The Management Behind the Fishery Industry

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Abstract

Information gathered from fishermen is crucial for managing fish stocks sustainably. Due to a lack of fishery data, the state of fish stocks is unknown, which might jeopardise the livelihoods of those who rely on those stocks and raise the risk of overfishing. An array of potential solutions to update and modernise fisheries data systems and considerably extend data collection and analysis has become accessible as a result of recent advances in technology for collecting, managing, and analysing data important to fisheries. However, despite the widespread availability of essential consumer technologies, technologically advanced data systems are still the exception rather than the rule in fisheries management. To better understand the barriers to widespread use of high-tech data systems in fisheries management, this article describes their current state, challenges, and potential future paths. In this paper, we demonstrate that a lack of trust and cooperation between fishers and management is preventing innovation in fisheries around the world by analysing the use of data technology dependent on fisheries in a variety of contexts. We suggest a solution based on a transdisciplinary strategy for fishery management that stresses the need of multi-stakeholder problem-solving. Our suggested approach relies heavily on data feedback to ensure that fishers and managers can collect, access, and benefit from fisheries data as they work towards a common goal. Improved fisheries outcomes can be achieved by implementing a novel strategy for fisheries data systems that encourages innovation to boost data coverage, accuracy, and resolution, all while decreasing costs and facilitating adaptive, responsive, near real-time management decision-making.

Introduction:

The food security and lives of hundreds of millions of people around the world are at risk due to overfishing, which has increased the urgency of implementing sustainable fisheries management (Golden et al., 2016; Jackson et al., 2001; Pauly, Watson, & Alder, 2005; Szuwalski, Burgess, Costello, & Gaines, 2017; World Bank 2009). However, regardless of the fishing sector or management system, having access to accurate, consistent data about how a fishery is doing, and what, where, and how much of a species are being caught, is a fundamental component for establishing effective fishery management (Beddington, Agnew, & Clark, 2007). Higher resolution spatial and temporal fisheries data over shorter durations are needed to address growing uncertainty regarding stock status and to allow managers to adapt reference points as the environment changes as a result of anthropogenic cli-mate change and natural climate variability (Pinsky & Mantua, 2014; Szuwalski& Hollowed, 2016). This necessitates improved methods of data collecting, reporting, processing, and analysis, as well as dissemination channels that allow for responses to be made in near real time (Wilson et al., 2018). The ecological characteristics of fished stocks, such as their relative invisibility in the oceans, widespread distribution and mobility across jurisdictional boundaries, and complex interactions within marine ecosystems and the physical environment, make data collection difficult, time-consuming, and costly.

Data dependent on fisheries are necessary for the effective management of all fisheries, but the specific nature of data needs and management goals varies by fishing sector (i.e. industrial fishing, small- scale fishing [SSF], and recreational and subsistence fishing), data availability (i.e. data- rich vs. data- poor), and management type (i.e.

top-down, de-centralized, and informal). In the most data-rich settings, dynamic population models are used to assess stock status by fitting a lengthy time series of fishery-dependent, fishery-independent, and other crucial fishery information. When it comes to an understanding and tracking landings and stock dynamics for effective assessment and management, data-poor fisheries—the >80% of global stocks that lack adequate data for a formal stock assessment (Costello et al., 2012)—often lack the resources and capacity to do so using traditional tools and techniques (Dowling et al., 2016). Syntheses of global fisheries data have revealed a crucial truth: well-managed fisheries, in particular those that are guided by formal stock assessments, are in better condition than fisheries that are poorly managed and lack comprehensive assessments (Costello et al., 2012; Mora et al., 2009). In the end, fishery statistics are required to assist efficient management and ensure the long-term viability of fished stocks and the economic and nutritional security of those who rely on them (Pauly et al., 2005).

Recent innovations and emerging technologies have the potential to contribute to fishery-dependent data systems by increasing or streamlining data collection, automating and empowering data processing and analysis, and facilitating the communication of results to relevant stakeholders. These innovations and technologies often take advantage of the widespread availability of mobile phones and tablets and the growing accessibility of cloud-based computing for data storage and artificial intelligence for analysis. More information can be gathered in less time and with greater accuracy using electronic reporting and on-board passive sensors like cameras and GPS (sometimes known as "electronic monitoring" systems). Management at more relevant spatial and temporal dimensions is possible with the use of artificial intelligence techniques like machine learning and computer vision, and the integrated processing and analysis of enormous amounts of near real- time, geo-referenced data. One-way flows of information (from fisher to management) can be transformed into a cooperative, mutually advantageous cycle of data collection, synthesis, and sharing with the help of technology, allowing fishermen to maximise their fishing based on the best available information. Fishers, whose livelihoods depend on knowing ocean dynamics, are typically the first to discover changes on the water, making the thousands of vessels operating at sea the logical first line of defencce in tracking shifting stock dynamics and environmental variability. However, high-tech fishery-dependent data systems remain the exception rather than the rule, despite the widespread availability of efficient, cost-effective technologies and the potential for technology to fulfil data demands in fisheries management.

To better comprehend the barriers that have prevented the widespread implementation of technologically advanced data systems in capture fisheries, we provide a comprehensive overview of the current state of these systems and the issues they face, and we propose a solution that would direct the increased use of technology to better fisheries outcomes. For the sake of brevity, we will only address data systems that are directly related to industrial, SSF, recreational, and subsistence fishing, and are gathered and/or used on fishing vessels or at the point of landing or first point of sale. We begin with a quick summary of traditional fishery-dependent data systems, then move on to discuss the ways in which fishery-dependent data technologies have been put to use. Cost and restricted access to finance, regulatory restrictions and institutional shortfalls that inhibit innovation, and a persistent lack of trust and collaboration between managers and fishers are some of the factors we propose explain the delayed penetration of technology in fishery data systems. Finally, we argue that the adoption of technological innovations in fisheries could be facilitated by adopting a transdisciplinary approach to fisheries management, which prioritises communication and coordination among various fisheries stakeholders and the development of direct data feedbacks.

Information systems for traditional fishing:

Fishers, fisheries managers, fish buyers and processors, and even non-profits and consumers can all play a role in collecting data in the fisheries industry. Information like this may be documented at the time of capture, landing, sale, or even later by survey or compiled from logbooks and vessel trip reports, onboard observers, landing records, port sampling or dockside surveys, points of first sale, telephone surveys, or experiential knowledge (Figure 1). Data collection is followed by a potentially lengthy and costly process of delivering, storing, entering, and analysing the data by a scientific body and/or management agency before the data may be used to inform management choices (Figure 1). Time lags routinely exceed the rapid rate of change in ocean conditions and their impact on fish stocks, making it difficult for managers to make informed decisions based on the information they have (National Research Council 2000). Although the specifics of fishery-dependent data collection sys-tems vary depending on factors like fishing sector, data availability, and management institution, the majority of existing systems have a pressing need to enhance the ways in which data can guide management and enhance fishing behaviour and outcomes at the right and most precise spatial and temporal scales. Self-reported paper-based logs and/or on-board observers are frequently used in industrial fisheries with top-down management. Since various parameters (e.g., location, gear, species, length/weight, by-catch, effort) are typically relevant, manual data recording may lead to challenges with data accuracy and dependability (Kindt- Larsen, Dalskov, Stage, & Larsen, 2012). Paper-based data systems are inefficient and prone to QA problems like illegibility, lack of standardization in data collection (e.g., species ID codes), lumping together of species into generic groups (e.g., elasmobranchs), transcription errors, and misreporting (Lowell, Mustain, Ortenzi, & Warner, 2015; Lowman, Fisher, Holliday, McTee, & Stebbins, 2013; Will, Campbell, & Holmes, 2014). It can be troublesome for entire fisheries industries if data is not recorded at geographically and temporally relevant scales. Lack of data at key spatial scales and hyper aggregation (e.g., species pooling) of the data led to increased ambiguity in the estimates of stock status, leading to the closure of the Northwestern Hawaiian Islands lobster fishery, which had begun in 1976. (Botsford, DiNardo, Fogarty, Goodman, & Hampton, 2002).

As a result, global fishery data repositories like the FAO are less likely to have coverage from data-poor SSFs due to the lack of automation, standardisation, and centralization in fishery-dependent data collection systems (Chuenpagdee, Liguori, Palomares, & Pauly, 2006; de Graaf et al., 2011; Pauly & Zeller, 2016; Salas, Chuenpagdee, Seijo, & Charles, 2007). Alternatively, local knowledge may be used to disseminate information about past catches and patterns within a certain SSF, although this type of information transfer may be difficult to standardise and translate into quantitative metrics or management actions (Hind, 2014). Due to a lack of resources and inefficient data collection systems, many of the world's SSFs lack even the most fundamental indicator data, such as total catch, number of vessels, and CPUE. This is especially true at the regional level, with large data gaps for all SSFs in the South Pacific, central America, and West Africa (de Graaf et al., 2011). In cases where landings data is available, it is sometimes reported as total landings of all catch rather than landings by species (de Graaf et al., 2011), which can help shed light on regional trends in catches and food security but may not be adequate for guiding stock assessments and management interventions.

Few commercial and subsistence fishing statistics are available (Post, Persson, Parkinson, & Van Kooten, 2008; World Bank, FAO, & WorldFish Center, 2010). Recreational fishery-dependent data can be gathered through routine mail-i n or phone surveys, or through on-site roving and access creel (i.e., angler) surveys; however, these data collection methods are costly (Connelly, Brown, & Knuth, 2000; McCormick, Whitney, Schill, & Quist, 2015); often biassed (Connelly et al., 2000; McCormick, Quist, & Schill (Post et al., 2008). Problems, such as disagreements between recreational and commercial fisheries sectors and fishery collapses, have arisen in large part due to a lack of knowledge on stock status and an inability to record fishery-dependent data at appropriate spatial and temporal scales. For instance, the recreational fishery for red snapper (Lutjanus campechanus, Lutjanidae) in the Gulf of Mexico continued unabated despite the fact that it has consistently surpassed its quota from 2007 to 2013. Responding to this, commercial fishermen sued the US National Marine Fisheries Service (NMFS; Guindon et al. v. Pritzker, 2014), alleging, among other things, that the NMFS had failed to implement catch restrictions once the quota had been met and to make use of the most up-to-date scientific data. Inadequate monitoring and assessment led to the public, fishery scientists, and management in Canada missing the signs of population collapses in some recreational fisheries aimed at Salmonids, Percids, Esocids, and Centrarchids (Post et al., 2002). However, subsistence fisheries frequently lack centralised data collection methods, thus their precise proportion to total catch is not fully resolved, despite the fact that they are crucial to food security in many nations (World Bank, FAO, & WorldFish Center, 2010). More than 10% of the entire population in industrialised countries fish for recreation (Arlinghaus, Tillner, & Bork, 2015), and the for the many subsistence fishermen worldwide, there is significant untapped potential to gather and utilise fishery-dependent data to support better fisheries outcomes.

Cyber-based surveillance:

Electronic monitoring systems, sometimes known as camera systems, are used to record capture and discard activities for auditing purposes on land or at sea. To supplement on-board human observer programmes or to provide a cost-effective, less biassed alternative that can improve monitoring and surveil-lance through increased coverage, EM systems were developed to record data on fishing gear, haul (target catch, incidental catch, by-catch, and discard), catch handling, processing, and/or fishing effort (location and time fished). The appearance of EM gear might vary widely amongst fishing operations. Industrial fisheries and some SSFs have used large camera systems (video or still) mounted aboard vessels to census effort and landings; SSFs have also used hand-held still cameras to capture images of the weight, size, and identity of landed species; and cameras set up to record fishing activity from shore have been deployed to log nearshore fishing effort in recreational and subsistence fisheries (Greenberg & Godin, 2015; Keller, Steffe, Lowry, Murphy, & Suthers, 2016; Powers & Anson, 2016). Closed-circuit television (CCTV) cameras, a global positioning system (GPS), a hydraulic pressure sensor, and/or a rotation sensor, as well as a control centre, are all components of an EM system used in industrial fisheries. Trials of EM have been used in many different types of industrial fisheries all over the world to ensure that catches are sorted and weighed accurately, that discard bans are being adhered to, that protected species quotas and interactions are being tracked accurately, and that fishing and on-board processing mandates are being reported in full (Table 1). Experiments have demonstrated that EM can provide reliable information about fisheries at a low cost, and it can also increase compliance with quota laws for endangered species (Hold et al., 2015; Needle et al., 2015; Sylvia, Harte, & Cusack, 2016; Ulrich et al., 2015; van Helmond, Chen, & Poos, 2015). The Atlantic pelagic longline fishery was the first in the United States to deploy a fleet-wide EM programme in 2015 to ensure reliable bluefin tuna by-catch reporting (Sylvia et al., 2016). Trials of EM to replace human observers were conducted in the U.S. West Coast groundfish bottom trawl and non-whiting midwater trawl fisheries and in all Alaskan fish-eries using longline and pot gear in April 2017 (Ames, 2005; Ames, Leaman, & Ames, 2007; Ames, Williams, & Fitzgerald 2005; Pria, McElderry, Oh, Siddall, &Wehrell, 2008; Hook-and-line groundfish fishermen in British Columbia, Canada, have been subject to mandatory EM coverage since 2006, and the use of video data to audit other catch accounting methods has been praised for its potential to eliminate bias in catch estimations (Stanley, McElderry, Mawani, &Koolman, 2011; Stanley, Olsen, &Fedoruk, 2009).

The Western and Central Pacific Fisheries Commission (WCPFC), which oversees the management of tuna and other highly migratory fish populations, has recently advocated for wider implementation of EM. Seven of the 26 member nations have recently trialled EM systems: Australia, New Zealand, Fiji, the Cook Islands, the Federated States of Micronesia, the Republic of the Marshall Islands, and Palau. However, most of these trials have only been conducted on two to five boats (WCPFC, 2017a). The recent endorsement of EM by at least one re-gional fisheries management organisation (RFMO; WCPFC, 2017a) may alter the global uptake of EM, as EM data are rarely used for fisheries management across all industrial fisheries (Wallace et al., 2015).

In small-scale fisheries (SSFs), where large fleets, small vessels, a lack of enforcement, and the high costs of paying people to monitor fishing activity have implemented traditional monitoring programmes, such as on-board ob-servers, difficult, EM has also been noted for its usefulness (Bartholomew et al., 2018). EM systems in SSFs may combine a camera and a GPS device, powered by solar panels (Bartholomew et al., 2018), or use mounted or handheld cameras; still images may be preferable to balance data collection and storage needs. Although EM pictures successfully caught shark, ray, and pinniped by-catch in Peru's small-scale elasmo-branch gillnet fishery, they were less successful in accurately capturing sea turtle and cetacean by-catch (Bartholomew et al., 2018). On-board Crew Operated Data Recording Systems (CODRS) are being utilised to photograph, measure, name, and geo- reference all fish captured from participating vessels as part of a joint effort between The Nature Conservancy in Indonesia and the fishing industry. Multiple species of snapper, grouper, emperor, and other landed finfishes throughout multiple Indonesian Fisheries Management Areas have had their data analysed to produce length- based stock assessments (P. Mous, 28 September 2017 personal communication). Overall, SSFs in Thailand, Malaysia, and Morocco have seen better supervision once EM programmes were put into place (Pitcher, Kalikoski, Pramod, & Short, 2009). There have been isolated cases of success with EM programmes, but this has not led to widespread adoption in SSFs. It is difficult to achieve full coverage EM due to the large number of vessels in many SSFs (Bartholomew et al., 2018).

Dockside or other shore- based camera systems can efficiently record fishing effort based on landings information, vessel activity, or effort around a specific feature (like an artificial reef) in recreational and subsistence fisheries, where similar electronic monitoring-like systems have been tested (Greenberg & Godin, 2015; Keller et al., 2016; Powers & Anson, 2016). Using dockside cameras, Greenberg and Godin (2015) demonstrated that significant length reductions in the red snapper recreational fishery did not result in proportional changes in fishing effort, so exposing a critical flaw in the management strategy for the fishery. When applied to recreational and subsistence fisheries, where thousands of people operate with little to no monitoring, it's possible that large-scale EM as outlined is just not practical beyond experimental runs.

Electronic reporting

Electronic logbooks (ELBs) are the most prominent ER use in industrial fisheries, while formal ELB systems in SSFs, recreational, and subsistence fishing are poorly documented (but see Section 3.3). ELBs are self-reporting tools like paper logbooks, making them easier to integrate into a fishery than EMs (Lowman et al., 2013). ELBs with GPS enables fishers to digitise catch information, record exact geographical and temporal effort, and catch data in near real-time (McCluskey & Lewison, 2008). When catch limitations are reached, certain ELB systems signal vessels to stop fishing or leave specified areas (Chang, 2011). Industrial management agencies have implemented ELBs. EU fishing vessels >15 m must have ELBs to record landings and discards. ELBs are employed on some US vessels to verify compliance with regulations, not to estimate catch (Cahalan, Mondragon, & Gasper, 2014; Kauer et al., 2018).

US commercial fisheries prefer electronic landing receipts (fish tickets and e-tickets) to record landings information using an online submission form to increase the temporal resolution of fishery-dependent data. E-ticket landing reports include the date and duration of each trip, gear type fished, area fished (designated fishing zone), weight and condition of purchased landings by species, for both processed catch and unprocessed catch discarded at the plant, which the processor records and submits electronically to a fishery management agency. Fisheries authorities have improved the accuracy and timeliness of commercial landings data for some US species by switching from a paper fish ticket method to an ER form (NOAA 2017). In 2005, ground fish and halibut joined Alaska's crab industry in adopting electronic fish tickets. E-tickets have helped Alaska's fisheries management agencies cut costs by printing and distributing huge quantities of paper tickets, reduce catch accounting errors by streamlining the data entry process, consolidate landings data, and improve data transparency by housing all e-ticket data on a single server accessible to all agencies (Carroll, 2006). E-tickets are now required for all commercially captured sablefish in the US West Coast catch sharing fishery to monitor annual catch limits and provide harvest data to fishery management and law enforcement (NOAA 2017).

Regional fisheries management bodies may again promote ER worldwide. Following trials between 2013 and 2017, the WCPFC formally supported usage of ER for catch and effort data in 2017 (WCPFC13) and for observer data in 2018 (WCPFC14) with proposed, but voluntary, data standards, specifications, and processes for purse seine and longline catch/effort accounting (WCPFC, 2017b). WCPFC's Pacific Island member countries submit all observer data via an ER system that meets WCPFC criteria, but the Republic of Korea and Chinese Taipei report all or most fleet data using ER systems that do not (WCPFC, 2018a). Several countries have expressed concerns over implementing any fleet-wide ER system, including costs, legal frameworks, and technical trainings (WCPFC, 2018a), and longline ER coverage for catch and effort data peaked in 2016 and has since declined (WCPFC, 2018b), possibly foreshadowing future large-scale adoption of RFMO-wide ER.

Mobile Technology:

Mobile technologies have revolutionised fishery-dependent data system developments and prospects worldwide. Smartphones and tablets are becoming increasingly useful for data collecting in all fisheries sectors due to their portability and ubiquity (Gutowsky et al., 2013; Lorenzen et al., 2016; Papenfuss, Phelps, Fulton, &Venturelli, 2015; Venturelli, Hyder, &Skov, 2016). Mobile technology, including smartphone/tablet apps, can gather, store, and analyse vast amounts of real-time or near-real-time fishery-dependent data, capturing the spatial and temporal dynamics of captures (reviewed in Venturelli et al., 2016). Mobile apps can influence fisher behaviour on the water to comply with quota and protected species rules and/or connect and engage fishers through data sharing and social networks by providing two-way, near-real-time information transfer.

The Nature Conservancy's eCatch app, a smartphone/tablet-based mobile logbook, allows fishers to share real-time information about by-catch species' location and amount with each other and fishery managers to ensure compliance with overfished species quota and facilitate real-time adaptive management in the US West Coast groundfish fishery (Kauer et al., 2018; Figure 3). In Hawaii's pelagic long-line fishery, NOAA's TurtleWatch online platform has reduced sea turtle by-catch by providing fishers with a map updated with near-real-time information about the predicted thermal habitat of loggerhead (Caretta caretta, Cheloniidae) and leatherback (Dermochelys coria-cea) sea turtles (Howell, Kobayashi, Parker, Balazs, &Polovina, 2008; Howell et al., 2015).

Mobile apps and online forms can help data-poor SSFs record and analyse fishery-dependent data at the moment of catch, landing, processing, and consumption. In a Japanese SSF sea cucumber fishery, fishers used an iPad-based digital diary and a GPS unit to send real-time data about fishing effort and catch location and quantity to an online server, where pre-programmed software immediately processed and analysed the data and shared results with the fishers (Saville, Hatanaka, Sano, & Wada, 2015). These high-resolution data streams lead the fishery to voluntarily reduce fishing activities weeks before the formal fishing season to avoid exceeding the overfished species quota (Saville et al.,2015). Integrated online reporting systems that record data at numerous locations along a fishery's supply chain may increase traceability and support seafood certifications. To comply with EU IUU regulations and Marine Stewardship Council certification standards in the Maldivian pole-and-line skipjack fishery, Fisheries Information System (FIS)—an online tool that links fishing vessel licence information and catch certificates to catch data recorded at landing, sale, and export—has been adopted (Kearns, 2016). Buyers' mobile app use has improved fishery-related data's spatial and temporal resolution. OurFish, a point-of-purchase mobile app used at SSFs in Belize, Honduras, Indonesia, and Myanmar, allows customers to register species, catch date, location, and weight using a picture-based form. The OurFish software provides digital bookkeeping for fish sellers, allows fishermen to track their landings through time and geography, and electronically submits data to government fisheries agencies and other stakeholders (Irby, 2017).

A diverse and competitive industry developing angler apps that can accurately record spatially and temporally explicit fishing effort and harvest data, discards, and species weight and/or length has grown rapidly in the recreational fishing sector (Jiorle, Ahrens, & Allen, 2016; McCormick, 2017; Papenfuss et al., 2015; Stunz, Johnson, Yoskowitz, Robillard, &Wetz, 2014; Stunz, Yoskowitz, Fisher, Robillard, & Topping, 2016; Table 2). The explosion of angler applications offers interesting prospects to alleviate recreational data shortages (Venturelli et al., 2016). For example, recreational fishers from around the world have reported more than 3.7 million catches with data on where, when, how, and what was caught on the Fishbrain app (www.fishbrain.com), but no data has been used to inform fisheries management. In the Florida common snook (Centropomusundecimalis, Centropomidae) fishery, angler app data were utilised to assess stock in the absence of a commercial fishery or data stream (Muller & Taylor, 2013).

The first step is identifying the relevant parties and agreeing on a common objective. Many distinct groups are invested in fisheries management, each with its own perspective on any given topic (i.e., various fishing sectors, managers, processors, and consumers). For fishermen, by-catch reduces efficiency because it lowers target catch and can lead to fines or even threaten fishing operations; for managers, it can pose a problem for regulations on protected or vulnerable species; and for processors and sellers, it can derail efforts to certify or market a product as sustainable in an industrial tuna fishery. Consequently, a transdisciplinary process enables the group to find commonalities and coalesce around shared goals, despite the fact that the issues and demands may vary between fishery sectors or stakeholders (Figure 2). The collaborative approach and shared decision-making generate transparency and a sense of justice, which may raise the chance of compliance, even when a stated aim may have short- term consequences for one group of stakeholders (e.g., cutting fish-ing quotas) (Turner et al., 2016).

Successful transdis-ciplinary engagement, like other kinds of co-management, is most likely to occur in fisheries with a history of collaboration and trust among stakeholders, which may be more likely in fisheries with bottom-up management systems. Top-down administration perceived as disenfranchising fishers can lead to a climate of mistrust and animosity, making it harder for the transdisciplinary process to succeed. However, in low trust situations, involving brokers—such as a non-governmental organisation (NGO) or an administrative entity specifically tasked with managing the collaboration—to facilitate the process of setting and working towards collective goals can be a means to overcome challenges associated with mistrust (Provan&Kenis, 2008). Management or facilitators with experience in collaborative methods should set aside time to cultivate a climate of trust among participants before launching the transdisciplinary interaction (Virapongse et al., 2016). New data systems can help strengthen trust between groups through the transparent sharing of information between all stakeholders once a baseline level of trust has been es-tablished and issues of trust and buy-i n preventing wider adoption of high- tech fishery- dependent data systems are addressed.

Plan of action and methods:

In order to ensure that a new technology satisfies the needs of all parties involved, it is necessary to first establish clear technical and performance stand-ards for fishery-dependent data collection and then to articulate the objective of the new technology in a way that takes into account the interests of all parties involved (Figure 2). Lacking stated goals, new technologies may be deemed unnecessary and never make it past the pilot stage (e.g., Table 1). For instance, in the case of EM programmes, failures are rarely attributable to flaws in the underlying systems, but rather to a lack of understanding of how these programmes can supplement or replace preexisting data streams to better assess the degree to which specific management objectives and goals have been attained (Lowman et al., 2013). In addition, it is essential to include well-defined goals and technical and performance requirements to avoid unintended consequences for the fishery or its stakeholders. Example: when criteria and objectives are not established, advances in technology have led to increased fishing efficiency, which has a negative impact on fishery sustainability (Sreekumar, 2011; Turner, Polunin, & Stead, 2014).

Within the transdisciplinary framework, a solution to an agreed-upon objective is reached through iterative discussion rather than as the result of a top-down decision-making process to accommodate varying viewpoints and win over all interested parties (Roux, Stirzaker, Breen, Lefroy, &Cresswell, 2010). The technology tools should not determine the solution if they are not appropriate for the problem. Although it's doubtful that everyone will be happy with the end result, it's more likely to be accepted if it was arrived at through this sort of structured, transparent, participatory decision-making process than if it had been produced in secret (e.g., failure to adjust existing ER systems to adhere to imposed data standards in the WCPFC).

Result and analysis:

A fishery can begin the process of implementation if it has concluded that a technological solution is an appropriate means to achieve a common goal. Most new fishery-dependent data technology will need to incorporate feedback mechanisms to guarantee that the fishing sector is benefiting from its data collection effort and to meet the demands and transparency expectations of those concerned. Those who fish have said they need to know what they're doing with the data they're submitting to fishery data collection programmes to keep their interest (Prescott, Riwu, Stacey, &Prasetyo, 2016). Information-sharing systems that rely on fishery-dependent data gathering techniques in near-real-time can achieve this goal by making data available to more users (Jensen, 2007; Salia, Nsowah- Nuamah, & Steel, 2011; Saville et al., 2015). Working together can improve the quality of data dissemination to fishermen so that the information may be used to inform and improve on-the-water decisions (Neitzel, van Zwieten, Hendriksen, Duggan, & Bush, 2017).

A new high-tech data programme can't be successful without first undergoing an evaluation of the data system's efficacy against the agreed-upon objective and data and performance standards (Lowman et al., 2013). The shorter time between data collection and action (e.g., management intervention, chosen fishing area) is an advantage of high-tech fishery data systems for both fishers and managers, and can be institutionalised if reached by consensus and entrenched within an iterative management process (Figure 2). Quick access to data can also help with evaluating employees' performance in real time. High-resolution temporal and spatial data streams and enhanced data sharing networks can be protected against unexpected outcomes through the refined application of fisheries technology, such as increased fishing efficiency leading to overfishing.

Potential dangers and unintended outcomes:

By involving more people in the management process, transdisciplinary approaches can ease the load on everyone participating in the resource system. A technology's ability to integrate data input with data output (e.g., an app) can help democratise management by reducing the reliance of fishers or local governance bodies on external experts or a centralised agency by making data collecting, analysis, and availability more accessible to them. Cooperation like this can help fisheries that have insufficient data or lack the necessary resources to properly manage their fishery. This includes both informal and decentralised management systems. Using technology to gather, analyse, and/or distribute data in a centralised management system still occurs inside the top-down management structure, but it decentralises some of the management process by inviting stakeholders to participate in decision-making. It's crucial to recognise the potential downsides of using technology that give fishermen greater control inside a management structure or provide them access to information in the absence of management.

Overfishing is a possibility if advanced fishing technology is employed to catch more fish in less time. The Northumberland lobster fish-ery and an SSF in Kerala, India are two examples of situations where widespread information sharing led to substantial increases in landings that were, in all likelihood, not sustainable in the long run (Sreekumar, 2011; Turner et al., 2014).

By increasing the relationship between certain groups of stakeholders at the expense of others, communication and information exchange can potentially impede cooperative efforts amongst diverse fishing stakeholders. Sreekumar (2011) found that purchasers in Kerala, India formed cartels and engaged in price fixing through the use of mobile phones to exchange real-time price information with one another.

Newly available data could be interpreted differently by different users, or seen as contradicting observations made on the water, leading to conflict between individuals or stakeholder groups, even after working collaboratively and iteratively to define a shared goal and implement an agreed- upon data solution. Although fishermen in the North Sea flatfish fishery reported seeing an increase in plaice stock, policymakers and nongovernmental organisations (NGOs) were not convinced by the results of catch reconstructions and instead dismissed the fishermen's claims outright (Verweij, van Densen, & Mol, 2010). Annual reductions in the total permissible catch were seen as arbitrary and counterproductive by fishermen, sowing discord and mistrust among fishery stakeholders (Verweij et al., 2010). While it is true that feedback, communication, and agreed-upon standards for information use and processing can help mitigate some of the conflict that can arise from differences in perception and/or interpretation of data (Prescott et al., 2016; Verweij et al., 2010), perception differences may persist.

The risk of unintended repercussions is inherent in any managerial shift or technical innovation; however, the collaborative decision-making and iterative nature of transdisciplinary cooperation can make it easier to identify these problems and address them in a timely manner.

Conclusions:

In order to ensure food and livelihood security, as well as preserve the ecological integrity of the ocean, it will become increasingly important to achieve sustainable resource use in all sectors of capture fisheries as the human population continues to rise and demand for seafood rises along with it (Hall, Hilborn, Andrew, & Allison, 2013). This is a fascinating time to be working on fisheries data systems, as technological advancements promise to enhance previous attempts dramatically. By equipping fisheries stakeholders with geographically and temporally relevant data for fishing and fisheries management, new tools can increase data collection, analysis, and distribution, leading to more sustainable resource use. Despite the clear potential for technology to improve fisheries outcomes across fishing sectors, innovation and acceptance of new technologies have been relatively slow, indicating that severe constraints have constrained support for new technologies across much of the world's fisheries. We propose transdisciplinary fisheries management as a means to increase support for and use of emerging data technologies in the fishing industry. By cooperating toward a common goal, fisheries managers can use fishery-dependent data technology as a value proposition to fishers. This is achieved through the use of tools that streamline and/or automate data col-lection and analysis, and returns information to users about where and how to best fish and/or improve market access.

It's not uncommon for there to be a significant learning curve when first implementing a new piece of technology. Expanded public/private partnerships may be required to leverage external expertise that may not exist within either management agencies or the fishing industry in order to develop and synthesise information from fishery data systems intended to meet global challenges such as rapidly changing ocean conditions due to anthropogenic climate change and natural climate variability. Management structures, meanwhile, should encourage the incorporation of better data. Embedding a high-tech fishery data system into an adaptive management framework helps institutionalise its many benefits, such as the reduction of the time between data collection and action (e.g., management intervention, fishing area selection) for fishermen and administrators. We understand that once in place, enhanced data streams may present new difficulties, such as an increase in the rate at which data is produced or an overreliance on the accuracy of models and the analytics they produce. No matter the fishing industry or kind of management organisation, data is an essential part of good management and cannot produce more sustainable fisheries on its own but can help inform better decisions. Improvements in both management and harvesting efficiency can result from using cutting-edge fishery data systems.

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