and cellular coverage may not be able to collect and transmit data to a central monitoring system, leaving room to cheat or engage in illegal behavior without being caught. Since many small-scale fisheries employ open deck vessels, there may be few places to safely place electronic devices onboard. In some areas, even basic communication among monitoring data analyzers, fishery managers and enforcement personnel is challenging.

### *Lack of governance*

Fishery governance consists of the rules governing fishing activities and the institutional capacity to promulgate and enforce those rules. Obviously, contexts such as highly corrupt fisheries, fisheries on the high seas and remote fisheries where the rule of law is weak or non-existent present serious challenges to fisheries enforcement.

Governance can also be inadequate due to lack of resources to process and analyze the data; lack of capacity to create and maintain up-to-date vessel and permit registries; transparency issues around who is responsible for which costs associated with electronic monitoring systems; and lack of resources to finance and implement an interface that fishermen can easily interact with. Some of these governance issues can be addressed to some extent with technology, while others will require policy reforms, behavior change interventions such as training or incentives, or deeper structural reforms (e.g., anti-corruption programs).

In some cases, lack of basic governance functions, such as the provision of up-to-date registries of eligible fishermen and vessels, can be a barrier to monitoring. The success of pilot programs in Mexican SSFs using low-cost GPS trackers was in some ways limited by incomplete or non-existent vessel registration systems (pers comm: Laura Rodriguez). An up-to-date vessel registration system or list can help link certain fishery behavior to individuals or groups associated with that vessel, leading to stronger accountability, enforcement and data collection capacities of electronic monitoring. In Mexico's curvina fishery, QR codes have been assigned for boat registration, which is a fairly low cost and simple technology solution, but one that is not yet widespread.

## DESIGNING MONITORING SYSTEMS THAT USE TECHNOLOGY

Not all technologies that look like they might help to increase surveillance or improve enforcement will actually prove to be useful. They might fail to catch on because they are too hard to use, too costly, prone to failure, hard to maintain, produce too little of value or any number of other reasons.

Here, we describe a human-centered design process aimed at overcoming barriers to monitoring and the use of monitoring technology that draws on the

Conservify technology development process, as well as on the human-centered design literature. This process has 10 steps for increasing the probability that monitoring technologies generate value for users and will actually be used, and incorporates implementation and scaling considerations.

**Step 1 - Motivate monitoring**. If fishermen or managers see no need to deter illegal fishing, or they fear the consequences of increased surveillance and enforcement too much, they will not adopt new technology. Participatory processes that allow people to freely air their concerns, and that make the benefits of monitoring—as well as the costs of not monitoring—salient and compelling, can go a long way toward alleviating concerns and generating buy-in and ownership of the idea that the fishery should be monitored and regulations enforced. Simply providing information about these issues seldom motivates people to make the investments of time, energy and money necessary to create or improve a fishery monitoring and enforcement program. A real dialogue that builds trust and belief in monitoring and enforcement is often essential.

**Step 2 - Articulate clear monitoring goals, objectives and metrics**. Without clear goals and measurable objectives that are directly related to those goals, monitoring and enforcement programs may deliver what is measured, but not what is needed or desired. For example, merely monitoring the number of fishing trips that occur in a season may not shed light on the extent to which limits on fishing effort aimed at curbing fishing mortality are being complied with, if fishermen are using gears or employing practices that increase effort or fishing mortality per trip. Monitoring goals and objectives must be feasible for the fishery, which will depend on cultural conditions, governance capacity and technical capacity.

**Step 3 - Evaluate existing monitoring data streams and find gaps.** In fisheries that are already collecting data, it is sometimes possible to find low-cost technologies that can process those data more efficiently, or fill key data gaps at lower cost and with less change required in fishing operations and management systems than would be associated with an entirely new monitoring and enforcement system. Mapping the flow of data from enumerators or new sensors into a quality control process, and then into analytical tools and management systems (e.g., harvest control rules), will help identify gaps to be filled with both technologies and new processes and rules. Monitoring technologies and the data they produce must be embedded within an enforcement system that makes use of the data to trigger timely enforcement actions.

**Step 4 - Elicit concerns, challenges and barriers.** No one knows the likely challenges of a technology better than the users. Each fishery will have its own specific set of challenges, but we discuss some common challenges and barriers in an earlier section. The key here is empathy with the users; technologies are solutions for people.

**Step 5 - Brainstorm potential uses of technology and consult with technology experts.** At this stage, there are no crazy or wrong ideas. The goal is to generate many creative ideas, and the best way to do that is to combine the perspectives, experience and knowledge of fishermen, managers and technology experts. In some cases, if not enough information is available it may be possible to rapidly prototype potential solutions to decide whether they are likely to be practical or effective.

**Step 6 - Converge on practical technologies by considering challenges and barriers.** Now it's time to sort through the ideas generated during the brainstorming session and figure out which ones will achieve the monitoring objectives at reasonable cost and in a practical way.

**Step 7 - Examine incentives for use and abuse and reduce risk of abuse (e.g., mis-reporting, disabling equipment, etc).** Fishermen and managers face different kinds of incentives in different fisheries. In contexts that reward fishermen who report higher catches than they actually are producing (e.g., during the run-up to the establishment of an Individual Quota System that will allocate catch shares based on catch history) fishermen have a strong incentive to over-report. In contexts in which fishermen are penalized for catching too much (e.g., after catch shares are implemented), they have an incentive to under-report. This is the time to identify the incentives for mis-reporting, disabling equipment and otherwise abusing the monitoring and enforcement system, and to find ways to counteract these behaviors. It is also essential to ensure that the solution will fill the gaps that were identified in step 3 and the goals identified in step 2.

**Step 8 - Pilot and evaluate new technologies**. Piloting is very important to make sure that monitoring technologies work in the actual fishery, to identify problems and to fix them before investments are made to outfit the entire fleet. Ideally, the entire monitoring system is tested in the pilot. This includes all of the data collection technologies that will be used (e.g., electronic logbooks, smartphone apps, cameras), the data management system (i.e., data quality control, analysis and visualization) and processes for using the data (e.g., enforcement response times to monitoring data). The pilot should be designed with fleet-wide implementation in mind, which means including the different kinds of vessels and gears used by the fishery in the pilot in order to optimize the placement and use of monitoring technology. It is important to design the pilots carefully, with discrete goals and an implementation plan that leverages the work on the ground. It is easier to get a pilot project running successfully in a smaller capacity and scale it community- or fishery-wide than try to implement too broadly. Generally, starting with those stakeholders that have the strongest relationship with the implementing organization will allow for understanding as issues are resolved and the process is streamlined. As the pilot shows successes, the effort can then be scaled to increasingly larger and more external groups. The risks around ineffective pilot implementation range from technology rejection to full project failure.

**Step 9 - Remove barriers that could not be removed through design.** Some barriers to the use of monitoring technology can be addressed through good design, while others must be removed by other means. Costs can be reduced by choosing less expensive technologies and creating rules for reviewing monitoring data that cost less but still achieve monitoring objectives. For example, video surveillance footage must currently be reviewed by trained technicians to detect violations. If the fishery uses logbooks as the primary means of collecting catch data, and if there is evidence that these data are reliable enough, then the video can be used as a check on the logbooks by auditing portions of the video data, saving time and money. Privacy concerns can also block progress toward monitoring and enforcement; these can be overcome using a transparent, participatory process for designing the monitoring system that builds trust that the data will be used only to improve the fishery and will not be shared inappropriately. Barriers such as the lack of sufficient motivation to monitor and enforce compliance within a fishery, fear of penalization as a result of monitoring, and weak prosecutorial systems that do not take fishery regulation violations seriously cannot be addressed through this design process; new laws or regulations may be required to increase motivation. Social marketing and communication strategies that explain the benefits of monitoring and enforcement, as well as the costs and consequences of not monitoring or enforcing, can also help build motivation and reduce conflict. In some fisheries, measures to reduce corruption, increase penalties, educate prosecutors and judges, and change standards of evidence may be necessary to ensure that monitoring and enforcement programs will be successful.

**Step 10 - Fleet-wide implementation, training and adoption.** After the monitoring technologies are modified on the basis of the pilot test, they can be installed throughout the fleet. Fishermen, analysts and managers must all be trained in how to use the technology and the data streams that it generates. In many cases, it will be desirable to start implementation on a portion of the fleet and use the good communications channel established during the participatory design process to generate demand and interest in the technology in the rest of the fleet.

Much will be learned in the early stages of implementation, and technologies will continue to evolve rapidly, so an adaptive management process is essential. This entails regularly measuring the performance of the monitoring enforcement program against its objectives, and modifying those attributes that seem to be contributing to poor performance. This should be done regularly, but not so frequently as to cause disruption and uncertainty in the fleet.

In the next sections we present the results of desk design exercises to develop monitoring systems for four small-scale fisheries: a shellfish fishery in Sinaloa, Mexico; the nearshore finfish fishery of the Los Rios region of Chile; an artisanal fishery for hake and tuna in the Piura region of Peru; and the Indonesian blue swimming crab fishery.

We applied the human-centered design process (as described above) to each of these cases, using available information and interviews with experts familiar with these fisheries to illustrate how monitoring programs can be designed for different kinds of small-scale fisheries.

## *The Shellfish fishery in Sinaloa, Mexico*

### Characterization

Altata Lagoon, in the state of Sinaloa on the northwest coast of Mexico, is part of a productive ecosystem fed by the Culiacan River and supported by a multitude of mangroves and wetlands.

The lagoon hosts many fisheries that thrive in its saltwater and estuarine conditions, including various species of bivalves, crab, shrimp and finfish. Shrimp are the main target for fishermen, with a smaller proportion targeting bivalves. Finfish harvest is mainly for subsistence purposes and local consumption. Bycatch in the lagoon is minimal with most catch utilized, though offshore shrimp fishing outside of the lagoon produces more unwanted catch. Fishing grounds for all of these species overlap to a considerable degree.

Management for the shrimp and bivalve fishery is broken up geographically into 11 cooperatives, each one being assigned a polygon over which they have exclusive fishing rights associated with permits. Each cooperative is given a certain number of permits for shrimp and bivalve harvest to be distributed amongst their members. For this reason, permitted fishers harvest both shrimp and bivalves in the same geographic polygon to which their cooperative is assigned. Unpermitted fishers harvest bivalves in banks not designated to any cooperative, creating *de facto* open access conditions.

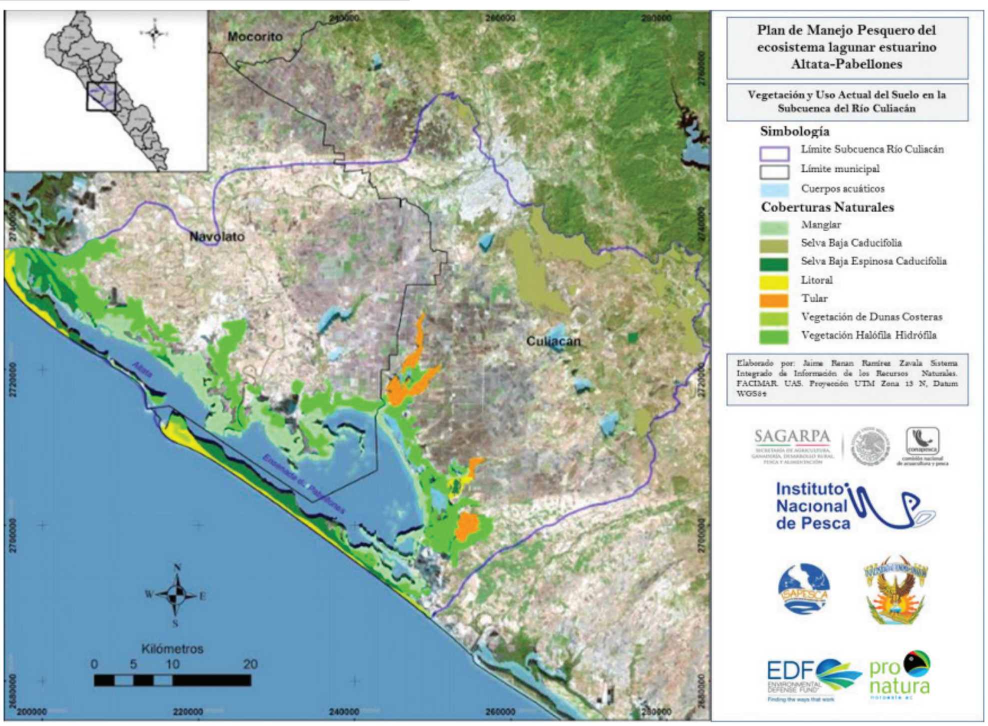


**FIGURE 6** State of Sinaloa, Mexico, showing Altata lagoon and important fishery zones. Source: FMP Altata

Eight of these cooperatives sell their shrimp harvest to Del Pacifico Seafood Company, which has achieved a Fair Trade certification for their product. These cooperatives use GPS tracking devices on their shrimp vessels and keep records of landings, gear used, catch size and fishing areas in order to maintain certification status. INAPESCA (the government's fishery science agency) seems satisfied with the current catch recording system for shrimp, but a more efficient monitoring system would save time and money and would probably be welcome.

Shrimp fishermen primarily operate five- to seven-meter vessels equipped with an outboard motor and use a 25-meter modified cast net called a "suripera". The shrimp season typically runs from September to March. Because shrimp command higher prices than other species, fishermen tend to focus on catching shrimp during the shrimp season and then shift effort towards the harvest of bivalves and other species during the "off" season.

**FIGURE 7** A bag of chocolate clams from Altata lagoon, Sinaloa, Mexico Source: http://blogs.edf.org/edfish/2018/06/04/in-sinaloa-mexico-fishermen-are-rewriting-their-legacy/

Bivalves are generally harvested by wading into intertidal or shallow subtidal waters and using small ratchets or steel bars to manually extract them. Bivalves are also harvested from open skiffs and canoes up to five meters in length with a rake-like tool called a "gafa." The bivalve community is quite diverse; some species, like the chocolate clam (Figure 7), appear to be relatively depleted, while other species of lower economic value (e.g. pata de mula and the chirla) appear to be in healthy condition.

Official records show 1,446 permitted fishermen across the 11 cooperatives and the operation of 17 licensed bivalve vessels. Most fishermen hold permits for shrimp, with a smaller proportion holding permits for bivalves and other shellfish. Some of the many participants in the fishery are not counted under the current permitting system or only fish in the area seasonally. For example, women who harvest bivalves have not yet been formally recognized and therefore still harvest in *de facto* open access bivalve banks. They are, however, committed to creating accountable and dependable cooperatives that could be supported by monitoring programs.

A Fishery Management Plan (FMP) was designed for Altata Lagoon's bivalve fisheries in 2017, though it has not yet been formally implemented. The FMP was developed using a participatory process that emphasized the involvement of local stakeholders, and with a focus on ecosystem-based management. FMPs in Mexico are not legally binding, and therefore do not establish a legal mandate for monitoring or data collection. However, the FMP includes several recommended management measures, including the setting of TACs, catch quotas for each cooperative within their designated polygon, area closures, seasons and size limits that will need to be monitored. Also, EDF and our partners will use the FMP as the basis for both implementing management measures and developing any legally binding regulations, which could eventually establish a mandate for monitoring. The chocolate clam fisheries in Altata Lagoon will engage in a Fishery Improvement Project (FIP) starting early in 2019 in order to try and meet certification standards, which would provide access to high value export markets.

The national government, in accordance with international agreements such as the Ramsar Convention[1] and with domestic statutes and varying government management programs for the fisheries in the region, has articulated many goals for Mexican fisheries, many of which require monitoring efforts to achieve. These include:

- Develop an up-to-date vessel registry
- Deter illegal fishing by local as well as outside fishermen
- Engage in more FIPs and monitor compliance with stock status and exploitation targets
- Monitor and prosecute illegal fishing

These goals imply the need for the following data streams:

- Enforce catch quantities for all species caught, including bycatch
- Create an up-to-date and complete vessel registry
- Collect accurate effort data

In addition, developing a database of length composition data from catch will prove valuable for any future stock assessments conducted for Altata Lagoon fisheries.

Limited data currently exist for fishery production, revenue, age and size structure of the catch, and effort (i.e., number of fishing permits) for all fisheries in the region. Data that does exist may not be accurate, as unpermitted fishers often use permit holders or co-ops to "wash" their catches, thereby hiding fishing effort and catch under nominal permits and obscuring data on effort and participation. The quotas and harvest limits, as well as the cap on the number of boats and fishers allowed in the FMP (and potentially the FIP), would benefit from a monitoring program tailored to detect catch and track permitted vessels and/or fishers. There has been some interest in the use of electronic tools for filling some of these monitoring gaps. For example, several years ago the national government hired a firm in Sinaloa to develop monitoring technology for the shrimp fishery. The firm implemented a QR code system for vessel registry and used VMS to monitor movements of vessels. However, this program was discontinued due to cost and improper design of the hardware used.

To summarize, in Altata Lagoon, diverse species are targeted with little known bycatch. There is a range of methods and gears used to target bivalves, some from skiffs and others from shore. Government interest in the fishery is quite high for shrimp but relatively low for bivalves, and existing management and enforcement reflects this difference. Some species are overfished, while some others remain relatively stable. There is little monitoring currently, but

[1] https://www.ramsar.org/

monitoring could be used for data collection or to enforce existing or imminent quotas, harvest control rules and evolutions in fisheries permitting and vessel registration.

**Design Steps**

**Step 1 - Motivate monitoring.** Monitoring in Altata Lagoon fisheries could potentially achieve multiple objectives set by multiple stakeholders. As a result, many different stakeholder groups could be motivated to design, finance and implement different parts of the monitoring system.

In the shrimp fishery, the main motivations for a monitoring system are to help ensure that yields and the value of the catch remain high, and to differentiate where shrimp are caught. The use of suripera nets in the lagoons to catch shrimp results in almost no bycatch. However, the offshore artisanal shrimp fishery does catch finfish incidentally, including many small fish. Stakeholders and government officials are not currently concerned with bycatch issues in the shrimp fishery as the offshore fishery only operates for a couple weeks every year, but if bycatch levels increase, this may lead to significant ecological and sustainability impacts worth monitoring. Without a social marketing campaign, the imposition of penalties or other measures, there may be little motivation for monitoring bycatch offshore and enforcing limits by fishermen themselves.

Currently, stock assessments do not occur for most species harvested in Altata Lagoon, and it is unclear if and when these might take place. If a monitoring system can overcome the government's existing capacity constraints to generate reliable and sufficient data, management institutions might be more willing to finance the development, implementation and maintenance of comprehensive monitoring programs that can lead to better science-based management,

The shrimp fishery in Altata Lagoon has already achieved Fair Trade certification, and others, including the chocolate clam fishery, are undergoing assessments to enter a certification process involving a FIP. A requirement of such certifications is the generation of data to assess fishery status and outlook, often through a monitoring program.

At least some fishermen appear to already be motivated to monitor in order to improve fishing practices and to demonstrate that they are following the rules. There are currently three women's cooperatives that are unpermitted but working to gain the right to fish with permits for bivalves and crab. They are very receptive to monitoring and management, and are actively working with NGOs such as EDF to maintain fishing permits and vessels.

**Step 2 - Articulate clear monitoring goals, objectives and metrics.** Given the traditional approach to fisheries management in this region, monitoring efforts should be focused primarily on compliance under the current permit scheme. At a minimum, a monitoring program should be able to distinguish unpermitted fishers from permitted ones, which would require an up-to-date registry of permitted fishermen.

With the recent implementation of a no-take zone in the lagoon, and the identification of high quality water and sediment areas safe for bivalve consumption, it has become important to monitor fishermen's spatial activity. Some areas also have a designated allocation of catch quotas. These areas are common fishing banks already identified by fishers and local authorities, which need to be closely monitored and enforced in order to maintain their natural productivity.

As a result, the following monitoring goals for the region have been identified:

1. Monitor for compliance with:
    a. size limits
    b. restrictions on catching gravid crabs
    c. catch limits for each fishing bank
    d. no-take zone regulations
    e. limits on the number of allowable vessels and fishers
2. Generate accurate and fisherman-specific catch data so as to generate a catch and effort record of hitherto unpermitted fishermen, which can improve the permitting process
3. Deter illegal fishing and "washing" catch through existing permits
4. Identify and distinguish bivalve catch from areas that have been classified as safe for human consumption for improved traceability
5. Start to generate data streams for future scientific assessments and management
6. Improve traceability and transparency along the supply chain

**Step 3 - Evaluate existing monitoring data streams and find gaps.** For bivalves, landings data are collected but not segregated by species. This is a barrier to ensuring correct catch accounting and preventing excessive fishing on depleted species such as the chocolate clam. An effective monitoring system for bivalves would clarify landings, which clams are caught, which permit holders caught them and in what areas. Another significant data gap in the bivalve fishery is that many participants are unpermitted. In addition, some fishers rent vessels from other fishers, making it difficult to link individuals with permits and vessels.

In the shrimp fishery, fishermen's cooperatives keep records of shrimp sizes, fishing gear used and the areas that are fished in order to comply with their certification requirements. A fairly effective system for tracking permits already exists since co-ops themselves ensure no free fishers or outsiders are allowed to fish their fishing grounds.

There is a lack of a good system to track comprehensive vessel registration and permit data for the entire shrimp fishery (including shrimp fishers not participating in the Fair Trade certification program) and the other fisheries in Altata Lagoon. Some Fair Trade certified shrimp vessels have Pelagic Data Systems (PDS) trackers, which are paid for by Del Pacifico Seafoods, the distributor and certification promoter from this region. An electronic vessel registration system was established in 2010 and lasted two seasons; it no longer operates due to funding issues and equipment problems.

**Step 4 - Elicit concerns, challenges and barriers**. There are many concerns, challenges and barriers to implementing an EM program in this fishery, including: the national and local government's capacity to finance monitoring programs, analyze data and enforce policies; an unknown number of unpermitted fishers; prevalence of organized crime in the region; and the geographic isolation of most areas where monitoring and enforcement may be difficult. Some of these are described in detail below.

*Poorly-defined government role in EM programs.* In the shrimp fishery, Del Pacifico Seafood has paid for monitoring with PDS and may pay for other types of monitoring in the future to ensure compliance with the shrimp FIP and certification rules. The government may share some of these costs, though it is not certain how much of the burden the government will assume. Further, many regulations are not enforced by the government, reducing motivation for monitoring and compliance.

The federal government's fishery management agency (CONAPESCA) may lack financial and technical resources to improve the monitoring program, or may not consider improving fishery monitoring a strategic priority. However, the government for the State of Sinaloa may be more interested in using monitoring data as they have more of an interest in the outcomes of all of the fisheries in Sinaloa.

*Unknown number of unpermitted fishers.* Some fishers may use a tracking device on one vessel but use another untracked vessel to harvest resources, making quantification of effort and total catch difficult. Likewise, unpermitted fishers wash their catch through permits, so detecting unpermitted effort is difficult and results in *de facto* open-access conditions in the fishery.

*Organized crime.* Because of the presence of organized crime, there is a strong aversion to cameras and/or drones in areas that are also used for drug trafficking and other illegal activities.

Many other enabling conditions beyond the scope of this exercise must be created to support an effective EM program. These include a stronger prosecution system, higher penalties, social norms for compliance and reductions in corruption.

**Step 5 - Brainstorm potential uses of technology and consult with technology experts.** Below, the monitoring goals outlined in Step 2 are matched with a brief description of which technologies could be applied to achieve them:

1. Ensure and enforce compliance with:
   - **Size limits –** Use a bucket of known volume and human samplers to quantify the number of shrimp per unit volume which could be a proxy for average size. A smartphone camera and the Poseidon[2] web-based tool to estimate length composition could also be used
   - **Restrictions on catching gravid crabs** – Use smartphone camera photos to document the presence of gravid crabs in the catch
   - **Catch limits for each fishing bank** – Use OurFish[3] app to record weight of catch at first point of landing at cooperative, and use these data to compare to weight of catch at buyer
   - **No-take zones –** PDS vessel trackers could be used to monitor spatial fishing activity
   - **Limits on the number of allowable vessels and fishers** – Create an electronic permit and vessel registry using unique vessel and permit identifiers (e.g., QR codes)
2. Improve traceability via PDS vessel trackers - distinguish bivavle catch from areas that have been classified as safe for human consumption.
3. Generate more accurate catch data and information on the effort by fishers who currently lack permits – Update permit and vessel registry and generate a complete registry of fishermen.
4. Deter illegal fishing and "washing" catch through existing permits – Vessel/permit registration and PDS trackers, cross-checked with self-reporting.
5. Data generation for future management – Combination of vessel registry, PDS trackers and catch accounting on size and effort. Data could be stored in secure and accessible cloud storage.
6. Improved traceability along the supply chain – Use PDS trackers to determine location of harvest; FishCoin[4] or blockchain technology to obtain and maintain a digital record of shrimp catch (e.g., methods, location, temperature, handling); price transparency app such as Odaku[5] for cooperative leaders who negotiate prices.

**Step 6 - Converge on practical technologies by considering challenges, barriers.** In this region, monitoring technology must be easy to use, with low upfront and maintenance costs. Any device installed on a small boat, or *panga*, should be difficult to remove, alter or disable. In addition, for full coverage, a monitoring system must account for fishing activity of permitted fishers who harvest from shore as well as from vessels. In that case, "easy-access areas" may need to be designated for many fishers to reliably land and record catch and ensure that data is harmonized with data on vessel and fishing permits.

[2] https://news.bloombergenvironment.com/environment-and-energy/plenty-of-fish-in-the-sea-for-big-data-ai-to-tackle
[3] https://www.rare.org/stories/tracing-fish-and-finances#.W9SKOxNKjoA
[4] https://fishcoin.co/files/fishcoin.pdf.
[5] https://www.f6s.com/odakufisheryplatform/about

The following considerations must be included in the design of any monitoring system in this fishery:

- If cameras are to be placed on vessels, their range of view should be strictly restricted to the area of the skiff. Drones should not be used due to security concerns of organized crime groups that have significant influence in the region and on the fishery.
- Cameras at cooperatives and buying facilities to be used for business purposes and to monitor compliance with catch and size limits are likely to be acceptable.
- GPS trackers are likely to be acceptable on all vessels, although a certain degree of misuse and removal should be expected.

Based on these considerations, the monitoring system could be comprised of the following components:

1. **Vessel registration and associated GPS tracking system**. Once all appropriate fishers are permitted with the right to fish, and that permit is harmonized with vessel information where possible, GPS trackers could be placed on vessels. This will allow managers to link landings with each vessel, and therefore deter activities where unpermitted fishers “wash” catch though existing permits. Because some fishers operate from shore or rent boats, this system would not comprehensively cover every fisher in the region. GPS trackers (as well as the M2 radar[6]) could also ensure compliance with no-take zones in the Altata Lagoon, allow shellfish fishermen to document the fact that they are fishing in areas that have been classified as safe for human consumption, and generate data for science-based management. Management authorities responsible for overseeing vessel registrations and fishing permits would have to be trained in analyzing data and detecting unpermitted activities. Vessel owners would have to be trained in how to deploy the device and how to make sure it is operating optimally.

2. **Buckets and scales.** Buckets of known volume on the vessel and a scale at first point of landing at the cooperative can be used to compare the weight of catch at buyer, so that the average size of the catch (estimated from the relationship between size and the number of animals per bucket) can be monitored and size limits enforced. This can also help generate data on catch size and volume for science-based management.

3. **Cameras and electronic logbooks**. Cameras based at the landing sites (cooperatives) and machine learning techniques could be used to estimate counts and size composition of bivalve catches. In order to calibrate this system and measure the reliability of electronic logbooks, these landings would be cross-checked with landing weights and sizes at the cooperative. This can generate data on landings and size for future management. If logbooks do not reflect the landings detected on the camera or at the cooperative, fishers could be penalized for misreporting or engaging in illegal fishing activity, therefore

[6] https://protectedseas.net/marine-monitor-m2/

ensuring compliance with catch and size limits for bivalves. Fishermen and shoreside workers at the cooperative would have to be trained in how to record landings in the logbooks and how to operate the camera systems.

**Step 7 - Examine incentives for use and abuse and reduce risk of abuse (e.g. mis-reporting, disabling equipment, etc.).** Any monitoring intervention that is perceived to threaten or impede the operations associated with narcos will likely be met with resistance, including the disabling of equipment that is too invasive. Likewise, if monitoring were to result in decreased access for some or all fishery participants, there is an increased risk of abuse of the system on their part.

Many enabling conditions beyond the scope of this exercise will be required to reduce the risk of abuse of a monitoring system, including new social norms for compliance, stronger prosecutorial systems and higher penalties. It will be helpful to work with the women's cooperatives to serve as an example, as they have a strong commitment to monitoring and compliance. If the monitoring program is framed as a way to ensure that sustainable catches and profits can be maintained rather than to punish fishermen, it will likely be successful. Monitoring, along with more incentives to comply with catch and effort limits, can ameliorate open access conditions that are the result of permitted and unpermitted fishers entering the fishery. If fishers experience the benefits of an avoided tragedy of the commons, the risk of abuse of a monitoring system is likely to be reduced.

**Step 8 - Pilot and evaluate new technologies.** A pilot focused on the chocolate clam—a major target in the bivalve fishery—is a viable option as this species is currently depleted, the subject of a recently developed FMP and due to fall under a FIP in 2019. As a result, the bivalve fishery is well primed to be the first to benefit from improved monitoring. In addition, a monitored bivalve fishery will not be seen as a potential threat by the narcos, relative to the much higher value shrimp fishery, so there may be fewer intangible barriers to implementation.

A pilot could begin with PDS GPS trackers on pangas that fish for bivalves. Since not all bivalve harvesting activity is carried out from boats, this necessitates drones or land-based cameras to document fishing activity over the entire region by all harvesters. However, there may be objections to this system.

Data from PDS vessel trackers could be harmonized with an up-to-date vessel and permit registration list, therefore allowing them to identify who is fishing and where they are fishing. This can help deter illegal fishing and allow managers to quantify the number of vessels and permit holders engaging in fishing activity. These data could be integrated with size composition data derived from the use of scales, buckets and cameras at the landing sites to demonstrate how size and catch limits can be monitored and enforced.

**Step 9 - Remove barriers that could not be removed through design.** There are several social barriers to monitoring that cannot be overcome through design. Social norms would have to evolve such that a monitoring system becomes commonplace and is trusted by all stakeholders. Additionally, a strong prosecutorial system with higher penalties would deter fishers from engaging in illegal or questionable fishing behavior. Without such deterrents, a monitoring program might not achieve some of its monitoring and enforcement objectives.

The federal government does not necessarily have an interest and capacity to manage and enforce regulations for fisheries other than shrimp, as shrimp is the highest value fishery. Other institutions such as the local government of Sinaloa or the women's cooperative have an interest in the outcomes of fishery management and a commitment to monitoring and enforcement. In that case, efforts should focus on building their capacity to finance, design and implement monitoring and enforcement programs.

The involvement of narco traffickers in the shrimp fishery poses serious constraints to the kinds of technology that can be used in this region.

**Step 10 - Fleet-wide implementation, training, adaptation.** If a pilot program with the chocolate clam is successful and scalable, implementing the monitoring system across the entire clam fishery is a logical next step. The small size of the fishery and current interest from diverse stakeholders—including the federal government, the state of Sinaloa, the FIP program and the women's cooperative—increase the feasibility of full-scale implementation. Commitment from permit holders to engage in such a program, so long as it does not impede their harvesting activity, may also encourage stakeholder buy-in.

To increase the likelihood of success for a comprehensive EM system, stakeholders in the fishery would have to be trained to understand the entire monitoring system. In addition, training on how to operate and generate data from the individual parts of the system will be required of specific stakeholders. Based on the monitoring plan proposed in Step 6, expected training requirements are outlined below:

1. **Vessel registration list and GPS tracking system.** Management authorities will have to devise an up-to-date vessel registry list that provides vessels permitted to harvest in Altata lagoon with a unique identifier, which can then be linked with a GPS vessel tracking device. Once these two components are harmonized, all vessel owners and crew will have to be trained in how to securely deploy the devices on pangas. In addition, they will have to be made aware that any attempts to tamper with or disable devices will be quickly detected; for example, PDS can inform their client when a vessel has been suspiciously inactive. Management authorities and data analysts will have to learn how to use the provided dashboard (a PDS website with log-in). This dashboard allows them to view fishing behavior in real time as well as collect historical tracking data. Data from PDS can be downloaded in a number of formats (e.g., .csv, .xml, .shp). Data analysts will need to develop familiarity working with spreadsheets as well as GIS systems.

Free GIS systems include QGIS[7] and Carto,[8] both of which are compatible with PDS output files.

2. **Buckets of known volume onboard vessels, and scales at first point of landing.** Scales are fairly easy to operate, but transmitting reliable catch data from scales to a database requires training both on vessels and at landing sites, as logbook records from vessels must be easily matched to landings records. Training must emphasize that records must include details such as the landing site, date of trip, time of trip, vessel and permit identification and more. Where an e-logbook on a smartphone or tablet application is used, training is required for how to use the device, how to log the data correctly, how to ensure it has been uploaded and how to take corresponding photos, when available.
3. **Cameras and electronic logbooks.** In addition to records kept by permit holders, cameras at landing sites can estimate counts and size composition of bivalve catches. Shoreside support workers must learn how to use cameras and make sure they are working, and how to position the cameras such that they capture all of the catch while minimizing privacy invasion at the landing sites. Management authorities and shoreside support workers will have to be trained in how to review camera data to corroborate catch accounting records and identify suspicious behavior.

Program performance based on the degree to which monitoring objectives have been achieved should be evaluated after a predetermined period of times, such as two years. The measurable outcomes of the trial EM program and any subsequent decisions based on EM data might include improvements in market access for FIP bivalves and oysters harvested in cleaner water, and the number of unpermitted vessels detected. If there is a desire to develop a new market from this process, a review should also be conducted after a longer period of time, perhaps five years, to determine the success of these efforts.

## *The Los Rios Sierra fishery in Chile*

### Characterization

Sierra (*Thyrsites atun*) is a mackerel-like species that has a large range, occurring in waters up to 500 meters deep throughout the southern parts of South America, Africa and Australia. They are slender fish that can reach up to 200 centimeters in length (but are more commonly about 75 centimeters long), can weigh up to about six kilograms, and live up to 10 years. Sierra favor continental shelves, feeding on pelagic crustaceans, cephalopods and small fishes like anchovy and pilchard. They often form schools which swim near the surface at night. Sierra appear to undergo seasonal migrations along Chile's coast, and have special cultural importance in Chile's Los Rios region (Fisheries Management Region XIV), which is home to approximately 4400 registered

[7] https://www.qgis.org/en/site/about/index.html
[8] https://carto.com/

fishermen (including divers, algae collectors, crew members and boat owners), organized into 25 community-based management units, or *caletas*. The Los Rios coastline is characterized by complex, rocky habitats with a multitude of inlets in which caletas are normally located, and the climate is temperate, with cold waters, inclement surface conditions and poor visibility conditions common during the winter months.

Approximately 2000 fishermen are officially engaged in the fishery for sierra in the Los Rios region, but it is estimated that an additional 2200 unregistered, unlicensed fishermen also target sierra. A number of different gears are employed in the fishery, but mainly hand-line with use of some gillnets on wooden boats between 5.8 and 12 meters in length, normally within 15 miles of the coast. Sierra are mostly landed at a handful of landing sites in the Los Rios region that are well connected to local distribution channels. Historically unmanaged, the sierra fishery was recently recognized by the government as an official fishery, opening the door to the creation of a fishery management plan. This will enable the setting of management goals and the implementation of management measures designed to achieve these goals. However, at the time of writing, the fishery lacks any management goals or objectives, management measures or formal monitoring and enforcement protocols.

EDF is working with local communities (FIPASUR, FEPACOM and FEPACOR) to strengthen their rights of access and to improve community-based management in the Los Rios region, including encouraging the development of an official fishery management plan to be approved and published by the Undersecretariat of Fisheries (SUBPESCA). Fishermen are generally part of fishing communities who are assigned exclusive access to designated areas for the collection of benthic resources such as the *loco*, a marine snail that commands a high market price. This exclusive access has encouraged a co-management mindset, and fishermen are generally well-versed in current fishery management measures, objectives and outcomes.

In Chile, a nearshore zone that extends out to five miles from shore for much of the coast is reserved exclusively for small-scale artisanal fishermen. There are common reports of industrial fishermen encroaching upon this zone, which is a significant source of conflict. Artisanal fishermen are defined as those fishermen who operate vessels with a storage capacity less than 80 gross tons, and that are less than 18 meters in length. In order to participate in artisanal fisheries, artisanal fishermen must be registered as such in a national registry, and their vessel must also be registered, for which there is no fee. Artisanal. Artisanal fishermen are organized around *caletas*, which are legal entities but are also geographically defined as strips of land above the high tide mark, granted as a concession by the state. Caletas are generally used to store and launch vessels, land catch and undertake maintenance. Fishermen are often organized into *sindicatos*, which are fishermen's associations based around specific caletas.

While sierra are culturally important in the Los Rios region and surrounding domestic markets, they are generally not exported out of the region, and ex-vessel prices are relatively low. Monitoring for traceability purposes, which can increase market prices for some species in some situations, is therefore not as important for sierra as it could be for other species. However, monitoring of fishing effort can help to legitimize claims for fishing privileges (e.g., future catch quotas), help to ensure that illegal fishermen are not poaching local resources, and contribute to the development of scientifically based catch quotas. Electronic tools may prove valuable for a future monitoring program given the wide geographic expanse of the Chilean coastline and the dispersed nature of caletas.

**FIGURE 8** The Los Rios Region of Chile Source: Wikipedia

**Design Steps**

**Step 1 - Motivate monitoring.** The declaration of the sierra fishery as an “official” fishery should motivate the development of a fishery management plan, which should, in turn, motivate fishery managers to conduct monitoring. In addition, it should also motivate fishermen to support monitoring in order to create an official record of participation and catch in the fishery. Chile has a long history with individual and community catch quota systems, and fishermen understand that an official record of historical participation is generally required for the eventual allocation of quota. The government of Chile has expressed a desire to recognize and manage subsistence fisheries, like the sierra fishery, which are important contributors to maintaining food security in Chile.

**Step 2 - Articulate clear monitoring goals, objectives and metrics.** When a fishery management plan is eventually formalized for the sierra fishery, it is likely that monitoring goals and related objectives will include the following:

1. Ensure that only authorized fishermen participate in the sierra fishery
    a. Register all legal fishermen
    b. Ensure all fishermen participating in the fishery are registered
2. Account for all catch of sierra
    a. Monitor all landings of sierra
    b. Estimate discards of sierra
3. Ensure compliance with rules designed to control harvest
    a. Monitor all gear used to ensure it is of legal type
    b. Monitor vessels to ensure compliance with spatial and temporal effort restrictions
4. Document levels and distribution of fishing effort in the fishery
    a. Monitor number of vessels participating and number of days fishing per vessel
5. Develop information on the spatial distribution of fishing to inform the setting of biological, social and economic objectives, as required by the Chilean General Fisheries Law

**Step 3 - Evaluate existing monitoring data streams and find gaps.** While some data streams for this fishery exist, they are incomplete, as data are collected by a range of organizations under different protocol, and are not collected continuously. For example, fishery-independent biological (age-length) and abundance data on this fishery have been collected in the past by Fundacion Ichthyologica, a scientific non-profit. IFOP (Instituto de Fomento Pesquero) also collects some fishery-independent data.

Stakeholders, including SUBPESCA (the fishery management authority) and EDF, are in the process of reviewing these data to understand gaps and focal points for future monitoring efforts.

Artisanal fishers in Chile are accustomed to self-reporting catch with logbooks, although these do not yet exist for the sierra fishery. Some dockside enforcement occurs to check fishing permits, which are issued to individual fishermen.

For all official fisheries, self-reported landings data are collected by the sindicatos, and then aggregated by SERNAPESCA, the fisheries scientific agency. These landings data include the total weight of catch of sierra, but not the number of fish or any length frequency data.

While some basic information exists for the sierra fishery, there are significant monitoring gaps that need to be filled. Overall, there is a need to improve the structure (i.e., types and time series) of data being collected to improve its usability for stock assessment. There is also a lack of monitoring to ensure that industrial vessels are not encroaching into the artisanal zone, and to develop a spatial distribution of fishing effort in the sierra fishery.

**Step 4 - Elicit concerns, challenges and barriers.** The sierra fishery is a relatively low bycatch fishery, with relatively selective hand-line used as the main gear. However, there are still some concerns related to lack of management and limited institutional capacity, illegal fishing, as well as characteristics of the geography and vessels of the fishery that limit the effectiveness of traditional monitoring techniques, as outlined below.

*Lack of management and limited institutional capacity.* All fishermen in the fishery would likely agree to become legitimized (licensed) and their vessels permitted. However, so far there is no management plan or other regulations and therefore no clear management goals in place. This is possibly the biggest barrier to implementing monitoring in this fishery, especially in the absence of a potential short-term economic value proposition for monitoring. The capacity of SERNAPESCA and IFOP to analyze the data and use it for management is relatively low, though it may be possible to partner with a local university to analyze the data.

*Illegal fishing.* Another challenge that could hinder the success of an EM program is that industrial vessels are sometimes found fishing illegally in the artisanal zone (0-5 miles from shore), often with destructive consequences. However, there is little existing infrastructure to monitor compliance with these spatial exclusion rules.

*Geographical and climate challenges.* The Chilean coast is exceedingly rocky with a multitude of inlets and coves. Fog can be an issue, and rain is common.

These factors impede monitoring efforts that rely on line of sight technologies, such as cameras.

*Fleet characteristics.* Another challenge is the limitations associated with the vessels in the sierra fishery. Vessels in the sierra fishery are small and do not have power sources, limiting which kinds of devices can be deployed on vessels. Additionally, camera placement would need to be such that fishermen can still have privacy while cameras are monitoring catch.

**Step 5 - Brainstorm potential uses of technology and consult with technology experts.** To ensure that only authorized fishermen are fishing (goal 1), a registry of legal fishermen and their vessels could be established, a unique identifier attached to each vessel and a regulation implemented to ensure that any effort limitations are specific to vessels and not to fishermen themselves. A network of shore-based radar stations could be operationalized to ensure that only authorized vessels equipped with a unique radar identifier are present on the fishing grounds.

To account for total catch (goal 2) and to ensure compliance with harvest control rules (goal 3), onboard cameras could be used to quantify catch and discard amounts, potentially identify hook size used on hand-line gear and identify the use of other types of gear.

Assuming there are no at-sea discards, accounting for all catch in the fishery (goal 2) could be achieved using a "smart" sorting table that incorporates a scale and a camera that can weigh and photograph catch. A machine learning protocol could be applied to images to automatically count catch and estimate lengths to generate length composition data. However, the most secure way of assuring that no discards occur at sea is to use cameras on vessels.

To ensure compliance with harvest control rules, effort limits and spatial restrictions to protect habitat (goals 3, 4 and 5), an automatic vessel tracking system could monitor for compliance with fishing effort restrictions (e.g., seasonal and spatial restrictions), and quantify levels of fishing effort in the fishery. This system could also develop information on spatial distribution of fishing to inform the setting of biological, social and economic objectives as required by the Chilean General Fisheries Law. If a camera system is used, vessel tracking could be part of this system, with no need for an additional tracker.

**Step 6 - Converge on practical technologies by considering challenges, barriers.** While surveilling the nearshore artisanal zone to ensure that illegal fishing does not occur—either by unlicensed small-scale fishermen or by larger industrial fleets—the geography and often poor weather conditions of the Chilean coast make it difficult to implement technologies that rely on line of sight (e.g., shore-based radars and cameras, acoustic sensors).

Perhaps the most important and feasible first step towards achieving monitoring goals is to increase the accuracy and coverage of the existing registry (Registro Pesquero Artesanal; RPA) of legal fishermen and their vessels to capture 100% of fishery participants. Once this step is completed, efforts can be made to surveil the fishing area to ensure only legal participants are present. An automatic vessel tracker that is low maintenance and that offloads data automatically to managers would be a feasible method of tracking effort in the fishery. Cellular connectivity exists along most sections of the Chilean coast, so a system that relies on cellular networks for data transmission is feasible.

As landings of sierra occur in only two or three landing sites, a "smart" table that can weigh all catch and use camera imagery to estimate length compositions is feasible and could build a valuable database of catch data. These data could be transmitted to a cloud data storage facility, which could be linked directly to data users.

**Step 7 - Examine incentives for use and abuse and reduce risk of abuse (e.g. mis-reporting, disabling equipment, etc).** Due to Chile's long history with catch quotas, and fishermen's recognition that being able to demonstrate historical participation and catch is essential for receiving these quotas, fishermen may be incentivized to over-report their catch in order to qualify for larger shares. This would be partially addressed if a camera-based system of catch reporting were implemented, such as the "smart" table.

Monitoring systems that are not participatory and collaborative are generally more difficult to enforce. If some actors see a monitoring system as adversely affecting their livelihoods, and there is a possibility to degrade it in some way, they will find a way to do so. For example, shore-based radar installations could easily be vandalized. Thus, monitoring should be designed in collaboration with all stakeholders to ensure buy-in.

**Step 8 - Pilot and evaluate new technologies.** The vessel registration system could be piloted in two or three caletas (fishermen's organizations), as vessel registries have historically been maintained by caletas. The tracking systems could also be tested in two or three caletas by fishermen who are early adopters of technology and interested in increasing monitoring. These systems, if successful and cost effective, could then be scaled to the rest of the Los Rios region.

The "smart" table could be piloted at one of the landing sites. If successful, the tables could scale to the rest of the Los Rios region, and then the entire country, as small-scale artisanal fisheries are common and widespread in Chile.

**Step 9 - Remove barriers that could not be removed through design.** The main potential barrier that cannot be removed through design is to develop a fishery management plan in a transparent manner, capable of achieving both the goals of the community as well as those of management. We hope that the government will adopt the participatory Framework for Integrated Stock and Habitat Evaluation (FISHE) as a way to develop a Fishery Management Plan for sierra.

Another barrier is the lack of directed enforcement capacity; however, if caletas provide data showing illegal fishing is occurring in a specific area, this could then be used to mobilize enforcement efforts.

**Step 10 - Fleet-wide implementation, training and adaptation.** Fleet-wide implementation of tracking technologies in the sierra fishery is important to ensure that illegal fishermen are not participating in the fishery and that there is full compliance with regulations. A fleet-wide implementation strategy should be designed to start with a small pilot, then gradually build political momentum and stakeholder support, eventually reaching the scale of the entire fishery. Political momentum is needed to secure national funding for a fully implemented monitoring program. Stakeholder support may also be required to raise money for monitoring through license fees.

Training will be necessary to ensure that license and vessel permit data are accurately inputted to the registry database, and that the database is updated and maintained. Little or no training will be necessary for tracker installation or data analysis if an established service provider is used. Some training may be required in the use of sorting tables and smartphone cameras to collect images suitable for analysis to determine species composition and length composition.

## *The Piura nearshore fishery in Peru*

### Characterization

The state of Piura in the Northwest region of Peru (Figure 9) is home to approximately one-third of all Peruvian artisanal fishermen, defined as those fishing with manually operated gear in vessels less than 15 meters long and with a hold capacity of less than 32.6m[3]. Artisanal fishers in iconic communities such as those of Cabo Blanco, El Ñuro and Los Órganos primarily target hake (*Merluccius gayi peruanus*), skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*), as well as a variety of nearshore reef fishes. Approximately 390 artisanal vessels, many of which are sailing vessels, participate in Piura fisheries. In El Ñuro and Cabo Blanco, fishers primarily use hand-lines and demersal longlines, while bottom gillnets are used in Los Órganos to capture hake and reef fishes on banks located two to six nautical miles offshore of these communities. To target tuna species, fishermen throughout the region use floating gillnets in the months between April and June. A sector of the artisanal fleet also targets Humboldt squid (*Dosidicus gigas*) and mahi mahi (*Coryphaena hippurus*) in offshore areas.

The artisanal sector is not currently subject to strict management regulations or monitoring, and while statistics are lacking, unregulated catch of hake, tuna and reef fishes appears to be high. A permit system that regulates access to the fishery does exist for some fisheries—for example, artisanal harvest of hake is still not permitted, though artisanal fishermen have historically targeted hake without fishing licenses—and this allows fishermen to target many different species, while nominally restricting their ability to access fully exploited or overexploited ones. A large number of artisanal fishermen are still unregistered and do not hold fishing permits, especial those with un-motorized boats. While the industrial fleet is subject to some management regulations and monitoring, blatant illegal fishing by medium-scale trawlers, occurring even when government officials are onsite, is a common occurrence. This illegal fishing occurs in the artisanal zone (in which industrialized fishing is banned), which extends out to five miles from shore. Artisanal vessels are not restricted in where they can fish in Peru's marine waters. Furthermore, as tuna stocks are migratory and hake stocks exhibit range expansions and contractions in response to changing environmental conditions, harvest control in Piura would likely only have an incremental effect on overall stock status. This uncertainty is compounded by an unknown amount of removals by artisanal fishers and illegal industrial fishing in the region.

Peru's National Fisheries Law does not currently include a mandate for the setting of fishery management plans in artisanal fisheries that include any transparent goal-setting process, and protocols for decision-making processes are not publicly available. Some responsibilities for the management of artisanal fisheries have been decentralized to the regional government, but local management offices often lack sufficient resources for effective management. For the industrial fleet, PRODUCE (the Vice Ministry for Fisheries at the national level) plays an important role in the management of hake and tuna for the industrial fleet; tuna are also managed internationally by the Inter-American Tropical Tuna Commission (IATTC). While there is no formal management of the artisanal fishery by Peruvian national or state fishery authorities, artisanal groups in these communities, called *Organizacionesó*


**FIGURE 9** The Piura Region of Peru showing the communities of Cabo Blanco, El Ñuro and Los Órganos. Source: Google Earth

*Social de Pescadores Artesanales* (OSPAs; Social Organizations of Artisanal Fishermen) have demonstrated a high level of interest and commitment to defending their fishing grounds from encroachment by other fishers, and to improving their fisheries. Despite the unregulated *de facto* open access nature of the artisanal fisheries, OSPAs have articulated community-based regulations with sustainability considerations at heart. For example, some community organizations have agreed to cease seining activities in rocky bottoms (which can be destructive to these habitats). However, the lack of a clear framework for regulation has led to conflict between organizations with different regulations and there is a strong desire to resolve this issue.

EDF is leading efforts in many of the communities in the Piura region to develop and build capacity for sustainable community-based fishery management by encouraging the use of scientific methods to assess fishery status. Most of these methods rely on data such as catch levels, effort levels and catch length compositions and would benefit greatly from monitoring programs that generate more data of higher quality. Given the lack of monitoring capacity in Peru, and especially in the artisanal sector, there is increasing interest in exploring the use of electronic tools to help collect these valuable data.

**Design Steps**

**Step 1 - Motivate monitoring.** Although the regulatory environment is not conducive to monitoring in the artisanal fisheries, without a fishery management plan and regulatory requirements in place, motivation for monitoring can potentially come from market forces. Hake are exported to, among other countries, Germany (~25% of exports), Russia (20%), Brazil (11%) and Spain (10%). There is an increasing market for traceable seafood with an associated price premium over non-traced seafood. Some hake caught in Piura are exported to the U.S., where mandated traceability requirements have motivated some fishermen to start to collect data that can be used for traceability purposes. These requirements derive from a U.S. commitment to combat IUU fishing worldwide, and data proving provenance of imports are required. These commitments, however, have so far been relatively weak, and strengthening U.S. resolve to demand better data to increase supply chain transparency would help motivate not only monitoring, but better management. At the national level, a ministerial resolution has been passed requesting a traceability system for the mahi mahi and giant squid artisanal fisheries; it may be possible to set up a similar system for hake and tuna. However, the mahi mahi and giant squid traceability system has not yet been implemented.

Another potential motivation for monitoring in the artisanal fishery is the possibility of the future implementation of an individual or community-based quota system. Such systems commonly involve an allocation of quota to fishers or communities that can prove historical participation in the fishery. This documentation would be one output of a monitoring system.

**Step 2 - Articulate clear monitoring goals, objectives and metrics.** While there are currently few clear monitoring goals, mainly due to a lack of a management plan, several goals are likely to be articulated in the future. These include:

1. Documenting all fishermen's participation in the artisanal fishery
2. Documenting catch to better characterize the fishery, improve "whole stock" management of the hake resource (which is shared with the industrial fleet) and support the potential implementation of a system of quota management
3. Ensuring that nearshore artisanal zone regulations are enforced:
    a. Ensure that only permitted, legal fishermen are fishing in the nearshore zone (0-5 miles)
    b. Ensure that limits on vessel size (up to 32.6 $m^3$, 15 meters in length) and gear type regulations (e.g., no use of hydraulics or other machinery to catch fish) are enforced
4. Mapping sensitive rocky reef habitats and ensuring that fishermen do not use bottom seines and other destructive gears in rocky reef habitat or hake *caladeros* (fishing grounds)
5. Creating a transparent, traceable supply chain that shows that fish are caught legally and sustainably

**Step 3 - Evaluate existing monitoring data streams and find gaps.** There are official landing statistics with some gaps. Some organizations are involved in the collection of some data (landing and fishing effort), including the regional government, national government and The Instituto del Mar del Peru - IMARPE (Marine Research Institute of Peru). These data streams are currently uncoordinated, but could potentially be harmonized and used for management. EDF is beginning to collect GPS tracker data in the Cabo Blanco community, and other monitoring data from the hake fishery in El Ñuro have been collected in the past, but these efforts are not ongoing.

Pilot programs in other artisanal fisheries in Peru are also contributing to data streams. World Wildlife Fund (WWF) has developed an app for recording and visualizing landings of mahi mahi and Humboldt squid in Peruvian fisheries, working with La Tortuga and La Islilla fishermen. EDF and CLS (a technology company) has a pilot project that is utilizing solar powered GPS trackers, but only one vessel is engaged so far. The plan is to expand the pilot to ten vessels within. the next year in order to demonstrate the utility of the GPS trackers and to start to generate data for management.

The major data gaps are the unknown number and identity of artisanal fishermen and the location of sensitive reef habitats, which are unmapped. Most fishermen do not use navigation aids other than the stars. However, knowing the exact locations of sensitive habitats and fishing boundaries is an important first step for implementing and enforcing spatial restrictions aimed at protecting them.

**Step 4 - Elicit concerns, challenges and barriers.** The barriers to implementing a monitoring system include: a lack of coordinated data streams, a poorly developed market driver for sustainability, capacity constraints associated with catch accounting, small scale characteristics of the fishing vessels and a lack of trust in government. These are outlined below:

*Data streams.* The main challenge for implementing a monitoring system in the Piura artisanal fisheries is that the existing data streams are not consistent or collected in a way that maximizes their utility for management. While a few organizations collect data, there is no coordination between them, and as a result data gaps are common.

*Lack of a market driver for sustainability.* This may come about through the implementation of access limitation as part of an individual or community catch share program in the future. In the meantime, demand for traceable seafood from export-oriented markets may provide some market incentive for monitoring.

*Vessel characteristics.* Small-scale artisanal vessels are generally too small to carry a human observer and lack a reliable source of power.

*Catch accounting vulnerabilities.* While there is legal authority for catch reporting, there is no culture of self-reporting or independent monitoring, although there appears to be an opportunity to create such a culture. For example, in one pilot study where artisanal vessels targeting mahi mahi were monitored using GPS trackers, initial resistance to monitoring turned to widespread acceptance once the data were available to be visualized and the benefits of monitoring made clear. While there are some formal landing sites, fishermen land in many undocumented sites that are spread out throughout the region as well.

*Low level of trust in the government.* The relationship between the government and fishermen is based mostly on top-down regulation followed by fishermen protests and strikes if a regulation is unpopular. There is a need for boundary organizations to play a facilitation role between fishing communities and the government.

**Step 5 - Brainstorm potential uses of technology and consult with technology experts.** To map sensitive habitats such as rocky reefs and hake caladeros (goal 4), a towed underwater vehicle such as the Batfish, outfitted with echosounders and other instruments, could be used to map the seafloor. These data could be ground-truthed using fishermen's knowledge. The shelf is relatively wide, and the water turbid with poor visibility, so the use of underwater cameras would prove difficult.

Low-cost solar powered vessel trackers could be used to provide a record of participation in the fishery, helping to achieve goal 3. Documenting all fishermen's participation in the fishery (goal 1) could be achieved with the help of a fisherman and vessel registration system, which could be combined with these trackers to create a record of individualized and spatially and temporally defined fishing effort.

Small camera-based EM systems, such as Flywire or Shellcatch, could be deployed on vessels to document catch (goal 2); these would also include a tracking system.

As many fishermen have smartphones, a mobile platform for self-reporting may be successful (goal 2). For example, fishermen could take time-stamped photos and use a GPS tracker to mark catch locations and document bycatch hotspots.

As artisanal vessels are prohibited from using any type of machinery to haul nets or retrieve hooks, passive acoustic buoys could potentially be used to detect vessels that violate these rules (goal 3).

As data collection is relatively non-existent in Piura, and the downstream supply chain may value fish that are associated with good information for traceability purposes, it may be possible to incentivize data collection through a platform such as FishCoin, which gives fishermen a monetary reward for their data. If successful, this could help create a transparent supply chain for high value export markets (goal 5).

**Step 6 - Converge on practical technologies by considering challenges and barriers.** As vessels are generally small, lack a reliable source of power, and there is a lack of capacity to analyze video data, the use of cameras to document catch may be difficult.

Because of the lack of experience with self-reporting, any program that requires fishermen to self-report catch amounts and other information is likely to prove unsuccessful. Solar powered, low-cost, maintenance-free and relatively unobtrusive trackers integrated into a fisher registration system would help to achieve the goals of documenting fishermen participation in the artisanal fishery, while also collecting information on fishing effort and monitoring compliance with protected area boundaries.

Passive acoustic buoys that monitor the five-mile artisanal "boundary" could potentially help to surveil nearshore areas, although shore-based radar systems have a larger range and may prove more effective as pinpoint positions of vessel can be ascertained.

The one-time use of a Batfish towed vehicle as a bathymetry mapper could provide a frame of reference for future management, and would be relatively inexpensive to deploy.

**Step 7 - Examine incentives for use and abuse and reduce risk of abuse (e.g., mis-reporting, disabling equipment, etc.).** If fishermen believe that there is a benefit to demonstrating participation in the fishery (e.g., future catch share quotas), people who have not traditionally fished in Piura may try to demonstrate participation, which would dilute the rights of local people and could result in overfishing and price depression. Local fishermen may also fish harder to demonstrate higher catch records if the value of the catch share depends on the magnitude of catch.

Passive acoustic buoys may be easily vandalized; outfitting buoys with a solar powered camera that transmits images wirelessly may help identify perpetrators and reduce the risk of equipment loss.

**Step 8 - Pilot and evaluate new technologies.** A pilot of vessel trackers could be implemented in a subset of communities where interest in adoption of monitoring is fairly strong.

The capacity to collect, store, process and analyze tracking data would likely need to be provided, or at least facilitated by a NGO for any pilot project. One of the initial projects could be mapping the fishery area using a bathymetry mapper.

**Step 9 - Remove barriers that you can't remove through design.** The main barrier that will be difficult to address through design of a monitoring system is the deep level of distrust between fishermen and fishing communities and regulators. The most effective way to overcome this barrier is to participate in open and transparent dialogue between all stakeholders in the fishery. Fishery management goals should be articulated clearly, and management measures—which may seem punitive to fishermen—should be justified in relation to these goals. Any commitments that are made should be rigorously followed up on with action to establish a trust relationship.

**Step 10 - Fleet-wide implementation, training and adaptation.** Fleet-wide implementation of any monitoring system will be difficult until the initial barrier of documenting and legitimizing all fishermen who are accepted as participants by local fishermen is addressed. Clear monitoring goals, a clear value proposition for fishermen (perhaps an increased price for documented or monitored catch), or a strong mandate to monitor will need to be created before implementation is attempted.

Training and considerable outreach will be necessary to identify eligible fishermen and vessels and to make sure their registration data are entered into a database that is updated regularly. Training on the use of trackers would be required if a service model that includes data analysis and visualization (e.g., with PDS) is used.

## *The Blue Swimming Crab fishery in Lampung, Indonesia*

### Characterization

The Indonesia blue swimming crab (BSC) fishery is focused on the harvest of BSC, though a variety of species are caught as bycatch. BSC is the third largest export fishery in Indonesia, behind shrimp and tuna, and is worth more than $300 million per year (Table 2). A Blue Swimming Crab Management Committee has been established to manage the fishery in the Lampung province of Indonesia, on the island of Sumatra. This committee has created an Action Plan with fishery management goals, objectives, indicators and harvest control rules. According to the Action Plan, approximately 10-15% of the country's total blue crab harvest comes from Lampung province.

**TABLE 2** Top Export Fisheries of Indonesia (Including Blue Swimming Crab) Value in 2016

| COMMODITY | VOLUME (TON) | VALUE (IN US$1000) |
|---|---|---|
| Shrimp | 193.276 | 1.627.473 |
| Tuna/skipjack | 172.293 | 583.588 |
| BSC/crab | 23.746 | 309.735 |
| Seaweed | 211.872 | 205.320 |
| Pearl | 539 | 33.543 |
| Other fish | 169.071 | 346.188 |
| Others | 307.049 | 838.089 |

*Source: Blue swimming crab fishery management plan (2016)*

The BSC life cycle begins as larvae suspended in the water column drifting with the currents. After approximately six weeks of drifting, the larvae move into the estuaries and mangroves for their juvenile phase. Juveniles move out into deeper and higher salinity waters, especially following heavy rainfalls. As juveniles move to the adult phase, they move offshore into deeper waters to spawn. Blue swimming crab reach sexual maturity at approximately eight or nine months. They are considered a highly productive species.

The BSC fishery off the east coast of Lampung is predominantly a small-scale fishery, with the majority of vessels less than 10 gross tonnes (GT). There are approximately 4000 registered and active fishers with more than 900 boats in the fishery. The fishers are either local to Lampung or are migrants (*andon*) from Java. The BSC fishery uses two primary gear types: bottom gillnets and collapsible traps (*bubu*). Generally, local fishers use gillnets, while bubu are used by andon fishers. A variety of vessels are used in the fishery, but the primary ones are the *pampang* and *asko*, local boats made from wood with an elongated shape and narrow width, and the *sope*, a wooden boat with a short and slightly rounded shape, commonly used by fishers from Java. The BSC supply chain contains a number of actors, with buyers and miniplants the most important to consider in monitoring. The buyers, also called middlemen or *pembinas*, not only purchase the catch, but finance fishing activities and generally have close relationships with their fishers. There are also miniplants, which are small-scale processing businesses that steam crabs, separate the shell and meat and sort meat into categories. Some miniplants are owned by pembinas, while others buy crabs from pembinas.

The fishery is generally conducted within 12 miles of shore; there are some crab operations that occur further offshore, but they are not included in the

Lampung management plan. The fishing grounds included in the management plan extend from Labuhan Maringgai District, Way Kambas National Park, East Lampung Regency and the coastal areas around Tulang Bawang Regency. The fishing harvest varies by season, with the peak season occurring from October to April or May, a medium transitional season from May to July, and the low season from August until October.

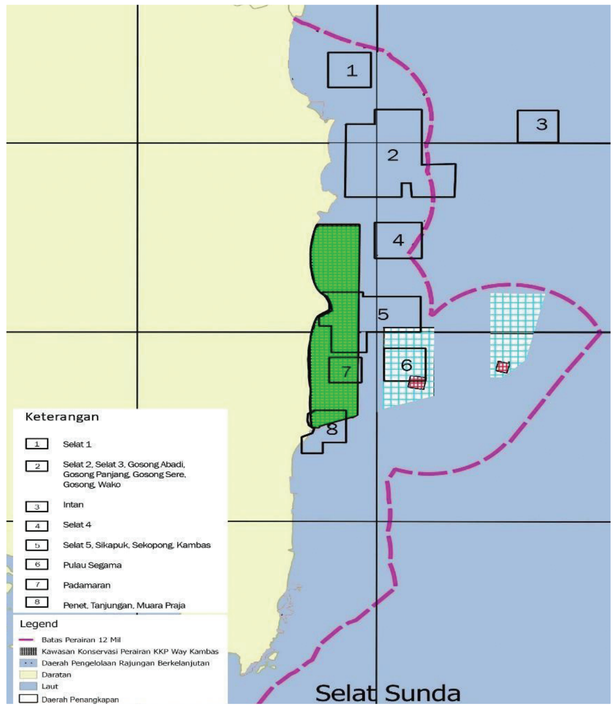


**FIGURE 10** Map of Blue Swimming Crab Fishing Grounds in East Coast of Lampung Province

Recent examination of the BSC stock status in Lampung indicates that the stock is being overexploited, which could impact the near- and long-term abundance of BSC. Zairion (2015) estimated a utilization rate of 0.76 relative to the assumed sustainable utilization rate of less than 0.5, indicating that the stock is experiencing overfishing. Recent spawning potential ratio (SPR) estimates for eastern Lampung were 8%, well below the management plan limit reference point of 20%.

The Lampung blue swimming crab fishery has just established a management plan and management team under the provincial government's authority, as the result of a systematic process involving key stakeholders and consultations with the fishing communities. The Sustainable Blue Swimming Crab Management Initiative (IPPRB) management team included representation from fishers from the three districts included in the plan, fisher organizations, academia, miniplants, local processors, provincial, district and national level government agencies. The adopted action plan includes goals, objectives, indicators, response rules and management strategies.

### Fishery Goals

The Lampung blue swimming crab management plan articulates two goals for the fishery with a total of six objectives, which are all taken from the *Action Plan for the Blue Swimming Crab Sustainable Fishery Management in the Eastern Coast of Lampung Province*.

The first goal is to “maintain the health of blue swimming crab resources and the ecosystem.” Under this goal there are two objectives: 1) to improve blue swimming crab stock condition and 2) to protect and maintain blue swimming crab habitat.

The second goal is to “increase the economic and social benefit of the blue swimming crab fishery for the fishers and all blue swimming crab stakeholders.” There are four objectives that support this goal: 1) to consistently meet export standards (i.e., quality and traceability); 2) to maintain the stability of blue swimming crab supplies; 3) to increase the revenues and profits of blue swimming crab fishers and stakeholders; and 4) to optimize the value of the blue swimming crab fishery for community development.

In addition to these goals, the fishery will need to comply with EU and U.S. import regulations.

The current monitoring focus is to establish fishery-dependent data collection for the region. This program will collect vital information on catch, fishing effort and catch length composition. Previously, monitoring has collected data on crab production from the miniplants; however, these data are considered unreliable and the data collection program was ended in 2016. There is a mandatory logbook program for all vessels greater than 5 GT. However, this requirement only covers a portion of the fleet, and even fishers who are required to fill out logbooks often fail to do so, making these data unreliable.

### Design Steps

**Step 1 - Motivate monitoring.** There are currently two main groups driving the need for monitoring. One is the government—particularly at the federal level, as they have assumed control of fishery data collection. Until 2016, catch data were collected by provincial governments—primarily from the miniplants—at least two steps removed from the fisher landings. Along with the requirements in the Action Plan, there is a strong motivation to collect fishery-dependent data such as landed catch, catch length composition and fishing effort.

The second group motivating the need for increased monitoring is the Indonesian Blue Swimming Crab Processing Association (APRI). Crab is primarily an export product to the U.S. and EU, and fisheries will need to comply with import traceability standards. This has resulted in industry pressure on the fishery and supply chain to obtain the appropriate documentation. Miniplants need a producer’s card (GMP), a Hazard Analysis and Critical Control Point (HAACP) card and a health certificate. The fishers need a fishery stakeholder card. It has been relatively easy for APRI to reach the miniplants and pembinas in order to obtain this documentation, but reaching the fishers has proven to be more difficult.

Both the government and the industry have begun working on methods to motivate fishers to be properly registered. APRI has been reaching fishers through the pembinas—who often have close working relationships with specific fishers to whom they lend money—to apply social pressure to get fishers and vessels properly registered. The government has also begun offering life insurance policies with the first year free to all registered fishers. While reaching fishers has been difficult, market forces are motivating the supply chain actors.

**Step 2 – Articulate clear monitoring goals, objectives and metrics.** The following monitoring goals for the region have been identified:

1. End overfishing in order to ensure healthy stock levels
    a. Monitor and quantify fishing effort and catch of BSC in the fishery
    b. Ensure the ability to evaluate the SPR indicator in reference to the target and limit
    c. Collect length composition data on at least 20% of the landings to estimate SPR and fishing mortality rate
2. Improve social and economic benefits to all stakeholders
    a. Quantify all landings in the fishery
    b. Check 20% of the landings for accuracy of weights
    c. Ensure that crab catch size targets associated with good profits are achieved
    d. Register and license 100% of fishers and fishing vessels in the fishery
    e. Ensure that illegal fishers do not participate in the fishery
    f. Make data collection electronic and accessible to those with permission
3. Ensure compliance with international market traceability requirements
    a. Ensure that data can be easily accessed and used for management and scientific purposes

**Step 3 – Evaluate existing monitoring data streams and find gaps.** Prior to 2016, landings data was collected by the provincial government at the miniplant level. These data were considered to be unreliable, as landed crab could be rejected by the miniplants. There was also a tendency to continually report higher levels of landings to indicate that the fishery business was consistently improving. Additionally, some pembinas and fishers have retained their landed catch records, though this is relatively recent and limited in numbers. In the past, the University of Bogor has conducted a one-time collection of catch length frequencies to generate SPR estimates for the region.

There is a federal government requirement that all vessels greater in size than 5 GT must keep logbooks. Only a portion of the BSC fishing fleet is greater than 5 GT, so logbooks would not be fully implemented across the entire fishery.

For those vessels that would be required to fill out a logbook, there is no enforcement and several barriers, such as illiteracy. Existing logbook data are not considered reliable, as there is no incentive to fill them out accurately. As a result, catch accounting is a data gap in the BSC fishery off of Lampung.

Beginning in early 2019, a fishery-dependent data collection system will be initiated. This phase of data collection will focus on landed catch that is being sold to the pembinas. The enumerators will collect data on the weight of the landed catch, the length composition of the landed catch and the fishing effort. The goal is to make the system as electronically-based as possible from the beginning, including using the iFish app that has been used to collect data in other Indonesian fisheries. Gaps in data collection will remain after this program begins; most significantly, there are still gaps in fisher and vessel registration, as most are not registered. Additionally, bycatch in the gillnet fishery will not be covered by the new fishery-dependent data collection system during initial implementation.

**Step 4 – Elicit concerns, challenges and barriers.** The most salient barriers associated with implementing a successful EM program are poor licensing and registration for fisheries, fishermen illiteracy and a lack of enforcement. These are described below.

*Licensing of fishers and vessels.* Throughout the region there are many unlicensed fishers and vessels, and a number of challenges that have created that situation. Many fishers cannot be licensed because they lack a government ID and may lack the required shipyard working papers to register a vessel. The fishing villages are also physically isolated and it is difficult to reach areas where there are government offices to license either fishers or vessels. As a result, few travel from the villages to the offices, and officials rarely travel to the villages to register fishers and their vessels.

*Illiteracy.* There are many fishers who cannot read or write, which is a major challenge to implementing any kind of self-reporting like a logbook. Those who are literate may also be quite busy on a trip and simply lack the time to properly fill out a logbook. There have been instances where fishery officers have been asked to fill out the logbooks when the fishers are unable to do so.

*History of non-compliance and a general lack of enforcement.* As stated previously, logbooks are required for vessels larger than 5 GT, and few are filled out because there is no punishment for failing to comply. As it is unlikely that the government will impose sanctions or other penalties, it will be important to generate positive incentives for monitoring and compliance.

**Step 5 – Brainstorm potential uses of technology and consult with technology experts.** A vital next step for this fishery, both in terms of understanding the capacity and improving traceability, is to improve the registration levels for both fishers and vessels; this will lead to improved social and economic benefits for all stakeholders. There are near-term plans to conduct a registration pulse by hiring community organizers to identify and register fishers and vessels in conjunction with the government. This will be a time and labor intensive process, and to sustain that level of registry over the long-term, social media apps such as WhatsApp could be useful for ensuring that fishers can update their registry without having to travel from their villages. Additionally, once fishers are registered, a QR code containing the unique vessel and fisher identification data can be affixed to registered vessels in a way that is visible but difficult to copy. Upon landing, the QR code could be scanned to start the traceability chain.

Because maintaining the length composition of the BSC population and catch is essential for achieving both of the main fishery goals—to conserve the population and to improve social and economic benefits to stakeholders—length composition monitoring will be important. These data will be collected via direct counts by enumerators at first, but because of the large number of vessels and landing sites in Lampung it may be necessary to use smartphones to take pictures of the catch on a sorting table and upload the photos to the cloud for automated quantification of length frequency composition.

At the landing sites, the enumerators will be taking pictures of the catch—not just crabs but also bycatch, which could form the initial basis for bycatch data collection, especially for the gillnet sector. With the development of appropriate programs to identify fish, gastropods or other marine animals, the identification process could become automated over time.

**Step 6 – Converge on practical technologies by considering challenges and barriers.** Practical technologies would include using apps—both new and existing familiar ones such as WhatsApp—to facilitate data collection by adding a self-reporting feature. For fishers needing to register themselves or their vessels, an app on a tablet kept in a central location in the village could overcome the challenges posed by the need to travel to a government office. Having the tablet and app in a central location would allow a community organizer or trusted village member to aid fishers with difficulties reading or writing to register properly. A similar concept is behind having enumerators use an already available tablet camera to capture images of catch and bycatch, which is not currently part of the data collection process. For all these technologies, file size will be an important consideration as the cellular connection may not be sufficient to transmit large file sizes.

Unique identifiers like QR codes could be used to differentiate legal from illegal fishers, and would also contain all the relevant information about the vessel ownership, licensing and fisher licensing for easy download by enumerators during the data collection process. Pembinas could also incorporate QR codes into their own recordkeeping. It is important to consider how to affix the codes to a vessel such that they cannot be stolen and/or easily copied.

There is a need for an efficient database to aggregate all the different data sources, but in many countries vessel registration is not handled by the same government agency as the fisheries management agency. Well-designed databases will be critical to link the appropriate data to ensure that they are easy to access and use for science and management.

**Step 7 – Examine incentives for use and abuse and reduce risk for abuse (e.g., mis-reporting, disabling equipment, etc.).** The government has already shown a willingness to use incentives to improve fisher registration through offering life insurance. If there is a need for further incentives to ensure compliance with registration or other monitoring needs, the government could offer additional incentives like iceboxes or outboard engines. It will be extremely important to generate sufficient positive incentives to comply, given the history of poor enforcement and lack of negative consequences.

**Step 8 – Pilot and evaluate new technologies.** Pilot studies for fisher and vessel registration could be conducted in the same villages where the fishery-dependent data collection system is being implemented. The system could then be spread through the region as familiarity with the technology grows and the technological capabilities of the villages become clearer.

The use of photos to document gillnet bycatch and estimate length frequency composition would also be piloted in the same areas where the fishery-dependent data collection implementation is occurring. There would need to be a programming partner willing to work on automated fish identification using images captured from the field, and would likely need to be helmed by a human during the initial stages. Experts would also need to go to the villages to examine bycatch in person to insure that the identification from an image is correct.

**Step 9 – Remove barriers that could not be removed through design.** The biggest barrier to implementation is the lack of enforcement. Historically, a number of regulations and requirements have been ignored (e.g., the logbook requirement) in large part because there are no consequences for failing to comply.

**Step 10 – Fleet-wide implementation, training and adaptation.** Fleet-wide implementation of fisher and vessel registration would be a major step to understanding the true capacity of the fleet, and is also necessary should the fishery need to engage in management systems that require managed or limited access. Registration may also help establish appropriate levels of traceability. Some training may be required in the use of apps to input registration data, but should be intuitive for most smartphone users. There may also be an opportunity for employing local experts, such as community officers, to assist and teach fishers. The more urgent need may be for training personnel charged with maintaining the registration database and linking it to other databases.

Capturing catch and bycatch data across the entire gillnet fleet is crucial to understanding the full impact of the fishery on the ecosystem, as gillnets already catch some highly vulnerable species such as sharks and rays, which could impact sustainability ratings for BSC. Some training in the use of sorting tables and smartphone cameras to capture images suitable for determining species and length composition and bycatch data will be necessary. The registration and monitoring program should be evaluated against monitoring goals after the first year to identify gaps or barriers that were not identified during the pilot study.

## SUMMARY AND CONCLUSIONS

Fisheries often have a variety of management goals, many of which require monitoring to achieve. Indeed, without monitoring, the risk of negative fishery outcomes—such as poor economic performance and fishery depletion—increases due to a lack of knowledge and accountability to management goals. However, it is likely that only a small fraction of the world's fisheries are monitored. This is because many fisheries lack drivers for monitoring, such as legal mandates or strong economic incentives. Moreover, monitoring programs are difficult to implement for a number of reasons: fishermen who have been fishing without restrictions may resist being held accountable to fishery regulations; the costs of monitoring may seem prohibitive; privacy concerns may drive opposition to monitoring; and prosecutorial systems may not generate sufficiently severe penalties for infractions, making monitoring seem futile.

Monitoring systems also require high levels of stakeholder buy-in to succeed, especially in situations where enforcement is ineffective. There are many ways to motivate the implementation of a monitoring system. A legal mandate to monitor is often a critical component in implementation and can result in fishery managers and fishermen working together, but this alone is often not enough. Stakeholders generally need to be incentivized to adopt a monitoring system beyond the threat of punishment, which is often ineffective or even non-existent in certain contexts; ownership of the idea that monitoring will lead to better fishing is obviously preferable, and this can be achieved by using participatory processes to co-create monitoring goals and design monitoring systems. Demonstrating and otherwise communicating the benefits of monitoring for fishermen—often in the form of higher fish prices, increased catches and increased sustainability—can help to achieve stakeholder buy-in.

When designing a monitoring program it is important to consider each individual's incentives for adoption and participation. Positive outcomes of monitoring can reinforce buy-in and willingness to participate in improving fisheries accountability. For example, if fisheries monitoring strengthens fishermen's rights by ensuring that no illegal fishing is taking place, and that scientific data are being used to manage the fishery, participants will likely approach monitoring in a positive manner. Indeed, fishermen have demonstrated this by agreeing to pay for monitoring and enforcement costs through taxes on landings and quota or administrative fees in the Newfoundland otter-trawl cod (Grafton, 1996), British Columbia geoduck

(Khan, 2006) and groundfish (Turris, 2000) and Iceland TAC fisheries (Pálsdóttir, 2016). However, if incentives are not aligned, top-down imposition of a monitoring program often results in a waste of time and effort.

There are many ways to monitor fisheries, and these vary in the types of data streams generated, the expertise required, the necessary level of stakeholder participation, infrastructure requirements and cost. It is important to strive to ensure that the benefits exceed the costs of implementing a particular monitoring program. Many fisheries probably cannot afford to implement an intensive monitoring system that involves the use of cameras in integrated systems that generate highly detailed data for management. But there are now many options available that can potentially achieve monitoring goals at a much lower cost, and often with higher levels of acceptance and uptake.

Often, the first step in monitoring is merely documenting who is allowed to engage in harvesting, processing and buying seafood. This can start with a list or database of permitted participants and a grace period to encourage fishermen to register. Apps on a tablet located in a central location in fishing villages can make it easier for fishermen to input their registration data, perhaps with the help of community organizers or NGOs if necessary. In some cases, institutional barriers such as poverty, illiteracy and remoteness (and accompanying lack of infrastructure) impede the capacity of fishers to be active in a vessel and permit registry list.

From this starting point, stakeholders and managers can decide how to fill the monitoring gaps and increase data coverage and quality within existing infrastructure and cost constraints. Fortunately, many low-cost technologies are now available to help fill gaps in fisheries monitoring, but to be effective they must be carefully chosen and modified, and embedded within a monitoring program and management system that generates incentives for use. The monitoring design process must be human-centered to increase the probability that monitoring technology will be cost-effective, practical and achieve monitoring objectives.

Because the use of technology in monitoring fisheries—especially small-scale fisheries—is in its infancy, there is an opportunity to socialize and mainstream the use of participatory, human-centered design processes. This is crucial to the creation of successful monitoring programs that rely on fishery adoption (as opposed to programs like Global Fishing Watch and Eyes on the Sea that use passively generated data to identify illegal fishing operations), because the diversity of technologies and systems available to fisheries means that there are many ways in which fishing communities can choose to engage with them, and many ways in which technologies can fail to be adopted or produce useful data. For example, some electronic logbook apps are highly structured, with specific tabs and inputs, while others allow fishers to enter logbook data in a more flexible way. Choosing an app that allows flexible input in a fishery where self-reporting is unreliable and there are many ways to make input errors may result in unreliable data. Further, some monitoring systems necessitate physical and analytical work on behalf of the fishing community (e.g., deploying devices and utilizing software to analyze fishery data), while others are administered and maintained by outsiders. It is likely that different combinations of technologies will be uniquely suited for each fishery. As a result, the needs and capacities of the fishery itself must be at the forefront of the design process.

Institutional barriers and insufficient capacity may impede the potential of any monitoring program. For example, several case studies highlighted the need to harmonize and streamline data coming from various sources, including the government, the private sector, universities and NGOs. The ability to do so will optimize the quality of data generated from monitoring. However, these efforts may prove in vain if the government does not have the interest or capacity to process the data or integrate it into their system. As noted earlier, the Australian government still will not accept logbooks produced through the Deckhand app, despite its noted success and uptake with fishermen and ongoing litigation dating as far back as 2013. This highlights the fact that technology alone will not create a successful monitoring program; rather, mechanisms for analyzing and acting on the data generated with monitoring technology must be institutionalized.

Stakeholders in fisheries that have strong legal mandates and rule of law, or a need to establish a catch history in order to qualify for catch quota, or that must avoid endangered or depleted species in order to keep the fishery open, or have a social commitment to monitoring and compliance, will be sufficiently motivated to invest the time and effort required to design and implement monitoring systems using technology. If they use a human-centered design process like the one illustrated in this report, the technology they adopt will likely be practical and help them achieve their monitoring and management goals.

Stakeholders, managers, government agencies and NGOs can work together to dramatically increase the number of fisheries that are monitored by taking advantage of the power of technology to generate high quality data. While small-scale fisheries are perhaps the least monitored fisheries in the world, they have great potential to improve monitoring As a result, these fisheries will be able to achieve their full potential to produce healthy food, good profits and sustainable livelihoods while conserving ocean wildlife and ecosystem health for today's world, as well as for generations to come.

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