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Original Article

An evaluation of information sharing schemes to identify what motivates fishers to share catch information

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Avoiding unwanted catches and reducing discards is an important objective of fisheries management. Fishers can avoid unwanted catches to some extent by improving selectivity of their fishing operations. This can be achieved through technical measures and gear modifications but also by adjusting when and where fishing takes place. Having access to real-time information, as provided through information sharing within a fleet, can help fishers avoid unwanted catches. Yet, there often remains a reluctance to share catch information with others. This paper compiles information from 15 case study examples of existing information sharing schemes in fisheries throughout the world. We compare the structure and operation of each of these schemes and determine what motivated participants to join and share potentially sensitive catch information. While there is no one-size-fits-all approach to designing and implementing information sharing schemes in fisheries, this paper highlights how industry and stakeholder support is often important, and understanding the needs, concerns, and motivations of any group of fishers is fundamental in developing and expanding such approaches.

Keywords: bycatch, catch avoidance, discards, fisheries, information sharing, real-time data.

Introduction

In mixed fisheries, where a number of different species contribute to the output of the fishery (Poos *et al.*, 2010), there is often a need to better target some species while avoiding others. Target species are usually those for which there is a quota or minimum size catch established, and/or a market, while non-target species include those that are banned, quota restricted, or species for which there is no or little monetary value (Catchpole *et al.*, 2014). Any non-target species caught are likely to be returned to the sea and this discarding of catches can represent a significant component of fishing related mortality for many stocks (Kelleher, 2005; Shephard *et al.*, 2014; Veiga *et al.*, 2016). Improving the selectivity of fisheries to avoid unwanted catches and reduce discarding is, therefore, an important objective of fisheries management (Fauconnet and Rochet, 2016; Kennelly and Broadhurst, 2021). Consequently national and international legislation and policy increasingly include requirements for the reduction of bycatch and discarding (European Commission, 2013; Little *et al.*, 2015). To comply with such legislation fishing vessels may have to better avoid unwanted catches and improve the selectivity of their fishing operations.

Improved selectivity can be achieved through technical measures and gear modifications and considerable effort has been put into conducting research on how adaptations in fishing gear can improve selectivity (e.g. O'Neill and Mutch, 2017). Fishing with selective gears is often used as a management measure in commercial fisheries to foster sustainable exploitation of fish stocks (O'Neill *et al*., 2019). Optimal gear design is, however, often very context- and case-specific and in mixed fisheries it can be difficult to set technical regulations that will be effective in avoiding all non-target species (Melli *et al*., 2020). Species and size composition of catches can also often vary both spatially and temporally, in part due to the varying habitat requirements of different species as well as their seasonal and diel migratory patterns (Poos *et al*., 2010). Thus, to further improve selectivity, fishers may be able to adjust when and where they fish to better target certain species while avoiding others.

The decision of where to fish can be influenced by available quota, fishing strategy, markets, economics, fishing experience, and the biology of the resource (Little *et al*., 2004; Salas and Gaertner, 2004; Turner *et al*., 2014). In terms of knowing where certain species of fish are likely to be found, commercial fishers often rely on their personal knowledge and experience and can have excellent spatial knowledge of fishing grounds (Paul *et al*., 2016; Calderwood *et al*., 2021). Having information on the exact location of fish can be a crucial factor in better targeting catches and maximizing efficiency of fishing operations (Gezelius, 2007). The ocean, however, is a complex and rapidly changing environment and fish are mobile (Wilson, 1990). Regardless of the extent of personal experience, it can be difficult to know the best location to fish at any one time to either target or avoid a particular species.

Real-time information on where a certain species of fish (either target species or unwanted catches) are concentrated can be gained through sharing information with other fishing vessels. Engaging in such information exchange can assist in reducing some of the uncertainty and risk in deciding where to fish and can overcome the individual limitation of not having full knowledge of where all of the fish are all of the time (Gatewood, 1984; Ramirez-Sanchez and Pinkerton, 2009). Such information exchange can occur on a number of different levels, ranging from the passive observation of where other vessels are fishing to having informal chats with fellow fishers over the radio, or exchanging messages *via* mobile phone, to organized information sharing schemes (Palmer, 1991; Branch *et al*., 2006; O'Keefe *et al*., 2014; Turner *et al*., 2014). Yet, while it has been acknowledged that no single fisher can acquire all of the experience necessary to optimize the exploitation of marine resources, there often remains a reluctance to share information with others (Wilson, 1990; Eliasen *et al*., 2015; Calderwood *et al*., 2021).

There are many different factors that can influence the willingness to share information including the size of the fleet, social cohesion, economic costs and benefits, the biology of the species involved, and self-interests of fishers (Gatewood, 1984; Branch *et al*., 2006; Gezelius, 2007; Ramirez-Sanchez and Pinkerton, 2009; Klein *et al*., 2017). Fishers are often recognized as being competitive and consequently can be reluctant to share information if it might mean they lose their competitive edge (Gatewood, 1984; Wilson, 1990; Ramirez-Sanchez and Pinkerton, 2009; Turner *et al*., 2014; Calderwood *et al*., 2021). There can also be a lack of trust in the information received from other fishers (Calderwood *et al*., 2021). Notable variation has been observed in the amount and accuracy of information that is shared between commercial fishers (Palmer, 1991). Yet, despite the reluctance of some to share or trust received information, sharing catch information can provide a more comprehensive understanding of where fish are at any one point in time (O'Keefe and DeCelles, 2013; Suuronen and Gilman, 2020).

Schemes of rapid collection, collation, analysis, and dissemination of information to provide real-time reporting of the location of bycatch can assist in its avoidance (Alfaro-Shigueto *et al*., 2012; Marshall *et al*., 2017a). Such schemes, however, often require participation of the majority of fishers in a sector or fleet to be successful (O'Keefe *et al*., 2014). There is also a need for truthful information to be shared, and for those receiving it to trust it and act upon it. Understanding of the human element of information sharing schemes is, therefore, required to improve chances of success (Klein *et al*., 2017). This is especially important for fleet managers who hope to use information sharing as a tool to aid in bycatch avoidance. There are existing review papers that examine how such schemes are implemented, governed, and managed as well as evaluating the effectiveness of fleet communication in reducing bycatch (Supplementary Table S1; Gilman *et al*., 2006b; O'Keefe *et al*., 2014; Little *et al*., 2015; Holland and Martin, 2019). This paper, therefore, aims to move beyond current understanding of information sharing schemes on fisheries and further reflect on what it is that motivates individuals to partake in such schemes. Through an examination of the literature, in addition to three in-depth case studies based on our direct experiences, this paper aims to determine what motivated fishers to join and share what could potentially be sensitive catch information while further evaluating the documented and perceived successes and effectiveness of these schemes and how these relate to levels of participation.

Material and Methods

Literature Reivew

A narrative literature review (Ferrari, 2015) was performed to find examples in both the scientific and grey literature of information sharing schemes in commercial fisheries, which were established to aid in bycatch avoidance or to inform real-time management of the fishery. Searches were made using Web of Science, Scopus, Google Scholar, and Google. Search terms included combinations of the following "information/data sharing/exchange fisheries/fishing vessels," "fleet communication", and "real time spatial management fisheries". The reference lists of the returned literature were reviewed to identify additional relevant literature. Case study examples were selected where it was clear that industry observations or catch information were being shared and could be accessed by other members of the fishing fleet. The literature available for each case study also had to provide details on the potential incentives available to encourage participation. Further detail was sought to provide some indication of whether each scheme had been deemed successful, not only in reducing unwanted catches but in encouraging and maintaining participation from fishers. A total of 15 examples of information sharing schemes that fit these criteria were identified, including ten from the United States of America, three from the United Kingdom, one from Peru, and one from Japan. A total of 5 of the examples from the United States represent fisheries that use Sea State Inc. to facilitate information sharing. Since its inception in 1995, Sea State Inc. now facilitates information sharing in a number of Pacific fisheries throughout the US (Gauvin *et al*., 1995; O'Keefe *et al*., 2014) but case study examples were only included where sufficient information on the fisheries involved could be found in the literature. For each case study fishery, the literature was reviewed to determine; which fisheries and fishing organizations were involved, who facilitated the information sharing scheme, who provided data, who is it shared with and how is it communicated to the fleet, how received information is acted on, what incentives exist to encourage participation and what potential measures of success and effectiveness have been noted, if any.

In addition to these case studies from the literature, we also provide insight from direct experience of working with fishers who are participating in information sharing schemes. We reflect on any incentives or barriers that may exist with regard to individuals being willing to share potentially sensitive catch information for three specific case studies; the North Pacific Fisheries Management Council and Sea State Inc., the BATmap app used on the west coast of Scotland and Peru's radio conservation for artisanal fisheries. These three in-depth case studies provide examples from different sized fisheries from small scale fisheries to large commercial fleets, addressing different problems. They also provide examples of the use of information sharing in fisheries from three different parts of the world operating under different jurisdictions. For all of these examples commonalities were identified as to who provides the information to be shared and what form this information takes. The case studies were further compared to determine how shared information was communicated back to participating fishers and what the response is to this information and how it is acted on within each fishery. Common themes were identified as to the incentives that existed for fishers to participate in each scheme. These themes were evaluated against the relative successes and benefits of each scheme.

Results

Case studies

North Pacific Fisheries Management Council and Sea State Inc.

The approach of using cooperatives to meet management challenges has become well-established in both the Pacific Northwest and Alaska regions. Unexpected shifts in species distribution (shortbelly rockfish) and abundance (dramatic increases in Pacific herring and sablefish and decreases in Chinook salmon and Pacific halibut) have led governing bodies (Pacific and North Pacific Fisheries Management Councils) to expect fleets organized as cooperatives to respond to such shifts in-season. Management rule-making is generally a longer-term process but in this arena as well, councils have depended on trawl cooperatives to provide adequate avoidance response to changes in abundance in anticipation of formal rulemaking. As detailed in Table 1, there are many examples of fisheries in the US that utilize Sea State Inc. to employ real-time reporting and bycatch avoidance schemes. Many of the fisheries involved have bycatch limits, which could result in the fisheries being closed prematurely if such limits are reached. Thus, there is a motivation to take part in information sharing schemes to reduce bycatch and extend fishing opportunities.

The NPFMC (North Pacific Fishery Management Council) was established in 1976 as one of eight regional fishery councils in the US to manage fisheries in the 200 nm Exclusive Economic Zone (Regional Fisheries Management Council, 2019). The NPFMC is responsible for managing over 140 species within 47 stocks and stock complexes (whereby stocks that are similar in geographic distribution and life history are grouped and managed together) in the Alaskan EEZ including pollock in the Eastern Bering Sea (EBS; Regional Fisheries Management Council, 2019). The EBS pollock fishery accounted for approximately 66% of the total Alaskan groundfish catch in terms of wholesale value in 2019 (Fissel *et al.*, 2021). There are three fleet segments within the fishery with the catcher–processor and mothership fleets operating at sea for extended periods of time, while the inshore fleet, organized across seven fishing cooperatives, has approximately 120 catcher vessels delivering shore side for processing (Strong and Criddle, 2011; Marshall *et al.*, 2017b). In 1998, the Pollock Conservation Cooperative (PCC) was formed and in 1999 together with the High Seas Catchers' Cooperative (HSCC) and seven cooperatives composed of shore-based catch vessels an inter-cooperative agreement (ICA) was signed (Strong and Criddle, 2011). The ICA effectively restructured the fishery into a fully functioning fishing cooperative with a private and contractually binding agreement for all cooperative members (Marshall *et al.*, 2017b).

In 2011, in the EBS pollock fishery, the NPFMC instituted caps on Chinook salmon that could result in a complete fishery closure by sector (catcher–processor, mothership, or shoreside), with an allowance for a multi-tiered cap if vessels joined an "incentive plan." Each Incentive Plan Agreement (IPA) requires a detailed plan for reducing Chinook bycatch in all levels of abundance (NOAA, 2021). Due to the challenges involved in reducing bycatch, with variability in salmon bycatch occurring at spatial and temporal scales that were not aligned with fixed closed areas, the issue was turned over to the fishing industry for them to develop their own approaches to further reduce salmon bycatch (Stram and Ianelli, 2009; Marshall *et al.*, 2017b). As a result, rolling hotspots were introduced to reduce incidental catch of chum and Chinook salmon, first as a replacement for fixed closures in 2006 and further modified in response to the 2011 hard cap on Chinook bycatch. This use of rolling hotspots was seen as important by industry as it allowed for a quick response to rapid changes in the location of migratory salmon. Industry participants developed threshold bycatch rate values that qualified an area for closure and also defined which vessels were subject to the closure. Sectors were given two caps (one low and one high) and are allowed to go up to the higher cap in 2 out of 7 years, in exchange for a documented plan to reduce Chinook bycatch even when caps do not appear to be constraining (Stram *et al.*, 2015). All vessels in the fishery opted to join one of the three IPAs that were subsequently developed along sector lines and all plans include, among other measures, these rolling hotspots. The formation of the ICA and IPAs played a large part in encouraging greater engagement of industry in co-management of the pollock fisheries. All pollock cooperatives then contracted Sea State Inc. to receive, monitor and evaluate catch and bycatch data to feed into the chum and Chinook salmon rolling hotspot programme on behalf of the cooperative (Marshall *et al.*, 2017b). All bycatch data were generated by federal observers as part of the North Pacific groundfish observer program, before being shared with Sea State Inc., and was thus viewed as completely trustworthy. Pollock catcher–processors had 100% observer coverage while inshore pollock catcher vessels were required to have 100% observer coverage on vessels greater than 125 foot and 30% observer coverage on those less than 125 foot; this changed to 100% observer coverage for all vessels with the incorporation of incentive plan agreements in 2011 (NOAA, 2010).

BATmap app for mixed fisheries on the west coast of Scotland

The introduction of the EU Landing Obligation (European Commission, 2013) between 2015 and 2019, meant any quota managed species could no longer be discarded at sea but had to be landed and count against quota regardless of size. This legislation could result in the possibility of choke species, whereby once any one quota

Table 1. Case study information sharing schemes in commercial fisheries.

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
Eastern Bering Sea flatfish fisheries	Red king crab, tanner crab, and halibut		Sea State Inc. (expanded into multiple fisheries since establishment in 1995)	On-board observers from the groundfish observer program organized by the National Maritime Fisheries Service provide daily catch updates. Observers originally provided 100% coverage for vessels > 125 ft in length but since 2007 increased to full coverage on all catcher-processors and pollock catcher vessels.	Provided directly from observer programme, *via* e-mail and private agreement with vessel management system (VMS) providers, to Sea State who then produce maps, tables, and commentary on hotspots and send information back to fleet *via* e-mail (or for pick up in port)	Non-mandatory recommendations of areas to avoid Informal agreements to avoid high by-catch areas	Implementation of seasonal closures if by-catch quotas reached. Many fisheries close for prohibited species catches rather than TACs peer pressure	7-fold decrease of king crab by-catch from 1994 to 1995. In yellowfin sole fishery > 25% of vessels did not initially take part resulting in high bycatch rates. No measureable effect in by-catch outcomes for halibut.	Gauvin *et al.* (1995), Gilman *et al.* (2006b), Haflinger and Gruver (2009), Haynie *et al.* (2009), Abbott and Wilen (2010), O'Keefe *et al.* (2014), Little *et al.* (2015), Gruver (2016), Holland and Martin (2019)
US Pacific groundfish whiting fishery	Rockfish and salmon	E.g. Whiting Mothership Cooperative, shore-based catcher–processor co-operatives and shore-based sector risk pools				Shore-based members signed risk pool agreement which uses a combination of precautionary closures, cautionary areas and fleet relocation, and stop fishing orders.	Fishery is closed if any rockfish or salmon quotas are reached. Benefits of risk pool scheme.	No studies attempted to measure effect in by-catch outcomes in whiting.	

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
						Catcher–processor co-operatives can impose in season closures of bycatch hotspots and stop-fishing orders. Mothership fleets have bycatch avoidance rules and area closures in addition to penalties and stop-fishing orders			
Eastern Bering Sea pollock fishery	Salmon (crab, squid, and Pacific halibut)	E.g. Pollock Conservation co-operative and High Seas Catches co-operative, Mothership Fleet cooperative and five individual shore-based cooperatives				Areas can be closed to fishing if close to reaching bycatch limits for species such as chinook salmon and squid. Depending on a vessels' chinook and chum salmon avoidance history, time spent in rolling hotspots has to be limited. Any violation by a vessel is reported back to co-ops. Vessels could be fined if they did not comply with an inter co-operative agreement	Participating co-operatives signed an Incentive Plan Agreement (IPA) in which vessels were required to provide information. Fishers face seasonal closures if salmon by-catch quotas reached	Estimated 20% reduction in chinook bycatch and 64% reduction in chum bycatch. No sector closures of pollock fishery due to chinook.	

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
Rock sole and yellowfin sole fisheries	King crab and halibut					Voluntary avoidance of hotspot areas	Fishery is closed if by-catch limits exceeded	Success in extending both fisheries prior to closure (rock sole at the time worth $50.00 per day)	
US Alaskan demersal longline fishery primarily targeting Pacific cod, Greenland turbot, and sablefish	Halibut and seabirds	North Pacific Longline Association/Freezer longline coalition cooperative	Initially the Fisheries Information Services and currently Sea State Inc.	On-board observers	Initially weekly report cards e-mailed to fleet with individual by-catch reports sent to vessel owners. Now daily information sent regarding bycatch rates and progression toward halibut catch limits.	North Pacific Longline Association can act as an enforcement body if any vessel shows too much discarding behaviour.	Voluntary participation. Annual bycatch caps on halibut mortality introduced in 1990 that could result in closures. Bycatch caps on seabirds introduced in 1999	During first 4 years of the programme, participation increased from 14 to 28 vessels. Once seabird caps were introduced all freezer longline vessels gradually joined the scheme. Bering Sea and Aleutian Island cod fishery has not been closed due to exceeding halibut quota since 2001. Halibut discard mortality rate reduced from 13 to 10% between 2010 and 2012.	Gilman *et al.* (2006b), Karim *et al.* (2012)

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
US Atlantic squid fishery	Butterfish, river herring, shad, windowpane flounder, yellowtail flounder, red hale, and haddock	Squid Trawl Network	Cornell University Cooperative Extension	Participatory vessels supply daily real-time communication of incidental catches of bycatch species *via* VMS	Cornell University Cooperative Extension compile information and send it back out *via* VMS as well as providing gridded maps online and communicated through social media	Voluntary avoidance of bycatch hotspots	Bycatch reduction assists in avoiding the introduction of more restrictive management measures	There have been quantified reductions in bycatch, helping to prevent shutdown of fisheries	Little *et al.* (2015), Squid Trawl Network (2021)
US North Atlantic longline swordfish fishery	Turtles	Blue Water Fisherman's Association	Industry managed 'Captain's Daily Communication'	Observations from fishers on sea turtle encounters, clusters of turtles, and oceanographic features	Radio and e-mail	Voluntary avoidance	Voluntary participation. Peer pressure from industry to avoid turtle encounters to ensure by-catch limits are not exceeded, thus preventing closures. Vessels already part of scheme to test new gears to reduce turtle by-catch so further by-in to share information	Trial conducted 2001–2003 but carried on informally since	Gilman *et al.* (2006a, b)

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/motivation to participate	Measures of success/effectiveness	References
US Northwest Atlantic midwater trawl fishery targeting Atlantic herring and mackerel	River herring and American shad	NA	University of Massachusetts Dartmouth School for Marine Science and Technology and Massachusetts Division of Marine Fisheries	Fishers provide trip and tow locations, estimated target species catch, and by-catch data, collected as part of the Northeast Fisheries Observer Program. Access also provided to portside sampling data.	Ratio thresholds used to identify areas with large bycatch and transposed onto coded grids, which are used to communicate the location and timing of bycatch events within previous 7 d via onboard Boatracs©	Voluntary avoidance of high ratio areas. Since the second year of the programme participatory vessels have signed a responsible fishing agreement, which includes commitments to reporting and avoidance standards.	Threat of possible introduction of increased regulations in mid water trawl fishery to reduce bycatch. Sign-up to responsible fishing agreement results in qualification for additional research set-aside Atlantic herring quota. Vessel names and catches are confidential within the programme. Areas containing zero bycatch often withheld from the fleet-wide distribution in acknowledgement to the competitive nature of the fishery.	Initially, nine mid-water trawl vessels participated, with an additional five joining by the end of 2012, representing vessels with > 95% of landings in the midwater trawl fishery. Avoidance programme shown to have influenced fishing behaviour in a way that contributed to reduced bycatch.	Bethoney *et al.* (2013, 2017), SMAST (2016)

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/motivation to participate	Measures of success/effectiveness	References
US Atlantic sea scallop fishery	Yellowtail and window-pane flounder	Nantucket Lightship access area fishery	University of Massachusetts Dartmouth School for Marine Science and Technology	Industry provide information on the location of fishing (within an identified grid cell), number of tows completed in each cell, and weight of bycatch flounder caught in each cell.	Cells classified as low, medium, or high risk based on reported bycatch and bycatch thresholds. Information reported to fleet using existing technology and email systems.	Voluntary avoidance of high risk areas.	In 2004, New England Fisheries Management Council implemented an area based plan for scallops with access to defined regions periodically restricted. From 2012, the scallop fishery moved from in-season bycatch closures to post-season closures and gear modifications.	Bycatch rate of Yellowtail to scallops was reduced by an average of 50% following the first advisory period. Sign up rates increased from 35% for the fleet at the start of the project in 2010 to > 65% of the fleet by 2012. From 2012 onward the reporting rate of the fleet declined year on year.	O'Keefe *et al.* (2013), O'Keefe and DeCelles (2013), Cadrin *et al.* (2018)
Californian groundfish fisheries	Overfished and long lived sensitive species	Californian Groundfish Collective	eCatch	Software developed to capture and visualize logbook data digitally (using iPads or data entry *via* a website)	Users can voluntarily share their logbook data with others as part of a 2-way sharing process	Data feeds into local spatial fishing plans used by the Californian Groundfish Collective, with voluntary closed areas identified if high risk of bycatch.	Participating vessels are already part of a fishing risk pool. Two-way sharing process allows users to choose who to share data with. The risk pool was awarded a "green" rating for their target species as part of Monterey Bay Aquarium's Seafood Watch program.	Between 2011 and 2017 those sharing information caught 22.5% less overfished species than the rest of the groundfish fleet	Labrum and Oberhoff (2013), Little *et al.* (2015), Merrifield *et al.* (2019)

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
Celtic Sea offshore gill-net fishery	Spurdog	Cornish Fish Producers Organization	CEFAS (Centre for Environment, Fisheries, and Aquaculture Science)	Fishers provide daily information, *via* e-mail, on spurdog by-catch within pre-defined reporting grids.	Data from all participating vessels is compiled and each grid cell is categorized using a traffic light system, based on pre-determined bycatch thresholds. This is provided back to participating fishers within 12 h.	Voluntary avoidance of high-risk areas.	Spurdog is a zero TAC species and has the potential to be a choke species (a species with a low quota that can cause a vessel to stop fishing if this quota is exceeded). At the start of the trial limited additional quota for commercial species, equivalent to a 50 tonnes spurdog by-catch allowance, was used as an incentive. The intention was to give participating vessels limited quota per month for dead spurdog bycatch to be landed, but this was not agreed to at December fisheries council in 2014.	Initial additional quota incentive was insufficient to obtain necessary buy-in of the ten vessels required for the trial. Lack of provision of bycatch quota for spurdog resulted in an end to reporting from participating vessels.	Hetherington *et al.* (2016)

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
Scottish North Sea demersal fishery	Cod	NA	Scottish Government—Conservation Credits Scheme	Logbook and VMS data analysed to determine fishing effort for cod. Fishers are also encouraged to report aggregations of cod.	Closed areas based on catches of > 40 cod per hour fishing. Closed areas communicated through the Scottish Government's website and email. Amber avoidance areas identified per quarter based on VMS-derived landings values from the previous year.	Real-time closures implemented based on bycatch information and are in operation for 21 d once implemented. Amber area avoidance voluntary.	Participating fishers rewarded with additional days at sea. Initially, industry proposed the ideal location and duration of potential closed areas.	Approximately 707 tonnes of cod catches reduced from real-time closure areas in 2009. Amber areas were dropped from the scheme due to a mix of unsuitability of the areas highlighted and minimal reduction in cod mortality.	WWF Scotland (2009), Holmes *et al.* (2011), Little *et al.* (2015)
West coast of Scotland demersal fleet	Cod, whiting, and spurdog	Scottish Fishermen's Organization, University of Aberdeen	BATmap	Fishers in the scheme enter their catch data for each of the identified species of interest into a mobile phone app	When catch values reach set thresholds an aggregate map showing locations of high bycatch is disseminated to participants via the app	Voluntary reporting and avoidance	Cod and whiting identified as possible choke species following the full implementation of the Landing Obligation in 2019	Currently in second year of rollout so effectiveness in bycatch avoidance cannot yet be determined.	Marshall *et al.* (2021, 2017b)

Table 1. Continued

Target fishery	Bycatch species	Fisheries organization involved	Information sharing facilitator	Who provides the information?	How is information communicated?	How is information acted on?	Incentive/ motivation to participate	Measures of success/ effectiveness	References
Peruvian small-scale fisheries	Turtles	NA	ProDelphinus	Fishers report locations of turtle bycatch via high frequency radio	Locations of bycatch communicated back to fishers working in the vicinity of these areas *via* high frequency radio. Radio coverage extended from Ecuador to Chile	Voluntary reporting and avoidance of bycatch of megafauna species (e.g. turtles, whales, and manta rays)	Information on safe release methods for incidentally caught turtles also provided *via* radio communications. Further information could be requested from fishers following the broadcast of information such as local oceanographic conditions, weather, and tides etc.	A total of 1395 reports of turtle bycatch received between January 2009 and December 2010. Additional requests made by fishers to receive educational materials on marine turtles and other target species. Some fishers provided additional photos of by-catch. In four instances, the system also helped facilitate rescue of damaged or adrift fishing vessels.	Alfaro-Shigueto *et al.* (2012)
Japanese Hokkaido Sea Cucumber fishery	To avoid over-exploitation of spiky sea cucumber stocks	Shinsei Marine fishery cooperative and Rumoi City dredge-net fishers	Programme funded by Ministry of Agriculture, Forestry, and Fisheries in Japan	Real-time location data for the fleet were recorded from a GPS receiver. Real-time catch records and start and end time of fishing operations are provided by fishers using an iPad.	Sea cucumber catchable stock index, CPUE, and a map of the trajectories of fishing vessels is shared to users in real-time via the Internet.	Participating fishers had weekly meetings to discuss and evaluate their catch status, referring to the data provided digitally to them.	Data provides useful information to support the self-management of the fishery.	Fishers chose to end the fishing season early in 2012 and 2013 to avoid overfishing.	Saville *et al.* (2015)

was exceeded fishing would theoretically have to cease even if quota remained for other species. Thus, the Landing Obligation and possible choke species were important drivers for industry engagement with information sharing in Scotland. Specifically, in August 2018, it became apparent that the Scottish demersal fleet fishing on the west coast of Scotland (ICES Subarea 6a) could experience a choke problem for cod and whiting due to the zero TACs set for 2019. This garnered industry buy-in for sharing real-time catch information for these two species to enable better avoidance of bycatch hotspots. Working with an Alaskan IT developer (Chordata) and the University of Aberdeen, the fishing industry designed, developed, and deployed software for real-time reporting of bycatch in ICES Subarea 6a (Marshall *et al.*, 2021). The software, named Bycatch Avoidance Tool using mapping (BATmap; https://info.batmap.co.uk/), was 100% funded by industry and development and deployment was coordinated by the largest producer organization in Scotland (Scottish Fishermens Organization).

BATmap was designed for use on any device (mobile, laptop, and tablet) having internet access, however, it was recognized that most fishers would use it as a phone app. Catch data per haul, including zeroes, are entered for each bycatch species (cod and whiting) but not target species. The software automatically combines catch reports with vessel position data allowing fishers to produce a map of their vessel's catch data on demand. When a threshold value for one of the bycatch species is exceeded in any haul participating fishers automatically receive an aggregate map created using recent data for all participating vessels. Fishers are then able to make informed decisions about where to fish to avoid unwanted bycatch, although this behaviour is voluntary. A user-centred, co-design process was used to ensure that BATmap would reflect fishers' tolerance for sharing information and meet their needs for data security (Marshall *et al.*, 2021). Several of the operational features that reflect this fisher-led, co-design process include:

Species: during the co-design process fishers requested that spurdog (*Squalus acanthias*), which is seasonally present in large clusters causing significant gear damage, be added to BATmap.

Security: fishers are sharing commercially sensitive data, therefore, all components of the system use IT industry standards for encryption for storage of catch and position data and during transmission of data. Maps are not circulated outside users or producer organizations without permission of all participants.

Hexbins: rather than show exact haul tracks fishers chose to display bycatch locations using colour-graduated hexagons (8 km between two opposite vertexes) referred to as hexbins.

Categorization of catch data: fishers enter their catch data into the app as absolute values in kilograms. However, the catch data is only stored in the database as categorical values in the form of ranged values (i.e. 0 kg, 1–100 kg, 101–200 kg, and so on).

Position data: VMS data were already automatically reported to government authorities for compliance purposes. Marine Scotland regards that communication as confidential and is, therefore, unwilling to share the data as a general point of principle. As a result it was clear from the outset that vessel position data would need to be generated independently of the VMS data reported to the Scottish government for compliance purposes. Costs for the hardware required to transmit position was included in the project budget including annual costs for data transmission.

Alert Threshold Values: the ATVs are the catch values (in kg/h CPUE based on an average 5.5 h duration of towing time) that trigger an aggregate map showing locations of high bycatch to be automatically disseminated to participating fishers. ATV for each bycatch species, including spurdog, were set in early 2020, following consultations with fishers.

The BATmap pilot began in the spring 2020. Initially all participating vessels belonged to a single producer organization (the Scottish Fishermen's Organization), however, vessels belonging to three other producer organisations were recruited giving a total of thirteen vessels at the end of the pilot in December 2020. Collectively, they account for $>$ 70% of ICES Subarea 6a Scottish cod landings. At the end of the pilot study over 1800 catch reports had been submitted and bycatch alerts had been triggered for cod and spurdog on over 67 and 22 occasions, respectively. No alerts were triggered for whiting during the pilot study.

Although it is too early to assess whether BATmap has been successful in reducing bycatch in ICES Subarea 6a, off of the west coast of Scotland, there are several encouraging signs (Marshall *et al.*, 2021). BATmap continues to be routinely used at sea by all the participating fishers with one new fisher recruited in 2021. The four producer organizations remain committed to the application of BATmap in ICES Subarea 6a and industry funding has been secured for a second phase of development. This will develop a data governance plan and a 5-year strategic plan for applying real-time reporting in Scottish fisheries. BATmap was inspired by worked examples on the west coast of the US (Little *et al.*, 2015; Marshall *et al.*, 2017b) illustrating the scalability of the approach to other fisheries. BATmap also benefits from being an industry-led initiative that operates independently of government databases (catch and VMS) that monitor regulatory compliance. This clear separation allows fishers to feel more confident using BATmap and they have the freedom to adapt the software to meet their own operational requirements.

Peru's radio conservation for artisanal fisheries

The radio conservation program, facilitated by Pro Delphinius, in Peru is an example of fleet communication implemented for small-scale fisheries. These fisheries are open access, and have limited regulations over target catch, with only about 40 species having minimum size of capture (Ministerio de la Produccíon, 2001). The catch of protected or threatened fauna such as turtles, marine mammals, seabirds, and two species of elasmobranchs are prohibited (Congreso de la Republica, 1996; Pesquería, 2001; Ministerio de Agricultura y Riego, 2014, 2019; Ministro de la Producción, 2015, 2017). Given that mortality from bycatch in these fisheries is one of the main threats for several of these populations (Alfaro-Shigueto *et al.*, 2010; Gaos *et al.*, 2010; Ábrego *et al.*, 2020), the main goal of this fleet communication program was to identify areas with high bycatch and communicate that information back to fishers for possible avoidance. The program was aimed initially at monitoring the bycatch of sea turtle. Other species of large vertebrates were, however, reported, including whales and manta rays, as these could damage gear, resulting in economic losses and safety risks, particularly for gillnet vessels.

The broadcast was from the city of Lima, using a high frequency radio, with a coverage reaching from Ecuador to northern Chile.

Communications were in real-time and two-way, and while the target was small-scale fisheries, some industrial purse seine vessels also started communications. The program did not target a particular fleet but rather was open to whoever engaged in a conversation. Communication was preferred with the skipper of the vessel, initiated with general information such as port of departure, vessel identification, target catch, and fishing gear, as well as information that would allow for fishing effort estimation (e.g. number of net panels, number of hooks, and days at sea; Alfaro-Shigueto *et al.*, 2012). Information collected on bycatch was more detailed, including species, capture dates, final fate of the animals (e.g. dead, released with injuries), and locations to allow for the creation of maps to report back areas to avoid. Guidelines on how to apply safe handling and release methods for threatened fauna were also shared with fishers.

In exchange for the information shared by fishers, using free online information on weather and oceanographic conditions, the program provided fishers updates on wind currents, sea surface temperatures, tides, and other weather-related information useful for their fisheries (e.g. coastal weather conditions impacting their landings and tsunamis). On four occasions, through the radio program, staff were able to provide support to adrift vessels and reach out to their peers or relatives to facilitate rescue. This fleet communication program served as a useful tool (low cost, widely used by fishers, an dwith extensive spatial coverage) to gather bycatch data, but also to establish links with fishers while at sea.

Structure of Information Sharing Schemes

Information providers

There are three distinct sources of information in the case studies in the earlier results section and Table 1. Information on catches are either provided by observers already working on fishing vessels, *via* digital logbooks or directly by the fishers themselves *via* input into an app, on-line platform, or through radio communication. Vessels utilizing Sea State Inc. provide the NOAA Northwest Groundfish Observer Program with an authorization to forward observer data to Sea State Inc. once it has been sent to the observer program office and has passed basic error detection tests. Data is generally available to Sea State Inc. for download within 20 min of receipt by the NOAA Groundfish Fisheries observer program office. Observer coverage rates, which are mandatory for all of the fisheries involved with Sea State Inc., have varied over the years, ranging from full observer coverage for vessels greater than 125 foot in length and 30% for those less than 125 foot (Gilman *et al.*, 2006b; Abbott and Wilen, 2010; O'Keefe *et al.*, 2014; Little *et al.*, 2015; National Marine Fisheries Service, 2020). This was later upgraded to full observer coverage on all vessels in the Bering Sea flatfish and pollock, Northwest Region whiting and Bering Sea catcher–processor longline fisheries. Digitized logbook data are used to provide catch information in both the eCatch programme, in Californian groundfish fisheries, and to assist with cod avoidance in the Scottish North Sea demersal fishery (Holmes *et al.*, 2011; Merrifield *et al.*, 2019). Other schemes require fishers to communicate catches of specified species directly, often *via* radio or e-mail (Gilman *et al.*, 2006a; Alfaro-Shigueto *et al.*, 2012; Hetherington *et al.*, 2016). Or *via* specific platforms such as through VMS as in the Squid Trawl Network, in the US Atlantic, or through the use of iPads in the Hokkaido sea cucumber fishery in Japan (Saville *et al.*, 2015; Squid Trawl Network, 2021). In some of the information sharing case studies highlighted, additional information is provided through portside sampling, such as in the avoidance of river herring and American shad in the US Northwest Atlantic midwater trawl fishery (Bethoney *et al.*, 2013).

How information is communicated back to participating vessels

In the case of the programmes managed by Sea State Inc., data provided by the observer programme is compiled and then used to produce maps, tables, and commentary on by-catch hotspots which can be accessed by each cooperative via a central database, with weekly, fortnightly, and seasonal reports also being produced depending on the fishery (Abbott and Wilen, 2010; Marshall *et al.*, 2017a). A number of the schemes in Table 1 compile the data provided by the industry to produce colour coded grids to identify potential bycatch risk. These include the US Atlantic sea scallop fishery, where information is also reported back to the fleet daily *via* e-mail (O'Keefe and DeCelles, 2013), the US Northwest Atlantic trawl fishery, where the on-board Boatracs© system communicates coded grids indicating the location and timing of bycatch events recorded within the previous 7 d (Bethoney *et al.*, 2017), in the Squid Trawl Network, in the US Atlantic, where hotspot maps are provided back through the VMS system as well as being published online and publicized through social media (Squid Trawl Network, 2021), and in the avoidance of spurdogs in the Celtic Sea, where a traffic light system is transposed onto a grid and provided back to participating vessels within 12 h of data submission (Hetherington *et al.*, 2016). Radio communication was also used to aid in avoidance of turtle bycatch in both North Atlantic longline swordfish fisheries and in Peruvian small-scale fisheries (Gilman *et al.*, 2006a; Alfaro-Shigueto *et al.*, 2012). The eCatch system, used in Californian groundfish fisheries, was unique amongst the case studies in that individuals involved could chose to voluntarily share their logbook data with others as part of a 2-way sharing process (Merrifield *et al.*, 2019).

Response to received information

For the majority of the case study fisheries in Table 1, there were no mandatory requirements for participating vessels with regard to subsequent bycatch avoidance. Many of the schemes rely solely on the voluntary avoidance of areas identified as having a high risk of encountering unwanted catches (Gilman *et al.*, 2006a; Alfaro-Shigueto *et al.*, 2012; O'Keefe and DeCelles, 2013; Hetherington *et al.*, 2016; Merrifield *et al.*, 2019). Although avoidance of areas with high ratios of river herring and American shad were voluntary within the Northwest Atlantic midwater trawl fishery, participating vessels did sign up to a responsible fishing agreement which included commitments to particular avoidance behaviours to allow them to qualify for additional quota (SMAST, 2016; Bethoney *et al.*, 2017). Many fisheries utilizing Sea State Inc. also formulated informal measures or group agreements on the move-on and avoidance behaviours that should be adopted in light of the provision of bycatch species information. For example, as part of the Non-Chinook Salmon bycatch Management Agreement within the Bering Sea Pollock fishery, rolling hotspot closures are implemented (Gruver, 2016). Fishing co-operatives operating within this agreement are assigned to one of three tiers based on their bycatch performance, with lower tier fisheries, as determined by the information collected by Sea State Inc., resulting in greater restrictions of fishing activities within these rolling hotspots (Little *et al.*, 2015; Gruver, 2016). Compliance with these closure restrictions is done by checking to see that all VMS points between the start and end of tows are outside closure areas. Although Sea State Inc. performs this analysis, a random subset of 10% of the fishing activity is also analysed by an independent auditor (Alaska Biological Resources) and a report on compliance analysis is submitted to the NPFMC. Any vessels participating in the US Pacific whiting fishery as part of a Whiting Mothership Cooperative risk pool who are not compliant with the risk pool agreement can be subject to fines or stop fishing orders, with Sea State Inc. again processing the data to determine how vessels are behaving within the fishery (Little *et al.*, 2015; Holland and Martin, 2019). In the Hokkaido sea cucumber fishery in Japan, participating fishers used the collated information on catch rates to support the management of the fishery and make decisions on when to close the fishery based on reaching TAC limits (Saville *et al.*, 2015). More formal closures were implemented in the Scottish North Sea demersal fishery to aid in the avoidance of cod, although the avoidance of fishing in amber areas was voluntary (Holmes *et al.*, 2011).

Incentives and motivations to participate

A number of the case studies offered explicit incentives for participating fishers to share catch information. Fishers participating in the Scottish Conservation Credits Scheme, operating in demersal fisheries in the North Sea, were awarded additional days at sea (Holmes *et al.*, 2011). Additional quota for commercial species were provided to vessels partaking in a spurdog avoidance scheme in the Celtic Sea (Hetherington *et al.*, 2016). And those vessels who signed up to responsible fishing agreements as part of the river herring and American shad avoidance scheme in Atlantic herring and mackerel fisheries were awarded with additional herring quota (SMAST, 2016; Bethoney *et al.*, 2017). In the Peruvian turtle bycatch avoidance scheme, by sharing information on the location of turtles, fishers received additional information on local oceanographic conditions, weather, tide state and safety advice (Alfaro-Shigueto *et al.*, 2012). This is information that may otherwise have been unavailable as the small-scale fishers involved had limited access to the technology and instrumentation that provide such information. In the Hokkaido sea cucumber fishery participation, an information sharing scheme provided vital information that could be used to better manage the fishery (Saville *et al.*, 2015). Additional benefits were also evident in the eCatch programme where vessels in the Californian Groundfish Collective were awarded a green rating for their target species as part of Monterey Bay Aquarium's Seafood Watch program, with awards from such schemes potentially resulting in a premium price or consumer preference for their fish (Gutierrez *et al.*, 2016; Merrifield *et al.*, 2019).

In many of the fisheries in Table 1, the presence of quotas and the potential for fisheries to be closed or fishing activity to be curtailed if quota limits were reached may provide a motivation for fishers to take part to try to reduce unwanted catches and extend fishing opportunities. This includes zero TAC for spurdogs in the Celtic Sea (Hetherington *et al.*, 2016), caps on halibut and seabird mortality in the US Alaskan demersal longline fishery (Gilman *et al.*, 2006b), restrictive rockfish quotas in the US Pacific groundfish whiting fishery, and potential closures in the US Bering Sea pollock fisheries if salmon quotas are exceeded (Little *et al.*, 2015). Further to the legislative quotas and restrictions, many of the fishing organizations, co-operatives and risk pools in the case studies have a requirement for information sharing if fishers are to participate (Gruver, 2016). In the case of the Bering Sea pollock fishery, access to a higher bycatch allowance in 2 out of 7 years requires participation in an IPA, which mandates data-sharing. There may also be peer pressure from other vessels working in the fishery to encourage participation and compliance to ensure the whole fleet benefits from participating in an information sharing scheme. In the case of many of the US fisheries in Table 1, the near 100% observer coverage on vessels meant the information on catches was already being collected so it did not require extra effort to collect and then share catch data. Nevertheless, sharing of catch information could still harm a fisher's competitive edge. Additional control over the data sharing could overcome this to encourageparticipation in the eCatch programme where the two-way sharing of log book data allowed control by fishers, operating in the Californian groundfish fisheries, over who else could access catch data (Merrifield *et al.*, 2019). The exclusion of information from areas containing zero bycatch in the Atlantic herring and mackerel fishery also allowed participating fishers to keep a competitive edge while sharing catch information (Bethoney *et al.*, 2017).

For vessels in the US North Atlantic longline swordfish fishery, prior involvement in gear trials to reduce turtle bycatch resulted in encouragement to also join an information sharing scheme (Gilman *et al.*, 2006a). Similarly, vessels involved in the Squid Trawl Network, operating in the US Atlantic, were also supported in the trial of new gear technologies to further reduce bycatch in the fishery (Squid Trawl Network, 2021). Industry had also been involved from the outset with the Scottish government's Conservation Credits Scheme, having initial input into the ideal location and duration of potential closed areas to be implemented as part of the scheme (Little *et al.*, 2015; Holmes *et al.*, 2011). Finally, the viewed success of some of the schemes resulted in greater uptake over time including in the US Alaskan longline fishery and the US Atlantic Sea Scallop fishery (Gilman *et al.*, 2006b; O'Keefe and DeCelles, 2013).

Discussion

The real-time reporting and sharing of catch information can be useful in aiding fishers to avoid unwanted bycatch. Information sharing schemes, where vessels record and share catch information either directly or through a third party or dedicated platform, have some proven successes in reducing catches of unwanted or prohibited species in some fisheries. The competitive nature of commercial fisheries does, however, mean it may be counterintuitive for fishers to share sensitive catch information with the wider fleet (Gatewood, 1984; Barnes *et al.*, 2017; Haskell *et al.*, 2019). Some incentive or reward is most likely required to encourage participation, which is especially important as maximizing benefits of information sharing schemes often relies on a majority to contribute and act on shared information (O'Keefe *et al.*, 2014). From the case studies explored in this paper the motivations and incentives identified to encourage participation within each scheme varied (Figure 1). Having a fuller understanding of what motivates fishers to share information with others is, however, important, if recruitment to future information sharing schemes is to be achieved.

Legislation and fisheries management

One major similarity across many of the fisheries included in the case study examples is that there were legislative requirements to reduce or avoid bycatch species. Throughout the case studies, restricted quotas often meant fishing activity of target species could be curtailed, and specific fishing grounds or fisheries could be closed, if any quotas were exceeded. These quotas are usually set by

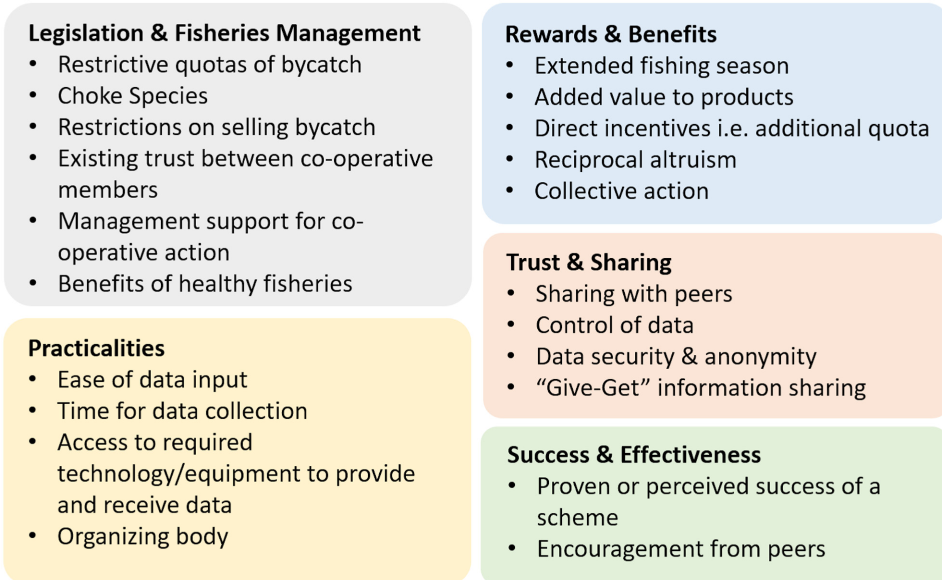

Figure 1. Summary of the potential drivers and incentives to reduce bycatch and encourage fishers to participate in information sharing schemes to achieve bycatch reduction.

fisheries managers to protect vulnerable or depleted stocks and ensure fisheries are harvested in a sustainable manner. While restrictions on catches of more vulnerable, by-caught species can impact upon harvests of commercially important species, effectively managing fisheries can ensure they remain productive for many years to come. If fishers also recognize the benefits of effective fisheries management they may be more inclined to avoid bycatch and participate in information schemes to achieve that. There may be further incentive to avoid quota restricted species when legislation means any catches of prohibited species cannot be sold for economic gain and are regarded as nuisance catches that are best avoided (Haynie *et al*., 2009). As such, reducing catches of any prohibited or quota limited species is necessary for fishers to maximize catches of target species and utilize all available quota in many of the featured fisheries, assuming illegal discarding is adequately monitored. This was certainly identified as the driver behind the initial use of data pooling, first facilitated by Sea State Inc. in 1995, to assist in avoiding halibut in Bering Sea flatfish fisheries (Abbott and Wilen, 2010). In the case of the US Northwest Atlantic midwater trawl fishery, it was just the threat of a possible introduction of increased regulations that led to fishers increasing their efforts to avoid river herring and American shad, ultimately avoiding fisheries closures (Bethoney *et al*., 2013; Little *et al*., 2015). Similarly, the threat of measures designed to restrict the pollock fishery in response to sablefish bycatch led to increasing pressure on the pollock fleet to avoid sablefish. These cases demonstrate that the experience of fishing under legislation that can result in restricted fishing opportunities, or even just the threat of the introduction of such measures can encourage information sharing among fishers to assist in avoiding bycatch.

The implications of quota restrictions driving participation in information sharing schemes is further emphasized by the case of the US Atlantic sea scallop fishery. Initially, fishers provided information on the location of restricted flounder species as temporary closures to scallop fishing grounds could be introduced by the New England Fisheries Management Council if catch thresholds for these species were reached (O'Keefe and DeCelles, 2013). The scheme had documented successes in reducing the bycatch rate of Yellowtail flounder and allowing for the harvest of the full scallop quota allocation with fleet participation increasing from 35% at the start of the project in 2010 to over 65% by 2012 (O'Keefe and DeCelles, 2013; O'Keefe *et al*., 2014). From 2012, however, the management of the scallop fishery moved from in-season bycatch closures, where there was a real threat of a fishing season being cut short, to post-season closures, where an area might be closed to fishing for a longer period after the current fishing season, and the requirement of more selective gear modifications. Without the possibility of in-season closures there was not the incentive for fishers to change their behaviour and avoid by-catch in real-time, or share information on the location of bycatch species (Cadrin *et al*., 2018). As a result, participation in the scheme reduced and by 2016 not enough data was provided to generate reliable bycatch advisories (Cadrin *et al*., 2018).

In many of the US fisheries among the case studies, it was not just the potential quota restrictions that encouraged information sharing but also the structure of existing fisheries organizations and the formation of various harvest agreements, including the use of risk-pools among their members. Participation in risk pool can act as a safety net, allowing fishers to access extra quota to cover any "lightning strike" catches of bycatch species which might otherwise cause them to exceed quotas. This is true of the Californian Groundfish collective who created bycatch risk pools and the Pacific whiting fishery that allowed the transfer of quotas for rockfish and Chinook salmon within the fishing co-operative (Kauer *et al*., 2018; Holland and Martin, 2019). In the case of many of the North Pacific fisheries, it is not possible to gain the benefits associated with such co-operative harvesting unless catch data is reported back on a timely basis, thus providing the incentive to share catch information (Gruver, 2016). Even with the requirement to share catch information, by removing the risk to the individual of encountering incidental bycatch and exceeding bycatch limits, membership in a risk pool could actually reduce an individual's motivation to subsequently try and avoid unwanted catches with private benefit winning over the common good (Holland and Martin, 2019). To overcome this, many of the case study fisheries have best practice procedures that members must abide by, increasing the motivation to act on information regarding the location of bycatch species (Kauer *et al.*, 2018; Holland and Martin, 2019). The Whiting Mothership Cooperative in the US Pacific whiting fishery for example employs precautionary closures as well as fleet relocation measures amongst its members, while the shore-based sector in this fishery adopts its own bycatch avoidance rules (Gruver, 2016). In the Eastern Being Sea Pollock fishery, a vessel may be able to spend limited time fishing in rolling hotspots established to reduce catches of chum salmon, depending on their own history of avoiding this species. Those vessels and co-operatives that have demonstrated good bycatch avoidance are not limited from fishing in these hotspots, while those with poor performance may be able to fish for a limited period or are completely excluded from these areas, thus, rewarding behaviours that result in reduced levels of by-catch (Little *et al.*, 2015; Gruver, 2016). Within these co-operatives, peer pressure may be an important factor in getting fishers to provide information and then act on it accordingly, as all members benefit from reduced by-catch rates to allow them to maximize on time available to catch target species prior to closures (Gauvin *et al.*, 1995). Another factor in encouraging participation in these cases may have been the willingness of management councils to accept cooperative action on bycatch as part of their management plans (Stram *et al.*, 2015), with the cooperative management of the harvest and the bycatch coming hand in hand.

With the introduction of the Landing Obligation in European fisheries (between 2015 and 2019; European Commission, 2013) it might be an expectation that there is an increased incentive to share information to aid in avoiding choke species, catches of which are likely to result in vessels operating in mixed fisheries having to cease operations before the quotas for their targets are reached (Schorpe, 2010; Calderwood *et al.*, 2020). How much of a motivation the Landing Obligation is to encourage information sharing may depend on how well catches and discards are monitored. Unlike many of the US fisheries where observer coverage is 100% of a fleet, in European fisheries observer coverage is limited and in many instances covers less than 1% of fishing activity (van Helmond *et al.,* 2020; Calderwood *et al.*, 2020). The threat of chokes was, however, identified as a motivation for vessels to participate in using the BATmap app in Scottish fisheries. Yet Irish fishers, operating in ground fish fisheries, have revealed they are reluctant to share information with others. This is somewhat because individuals do not want to lose their competitive edge, partly due to a lack of trust in the information they would be likely to receive from others and a fear of any information provided being used against them and resulting in tighter restrictions or more closures (Calderwood *et al.*, 2021). Such distrust of management and a fear of information sharing due to potential control issues has been previously recognized (Ramirez-Sanchez and Pinkerton, 2009). Basing information sharing on existing social networks can facilitate collaboration, as was the case in the turtle bycatch avoidance scheme in the US North Atlantic swordfish fishery where vessels had already worked together as part of a scheme to test new gears (Gilman *et al.*, 2006a; Österblom and Bodin, 2012). This was also the case in the Squid Trawl Network, where vessels were already working as part of a collaborative industry, science, and management network to tackle the issue of discarding using a number of approaches including the development and trial of more selective gears in addition to information sharing on the location of bycatch (Squid Trawl Network, 2021). Sea State Inc. has also built on well established relationships in the fisheries where it is utilized, with many of the co-operatives and organizations involved demonstrating a long history of working together to tackle issues such as reducing bycatch. The importance of social networks for collaboration with other vessels has also been identified by Irish fishers, who are often reluctant to share information with the entire fleet but who will share within a close peer group (Calderwood *et al.*, 2021)

Rewards and benefits

Reciprocal altruism, or sharing information in the knowledge that you will get something in return, may be a motivating factor to sharing information in fisheries (Palmer, 1991). While all the schemes among the case studies provide data back to participating vessels to assist in bycatch avoidance, individual fishers may feel this knowledge does not significantly add to their own individual knowledge and so it is not worth taking part. There may also be concerns that others with less experience or less success could "free-ride" and benefit more from a shared information scheme (Evans and Weninger, 2014; Turner *et al.*, 2014). Or fishers may not trust information received from others as there can be considerable variation in the accuracy of information shared among commercial fishers (Palmer, 1991). A method like that employed in the eCatch system could be successful in overcoming some of these issues as users chose to share their logbook data with others as part of a 2-way, or "give-get," sharing process (Kauer *et al.*, 2018; Merrifield *et al.*, 2019). This ability to choose exactly who information is shared with and received from gives control of their data to the fisher and allows them to opt out of sharing with anyone that they do not want to. In other cases, anonymity is important, rather than a transparent sharing process. For the majority of the schemes, data is collected and amalgamated together at a coarse enough resolution so that no individual vessel's catches could be determined from the shared bycatch distribution information. Both the security around data handling and the resolution of data, so as to ensure anonymity, were key in the development of the BATmap app. Catch information remains a business asset and there could still be reluctance to share information that could give other vessels a competitive advantage. In the case of the Northwest Atlantic midwater trawl fishery, not only were vessel names and catches confidential within the program but areas containing zero bycatch were often withheld from the fleet-wide distribution in acknowledgement of the competitive nature of the fishery (Bethoney *et al.*, 2017).

In addition to trust, the exchange of information is more likely if there are economic benefits to the individual fishers and without a reward volunteerism often wanes (Gauvin *et al.*, 1995; Haynie *et al.*, 2009). Members of risk pools can increase profit if they can collectively avoid exceeding bycatch quotas to ensure their fishery does not have to close early, with success in extending the US rock sole fishery for example being worth $50000 per day (Gilman *et al.*, 2006b). There is the possibility of adding value to a product by demonstrating more sustainable fishing behaviour through participation in an information sharing and bycatch avoidance scheme and gaining accreditation through schemes such as Monterey Bay Aquarium's Seafood Watch program (Merrifield *et al.*, 2019). There is also the value of just having access to data that allows for the better management of the fishery, as was the case in the Hokkaido sea cucumber fishery (Saville *et al.*, 2015). It is also possible, however, that some individuals are prepared to achieve the benefits of collective action by initiating reciprocity, without additional rewards or incentives (Ostrom, 2000). There is also evidence to suggest that when individuals are given the opportunity to shape their own situation they may work to achieve higher joint outcomes, even without some form of external enforcement (Ostrom *et al.*, 1992). This is evident in the case of the fisheries now involved with Sea State Inc. where co-operatives took action to avoid unwanted catches, without constant management advice from governing bodies being required to achieve this. Certainly bottom-up approaches, with co-operatives working to solve their own problems can be important whilst encouraging collective action and participation in information sharing schemes.

Additional incentives were, however, evident in some of the other schemes including access to additional Atlantic herring quota for vessels in the US Northwest Atlantic midwater trawl fishery (SMAST, 2016). In the Scottish North Sea demersal fishery, participating fishers were also rewarded with additional days at sea (Holmes *et al.*, 2011). While additional quota or days at sea can allow fishers to catch and sell more, and potentially make more money, this alone was not a big enough incentive to encourage participation in the spurdog avoidance scheme in the Celtic Sea offshore gillnet fishery. The original intention of the program had been to give participating vessels limited allowance to land dead spurdog, a species currently managed by a zero TAC, which has potential to be a "choke" (Hetherington *et al.*, 2016). This allowance was not granted prior to the start of the project and instead an incentive of additional quota for 50 tonnes of commercial species was offered to participants (Hetherington *et al.*, 2016). This quota failed to entice enough fishers to join the program with it being noted that in this case the incentive to join the program was based on morals rather than economics. Fishers were keen to reduce spurdog bycatch and any discarding of dead spurdog, but they were unwilling to swap to less-productive fishing grounds while still potentially catching and discarding dead spurdog (Hetherington *et al.*, 2016). This practice was seen as a waste and it was the potential of being able to land the spurdog that were caught, while demonstrating avoidance behaviours and bycatch reduction, that the fishers sought. This demonstrates that economic benefits do not always provide the incentive to share information and addressing fishers' greater concerns about the inadequacies of certain management structures may instead be required. It was also possible that the incentive of extra days at sea was an insufficient incentive for fishers to avoid amber areas in the Scottish Conservation Credits scheme. Amber areas were originally introduced in the scheme to highlight where there were higher levels of cod, but where levels still remained below a threshold that resulted in real-time closures, and if they were avoided by a vessel they benefited from extra days at sea (Holmes *et al.*, 2011). Few vessels signed up to avoid amber areas and it was acknowledged that managers could not offer a great enough incentive to outweigh the loss of catch opportunities by avoiding these areas (Holmes *et al.*, 2011). This was also compounded by amber areas not always being most effective in predicting areas with high cod catch rates due to them only being updated quarterly and as a result they were dropped from the scheme (Holmes *et al.*, 2011).

Practicalities of information sharing

In terms of practicalities, the ease of sharing information may be an important consideration for any fisher taking part in such a scheme. In Irish groundfish fisheries, for examples some fishers have explained that they already have to fill in too much paperwork with regards to their catches and fishing operations, and it can be difficult to find the time during busy fishing trips (pers comm.). Having to spend more time to participate in an information sharing scheme may, therefore, act as a barrier to participation. Time consuming data entry is not a barrier for many of the US fisheries participating in the Sea State Inc. program as all vessels already have observers operating on their boats on a full-time basis collecting the necessary catch information. Further fisheries, encouraged by the NPFMC, were willing partners in allowing the fleet to access both observer data and shore side landing data, *via* Sea State Inc., for the fishery participants (Haflinger and Gruver, 2009). In these fisheries, there is no extra burden for fishers to provide the necessary data to Sea State Inc. and it is likely that the programs would be very different if management agencies were not cooperative in allowing access to these data. By participating in the scheme extra value is being added to the data collected by the observers, as otherwise the resources do not exist to turn out collected data, in a useful format, so quickly (Gauvin *et al.*, 1995).

When data is provided directly by a vessel, an appropriate platform or method needs to be used to reduce the time spent on this process and further encourage participation. A number of the case studies used the VMS system on board to upload data (Bethoney *et al.*, 2013; Little *et al.*, 2015; Squid Trawl Network, 2021), thus utilizing existing technology rather than adding an additional platform which fishers have to use. This is also true of the BATmap app, which collects position data automatically from VMS units specially fitted on participating on vessels, thus speeding up data entry. In the case of the eCatch system, a new digital logbook platform was developed to replace existing paper records, while also providing the opportunity for fishers to share catch information with each other (Merrifield *et al.*, 2019). In this instance, the streamlining of the collection of catch information resulted in a much more efficient system, which acted as an incentive for fishers to adopt this technology (Merrifield *et al.*, 2019). Using such platforms for the timely return of information to participating fishers may also be important. Many of the schemes processed and provided data back to fishers within 24 h. This allows fishers to act on timely information to avoid bycatch, which is especially important for more mobile species.

Advanced technological solutions to aid in information sharing in fisheries are not always possible, especially in many small scale fisheries where there are few examples of where information and communication technology (ICT) is used for extension services (FAO and WorldFish, 2020). This lack of instrumentation on vessels was used as an incentive to encourage information sharing to aid in the avoidance of turtles in Peruvian small scale fisheries. Fishers who reported the location of turtle bycatch *via* high frequency radio could engage in conversation with the project team and request additional information that they might not have access to such as on local weather or tides (Alfaro-Shigueto *et al.*, 2012). Such added value to sharing bycatch information could certainly encourage participation and success of the scheme was noted, which received 1395 reports of turtle bycatch in a 24-month-period from January 2009 (Alfaro-Shigueto *et al.*, 2012).

Successes and effectiveness of information sharing schemes

Finally, the proven or perceived success of a scheme may be important to encourage participation. It can be hard to empirically determine the success of spatial selectivity in reducing unwanted catch. While the reduction of unwanted catches in any one fishery could be due to a number of different factors and management measures, there is evidence of various degrees of success in reducing bycatch rates and extending fishing seasons across the examples in this paper. Even if no one factor can be attributed to reduced bycatch rates, if fishers perceive information sharing to have contributed it could encourage further uptake of such schemes. In the Sea State Inc. programme there was documented success in reducing bycatch of less mobile species such as crabs, although the introduction of the Red King Crab Savings Area in the EBS in 1995, could also have contributed to successful reduction in bycatch of this species (Kruse *et al.*, 2010). Less success was evident for reducing the bycatch of species such as halibut or Chinook salmon in this region (Abbott and Wilen, 2010; O'Keefe *et al.*, 2014). Halibut discard rates did decrease in the US Alaskan longline fishery, with the scheme seeing an increase in participants over its first 4 years of operation, possibly as a result of the perceived success of the scheme in assisting in reducing discards (Gilman *et al.*, 2006b; Karim *et al.*, 2012). Equally, there have been quantified successes attributed to information sharing in the Squid Trawl Network, for example, where bycatch reduction for nine key species has been evident (Squid Trawl Network, 2021). A reduction in bycatch in Northwest Atlantic midwater trawl fisheries targeting herring was also attributed to a change in fishing behaviour following the introduction of a bycatch avoidance program. A comparison of behaviour prior to and following the implementation of the scheme showed a reduction of re-entry into high bycatch areas once vessels had access to information on the location of bycatch hotspots (Bethoney *et al.*, 2017). Vessels participating in the eCatch program, in Californian groundfish fisheries, were also shown to catch over 20% less overfished species compared to the rest of the fleet, indicating success of the scheme (Merrifield *et al.*, 2019). Such successes address some of the earlier incentives we highlighted to encourage participation in information sharing schemes, including helping fishers to not exceed quotas for any prohibited, restricted or choke species.

Conversely, if a scheme is not deemed to be successful or beneficial, this may discourage participation. It can be hard to quantify the exact success of information sharing on bycatch reduction, as there are many factors that affect catches, including environmental variables, that cannot be controlled for when assessing such schemes. There may not even be attempts made to measure any potential benefits. Where assessments of information sharing schemes have been made, results that indicate any potential benefits of information sharing should be communicated to fishers. Concrete evidence may not be required, however, and longevity of any scheme could in itself be a recognition of success. Encouragement from peers who feel they benefit from information sharing could also encourage others to also participate.

Conclusions

From all of the examples in this paper, it is clear that there is no one size fits all solution for designing and incentivizing participation in catch sharing and bycatch avoidance schemes. There certainly may be more success in at least achieving longevity in information sharing schemes where data collection on bycatch is mandatory within a fishery, as in the US examples, rather than voluntary, as in many European fisheries. Trust between participants and willingness to join in schemes may also be more likely when there are already established relationships of fishers working together, through a co-operative for example. Additional incentives may be required to encourage data collection and information sharing, especially where data collection is voluntary. Yet there were examples of the use of additional incentives across both schemes with mandatory and voluntary data collection, and an additional reward may be required to increase bycatch avoidance behaviours regardless. It is clear that these incentives and rewards need to be sufficient to outweigh the time and burden of providing information and of avoiding unwanted catches. There is also evidence across a number of the schemes that it is important to ensure sharing of information does not reduce an individual's competitive edge in a fishery. The importance of anonymity was evident across a majority of the case studies. Assurances that information sharing will not result in harsher restrictions or individual penalties may also be important for some. All of these factors need to be considered when designing and implementing any form of information sharing scheme in fisheries, as industry buy-in is essential (O'Keefe and DeCelles, 2013). Despite this seeming like an almost impossible balancing act, many of the examples in this paper demonstrate that it is possible to design schemes which have industry support. It is clear, however, that it is important to avoid making assumptions about what will motivate fishers to participate in information sharing schemes. This highlights a need for more research to be focused on better understanding these motivations, which could be achieved through directly asking and interviewing those who have shared catch information to reflect on their experiences. Taking a collaborative approach, when designing and implementing such schemes, is also vital to fully understand the needs, concerns, and motivations of any group of fishers, which is certainly fundamental in adopting and expanding such approaches.

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Data availability statement

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Author contributions

JC conceived the study, conducted the literature review, and contributed to the writing and editing of the manuscript. CTM, KH, J, A-F, and JCM wrote case study examples and contributed to the writing and editing of the manuscript. DGR supervised the project and contributed to the writing and editing of the manuscript.

Conflicts of interest

KH is a partner in Sea State Inc.

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