Received: 22 September 2017 | Accepted: 19 February 2018
DOI: 10.1111/faf.12279

ORIGINAL ARTICLE

WILEY FISH and FISHERIES

Progress in designing and delivering effective fishing industry–science data collection in the UK

Stephen C Mangi[1] | Sven Kupschus[2] | Steven Mackinson[3] | Dale Rodmell[4] | Alexandra Lee[2] | Elizabeth Bourke[4] | Tom Rossiter[5] | Jim Masters[6] | Stuart Hetherington[2] | Thomas Catchpole[2] | David Righton[2]

[1]Baylys Wharf Fish Quay, Centre for Environment, Fisheries & Aquaculture Science, Plymouth, UK

[2]Centre for Environment, Fisheries & Aquaculture Science, Lowestoft, UK

[3]Scottish Pelagic Fishermen's Association, Fraserburgh, UK

[4]National Federation of Fishermen's Organisations, York, UK

[5]Succorfish Ltd, Hull, UK

[6]Fishing into the Future, Unit C041, Brixham Laboratory, Freshwater Quarry, Brixham, UK

Correspondence
Stephen Mangi, Baylys Wharf Fish Quay, Centre for Environment, Fisheries & Aquaculture Science (Cefas), Plymouth, UK.
Email: Stephen.mangi@cefas.co.uk

Funding information
Department of Environment, Food and Rural Affairs (Defra); Seafish Strategic Investment Fund (SIF); Celtic Seas Partnership (CSP)

Abstract

This study was undertaken to address the increasing need for a strategic approach to industry–science data collections in the face of reducing resources and growing need for evidence in fisheries management. The aim was to evaluate progress in the development of plans and procedures that can be employed to collect, record and use fishing industry knowledge and data in the evidence base for managing fisheries. This was achieved by reviewing industry-led data initiatives already undertaken or ongoing within the United Kingdom to document how these projects have/are incorporating fishing industry data into the process of management decision-making; canvassing stakeholder opinion on data gaps and whether these could be filled by data gathered by commercial fishing vessels; establishing what issues might prevent or stimulate commercial fishing vessels in collecting data when they have the opportunity; and describing guidance on a step-by-step process for gathering scientific information such that fishers are empowered to collect the right data, at the right times and in the right format for their fishery. Given recent advances in the collection, interpretation and application of fisheries-dependent data, we compare progress made in the UK to other areas of the world. We conclude that there is considerable evidence of a paradigm shift from the conventional practice of scientists asking fishers to provide data for scientific analyses towards full engagement of key stakeholders in data collection.

KEYWORDS
collaborative research, data collection protocol, fisheries management, fisheries-dependent data, incentives, stakeholder engagement

1 | INTRODUCTION

The demand for data and knowledge on marine resources to underpin management decisions is increasing. The ecosystem approach to management requires knowledge of how marine ecosystems function and being able to predict, with some reliability, their productive capacity and the consequences of management actions (Greenstreet & Rogers, 2006; Jennings, 2005; Sherman et al., 2005). This necessitates information on (i) the marine environment to understand its state and the impacts of various pressures such as climate change, fishing and anthropogenic inputs (Pikitch et al., 2004); (ii) marine biodiversity to support development and implementation of marine planning and protection of vulnerable or sensitive marine habitats and species (Pikitch et al., 2004; Sale et al., 2005; Sherman et al., 2005); and (iii) the sustainability of fisheries to strengthen the evidence base and assessment approaches for target species, and to deliver legislation and political commitments such as the Data Collection Framework (DCF) (Apitz, Elliott, Fountain, & Galloway, 2006; EC, 2008; Frid, Paramor, & Scott, 2006; Jennings, 2005). Fisheries are also increasingly recognized as an integrated system with ecological, economic, social and institutional aspects that require interdisciplinary approaches and a more participatory governance structure (Stephenson et al., 2016). Further, there is increasing uncertainty in resource management, resulting from the impact of climate change on many marine ecosystem components (Littell, McKenzie, Kerns, Cushman, & Shaw, 2011; Payne et al., 2016). These challenges and the expanding objectives for sustainability need to be supported by diverse types of information and methods to provide tactical and strategic decisions across multiple spatial and temporal scales.

The effectiveness of fisheries management, whether it is stock management or the management of activities for nature conservation purposes, is dependent on the timely provision of data and evidence. As a minimum, data and information are needed on the biological characteristics (such as age and length distributions of the species), total catch (landings plus discards), ecological data (impacts on habitat, local growth rates) as well as information about fishing effort, fishing efficiency and fleet behaviour. Currently, there are considerable capacity shortfalls in data collection and large knowledge gaps in our understanding of the marine environment that are preventing effective fisheries management (Dorner et al., 2015; Graham et al., 2011; Simmonds, Doring, Daniel, & Angot, 2011). For instance, biological reference points have not been defined for several commercially important fin- and shellfish, such as brown crab (*Cancer pagurus*, Cancridae) skates and rays (superorder: Batoidea), preventing the development of management plans (Large et al., 2013; Pilling et al., 2008; Tully et al., 2006). Many data-poor (or data-limited) stocks are deemed as a "high risk" by the supply chain, whose purchasing and sourcing policies do not allow them to source from such fisheries (MRAG, 2010; Parkes et al., 2010). No matter how sustainable such fisheries might be, while they continue to lack evidence they will remain off limits to many suppliers and retailers. The paucity of information on seabed habitats even within designated marine-protected areas (MPA) is such that fishing grounds have been closed as a precautionary measure (Agardy et al., 2003; Sale et al., 2005). From the point of view of the fishing industry, the use of precautionary management and decisions on fishing opportunities/access have immediate consequences for fishing businesses' ability to operate (Kraan, Uhlmann, Steenbergen, Van Helmond, & Van Hoof, 2013; Pita, Fernández-Vidal, García-Galdo, & Muino, 2016; Stephenson et al., 2016).

While the need for better data, improved stock assessments and real-time fisheries management is growing, research institutes and state-funded research efforts are suffering from reduced funds and capacity. The fishing industry, however, offers a unique opportunity to help fisheries and marine environment monitoring requirements. Case studies on fisheries-dependent data (Hoare, Graham, & Schon, 2011; Lordan, Cuaig, Graham, & Rihan, 2011; Pennington & Helle, 2011; Roman, Jacobson, & Cadrin, 2011; Sampson, 2011; Uhmann, Bierman, & van Helmond, 2011) show that the fishing industry can play a central role in addressing data gaps across many fisheries. Experiences from the UK involving the fishing industry in the commissioning and implementation of fishery science projects indicate that fishers have a keen interest in helping provide data that may avert unnecessary precautionary measures being implemented (Armstrong, Payne, Deas, & Catchpole, 2013). Indeed, when there is insufficient evidence, the application of precautionary management often entails an opportunity cost in untapped resources (Mangi, Dolder, Catchpole, Rodmell, & de Rozarieux, 2015; Mangi, Smith, & Catchpole, 2016; Stephenson et al., 2016; Stram & Ianelli, 2015). Consequently, industry-led data collection schemes are increasingly being turned towards to supplement existing research programmes or provide information where it is otherwise absent (Johnson, 2007; Johnson & van Densen, 2007; Mackinson & Wilson, 2014; Neis & Felt, 2001; Reid & Hartley, 2006). These schemes are being encouraged towards regionally coordinated programmes based on sound statistical design principles because they need to be compatible with existing data collection, especially if they are to be combined in some way. While this is encouraging, the transfer of knowledge does not always seem to happen effectively (Rice, 2005), and more effort is required to ensure fishers' knowledge is integrated with knowledge from scientific research and monitoring.

With limited financial resources and evolving assessment/management needs (including management strategy evaluation), delivering the evidence base for sustainable fisheries management requires fishers, scientists and managers to work together in a collaborative way. Here, we define industry–science data collection as the active participation and engagement of fishers in data collection. This definition therefore excludes passive participation where scientists, for example, use fishers' vessels as platforms to collect data, such as in the Cefas Observer Programme (Catchpole, Ribeiro-Santos, Mangi, Hedley, & Gray, 2017; Catchpole et al., 2011; Enever, Revill, Caslake, & Grant, 2010) and many gear-based selectivity trials (e.g. Anseeuw, Moreau, Vandemaele, & Vandendriessche, 2008; Catchpole, Revill, & Dunlin, 2006; Depestele, Polet, Van Craeynest, & Vandendriessche, 2008; Revill, Dunlin, & Holst, 2006). It is worth noting that the industry is engaged with active fisheries data collection and research more than ever before. Dorner et al. (2015) note that there is a paradigm shift from the conventional practice of scientists asking fishers to provide data for scientific analyses towards full engagement of key stakeholders in data collection. Recent efforts towards industry–science data collection programmes have involved two ICES symposia on fisheries-dependent information in Rome, Italy, in 2014 (Dorner et al., 2015) and in Galway, Ireland, in 2010 (Graham et al., 2011). In both conferences, assembled scientists, fishing industry representatives, policymakers and other stakeholders discussed how to make best use of data and information collected directly by fishers and how to merge that information efficiently with data from other sources. Similarly, recent projects on science–industry partnerships such as bridging the gap between science and stakeholders (GAP1 and 2) (Holm, Hadjimichael, Linke, & Mackinson, 2018; Mackinson & Wilson, 2014) and the Canadian Fisheries Research Network (CFRN) (Thompson & Stephenson, 2016) have promoted active engagement in the planning and execution of industry–science research. In Europe, the emergence of the principles for Responsible Research and Innovation (RRI) provides compelling reasons to actively involve relevant stakeholders in developing and delivering fit-for-purpose science research projects.

This manuscript addresses the increasing need for a systematic approach to industry-led data collection in the face of reducing resources and growing demand for evidence in fisheries management. We explore how to design and deliver effective industry–science data collection programmes by:

1. reviewing industry-led data initiatives already undertaken or ongoing within the UK to document how these projects have/are incorporating fishing industry data into the process of management decision-making, with a view to assessing their degree of success and any barriers experienced;
2. canvassing stakeholder opinion on data gaps and whether these could be filled by data gathered by commercial fishing vessels;
3. establishing what issues might prevent or stimulate commercial fishing vessels in collecting data when they have the opportunity; and
4. describing guidance on a step-by-step process for gathering scientific information such that fishers are empowered to collect the right data, at the right times and in the right format for their fishery.
5. Given recent advances in the collection, interpretation and application of fisheries-dependent data, we compare progress made in the UK to other areas of the world.

2 | LESSONS FROM PAST INITIATIVES

2.1 | Literature review

A literature review was conducted to document industry-led data initiatives already undertaken or ongoing within the UK. Through e-mails, fisheries scientists working in close partnership with fishers in the UK were asked to provide details of recent fisheries-dependent data collection projects they have been involved in. Each recipient was asked to provide the name of the project, state whether it was undertaken in close partnership with fishers or completely independently by fishers and provide a report or other outputs from the project. The websites of various organizations (e.g. Cefas www.cefas.co.uk, Marine Scotland Science www.gov.

scot/Topics/marine/science) were also searched to identify projects in which collaborative science involving the fishing industry has been undertaken.

A list of the projects/initiatives including the name of the Project Lead was compiled through the information gathered. Each project on the list was reviewed based on its suitability, relevance and availability of evidence to elucidate the key components of a successful industry data collection process but also highlight pitfalls that need to be avoided. To support the review process, a matrix of key attributes common to most initiatives was created and used to analyse the projects (Table 1). Where information for an attribute was missing from the report, telephone and face-to-face interviews were conducted with the Project Lead to gather the information.

A qualitative assessment of the evidence was made from each project, and the findings used to populate a data table. Each of the attributes was analysed to identify features that best contribute to a successful initiative. Furthermore, we sought to condense the 19 attributes into a smaller and simpler set of key characteristics that could be more easily understood and communicated.

TABLE 1 Key attributes that formed the basis of data extraction from past/ongoing industry-led the data the initiative needed to collect

Attribute	Details sought
Drivers	The reasons behind the inception of the initiative
Objectives	What the initiative sought to do?
Data required	Data the initiative needed to collect to meet the objectives
Scale	How big or small was the initiative?
Timelines	When did the initiative take place?
Funding	Who paid for the initiative?
Partners	Who worked with the fishers to deliver the initiative?
Role of fishers	What data were the fishers required to collect?
Industry incentives	What incentives were given to the fishers?
Resources employed	What resources (people and equipment) were supplied to the fishers?
Data collection methods	What methods did the fishers use to collect the data?
Data customer	Who was the data collected for?
Objectives met - Why?	Were the objectives met and what were the main reasons for this?
Address science/Policy	Was the data aimed at addressing science or policy needs?
Impact	What, if any, impact did the initiative have?
Strength	Key strengths of the initiative
Weaknesses	Key weaknesses of the initiative
Opportunity	What opportunities were identified to build upon the initiative?
Threats	What issues were identified that would prevent future success?

2.2 | Key attributes of industry-led data collection

In total, 20 projects from Shetland in the north to the English Channel in the south were identified for analysis. Three of these had missing documents or no person to contact and were therefore not reviewed. The remaining 17 were analysed, and key information for each attribute extracted and entered onto a matrix (Table 2). These can be summarized into the following attributes.

2.2.1 | Drivers

The drivers of industry-led data collection initiatives are exogenous, and can be largely broken down to spatial, scientific and changing management contexts. Spatial drivers mainly come from the growing competition for the marine space with other uses such as offshore wind farm developments and marine-protected areas (MPA). For example, the Holderness Fishing Industry Group (HFIG) data collection scheme is associated with the Westernmost Rough offshore wind farm owned by Dong Energy (https://plus.google.com/+HfigOrgUk). Similarly, the Lyme Bay fully documented fishery project was in response to the Lyme Bay closed area (Woo, Rossiter, & Woolmer, 2013). In this regard, fishers have not only used the data collection process to evidence and justify their activities (one that they hope will show where they fish and protect their right to fish in those areas), but also to assess the scale and impact of MPAs. Similarly, a lack of data supporting science has also played an important part in motivating fishers to take part in several projects, for example SESAMI—self-sampling in the inshore sector (Mangi et al., 2016). Economic drivers, including the categorization of sharks, skates and rays as data-limited stocks resulting in quota restrictions and fishing opportunities, have led skippers to engage in data collection schemes, for example, in Shark By-Watch UK (Hetherington, Nicholson, & O'Brien, 2016). Changing management contexts such as the Landing Obligation (a new rule under Europe's Common Fisheries Policy (CFP) in which all catches of regulated fisheries are to be landed and counted against quotas of each Member State), requiring full documentation of catch, has led fishers to test the efficacy of remote electronic monitoring (REM) devices (CCTV) as a tool to monitor catch and discards (MMO, 2013; Roberts, Course, Pasco, & Sandeman, 2015; https://www.ssmo.co.uk/).

Most of the projects reviewed here sought to address science and policy, and recognized an intrinsic link. Science tends to be long term and requires the collection of data year after year, and is thus slow to change. Policy may offer more immediate result (particularly if associated with regulatory change) but needs patience and evidence which must be based on scientific information. Fishers have directly collected data for scientists, management authorities (e.g. Marine

Management Organisation (MMO), inshore Fisheries Conservation Agencies (IFCAs), Department of Food, Environment and Rural Affairs (Defra)), Science Technical and Economic Committee on Fisheries (STECF), representative bodies such as the National Federation of Fishermen's Organisations (NFFO) or local fishing associations and commercial businesses within the supply chain. Society too was found to be a customer—in the form of data and information for traceability or provenance, or to aid understanding of the marine environment and improve the public image of fisheries.

2.2.2 | Data required, scale and timeline

Data requirement as an attribute varies among the projects reviewed here but is wholly dependent on the objectives of the project. In addition, the available technology used has a considerable influence on the data collected. In most projects, the data required are usually set by the cooperating scientists. However, in some cases the fishers provide the lead, for example Holderness Fishing Industry Group (HFIG) ongoing work. Most of the initiatives investigated can be best described as pilot projects, or specific targeted projects within a wider programme. The most successful initiatives were found to be the small and local, where the participants felt a commonality with the other participants. Due to funding limitations, most of the projects were short, usually lasting one or two years at the most. Furthermore, earlier initiatives were often pioneering but short term; their success was limited as a result. A few longer-term initiatives have begun to build time series and have incorporated the lessons learned from past experiences, for example the Shetland Shellfish Management Organisation review of progress (https://www.ssmo.co.uk/), the Fisheries Science Partnership (FSP), which albeit focused on short-term individual projects has a long-term approach (https://www.gov.uk/government/organisations/centre-for-environment-fisheries-and-aquaculture-science/about/research#fisheries-science-partnership-fsp), and the Fishing into the Future (http://www.fishingintothefuture.co.uk/) initiative, which is laying foundation for a long-term strategic approach.

A spectrum of data collection methods is evident in all the projects. Broadly, they fall into two categories: active and passive participation. Active participation involves fishers altering their normal activity to collect the data. Examples include sampling, surveying, measurement (sexing, ageing), tagging, survival rates, identification of spawning and nursery areas. Passive data collection utilizes the fishing operation as an opportunity to collect valuable data and causes no real inconvenience to the fishers themselves but does require their permission and cooperation. Passive collection normally involved the carrying of an observer or the deployment of technology such as CCTV, inshore vessel monitoring system (iVMS), VMS, e-logs, apps or remote sensors.

2.2.3 | Funding and research partners

Public funding in one form or another has been important in supporting most of the initiatives (15 of 17). Findings show that initiatives with longer timelines tend to have private income at their foundation stage and public funding is added on a project by project basis. Overall, the industry-led data collection initiatives reviewed here have been delivered through partnerships of one form or another. Scientists are the most frequent research partners, providing advice and guidance to ensure scientific rigour. Other partners include relevant government agencies, environmental NGOs and private enterprise. In general, project partners have been important in building credibility and ensuring buy-in to the results. There appears to be a need for a mix of partners, ideally fishers, scientists and some form of management. A considerable amount of resource is evident in all the projects investigated. By far, the most important professional resource found was scientific support in the form of project design, observers, training and analysis. Tangible resources such as equipment, premises and money are also commonly used. The exact resources deployed vary from project to project and are usually dictated by the objectives and the project budget.

2.2.4 | Role of fishers and incentives

The main objective that fishers who collected data had in common was one of self-preservation or betterment. They see data collection not as their primary purpose, but as a necessary adjunct. For instance, in the National Evaluation of Populations of Threatened and Uncertain Elasmobranchs (NEPTUNE) shark, skate and ray scientific bycatch fishery, fishers collected data to increase understanding of porbeagle (*Lamna nasus*, Lamnidae), spurdog (dogfishes, Squalidae) and common skate (*Dipturus batis*, Rajidae) distributions in Celtic Sea fisheries (ICES VIIe-j), while demonstrating the level of bycatch and on-deck vitality of these zero TAC (total allowable catch) and prohibited species. In the case of spurdog, the motivation for participation by fishers was the moral principle of reducing spurdog bycatch and subsequent dead discards. A second motivation was to explore the economic opportunity to land what was already dead (Ellis, Bendall, Hetherington, Silva, & McCully Phillips, 2015; Hunter et al., 2016).

Fishers in all the selected projects played an important role in establishing the initiative. They contributed to the design of the project and the execution, often carrying observers, participated in training to take measurements, engaged in tagging work, and agreed to provide electronic log (e-log) data, or carry REM devices. In all cases, the costs of the data collection were subsidized to some extent, varying from provision of the data collection device through to a payment being made to compensate for time lost in collecting data. For instance, participants in the catch quota trials received extra quota to offset the cost of behavioural change to avoid discards that could lead to reduced marketable catches. The value of the data collected was noted as an important incentive to the fishers. The rationale behind the incentive being to minimize the chance of choke species (i.e. species that are incidentally caught at a greater quota proportion than the target species) forcing fishers to alter behaviour or forego future fishing opportunities as catches from these studies counted towards the quota.

TABLE 2 Summary of the projects/initiatives reviewed and assessment of how they addressed the key attributes of industry-led data collection

	Project	Objectives	Driver	Date, scale and data required	Source of funding and research partners
1	Blue Marine Lyme Bay fully documented fishery	To assess the scale and impact of the fishery to support a voluntary management agreement and local fishery managers	Voluntary agreement, market access, local management	2013—ongoing; full scale iVMS/pilot collection of catch and effort (44 vessels)	£80k from EFF & Blue Marine Foundation; MMO, IFCA, Plymouth University, Succorfish
2	Welsh whelk fishery study	Real-time spatial catch and effort data collection to advise consultation and calculate CPUE	Implementing a management plan	2016—ongoing; pilot prior to roll out (five vessels); iVMS, catch and effort	£10K from central government; Welsh Fishermen Association, Welsh Government, Succorfish
3	SESAMI–Self-sampling in the inshore sector	To test capability, willingness and practicalities of data collection by skippers	Need for more and better (under 10 m) data that fishers can trust to provide evidence on their fishing practices	2012–2014, SE and SW of England (30 u10 vessels); catch, effort, gear type, fishing location, discards	£200k from Defra and EFF; Cefas, <10 m fishers
4	Seafish SW beam self-sampling project	Fisher self-sampling effort in parallel with normal data collection by discard officers to characterize and compare the two types of sampling	Cost/need for better data leading to better science	2000 –2001; SW England (317 hauls from 14 vessels); catch including discards	DEFRA and Seafish; Seafish, fishers
5	Clyde Fisheries Development Project	Define a baseline from which a sustainable fishery management plan could be implemented	Environmental pressures, misinformation and declining catches	2007–08; Observers (fleetwide self-sampling); retained and discarded by species	£300k from FIFG, Seafish, Private; Fishers, processors, NGO, Trade bodies, Academia
6	Holderness Fishing Industry Group (HFIG) ongoing work	Provide a baseline on shellfish activity and establish a plan for monitoring changes following construction of offshore windfarm	Dong Energy licence application for Westernmost Rough offshore windfarm	2013 and 2014; Surveys at fixed points; data on three shellfish stocks within proposed and control inshore and offshore areas	Commissioned by Dong; Holderness Fishing Industry Group
7	North Sea real-time cod closures	Reduce cod mortality to gain exemptions from the Cod Recovery Plan	Restrictions on fishing activity through limited days at sea	2009—ongoing; North Sea and West of Scotland; abundance of cod in hauls	Various sources (EFF, Scottish Government); chiefly SWFPA and MSS, later SFF
8	North Sea (English) CCTV	To test efficacy of CCTV as a tool to monitor catch and discard activity in North Sea cod fishery and any variations, for example length frequency measurement	Excessive discards and a desire by fishing industry to land more of what they catch	2012–2015; North Sea (17 vessels); automatic and continuous catch data	£400K from central government; Fishers, MMO, PO
9	Channel Sole CCTV	To test efficacy of CCTV as a tool to monitor catch and discard activity in SW fishery and year-on-year variations	Excessive discards and a desire by fishing industry to land more of what they catch	2011 - 2013; English Channel (11 vessels); automatic and continuous catch data	£250k from central government; Fishers, MMO, PO
10	Shetland Shellfish Management Organisation—Review of progress	To implement fully functional management supported by sound data for all shellfish stocks inside the 6-mile limit of Shetland	Establishment of the regulating order and SSMO	2000—ongoing; 70 vessels; all data to support effective management of inshore shellfisheries	Various sources (self, local council, central government, grants); local council, fishers
11	SFF West of Scotland Sampling Project 2016	Provide a baseline on whitefish and *Nephrops* stocks	Cod Recovery Plan reductions in quota and increasing pressure from competing interests with marine spatial planning	2016; West of Scotland; Stock abundance, age and sex	EFF and Scottish Government; SFF, MSS, Aberdeen University
12	North Sea Stock Survey	Provide early information on the state of stocks and feed into ICES assessments	Difference in perceptions of stock abundance between fishers and scientists	Pilot 2002 continued until 2015; North Sea; Qualitative changes in stock abundance	NSFC, NSAC, UHI, SFF, VisNed, NFFO, CVO, Rederscentrale, Danish Fishermen's Association
13	Monthly Shellfish Activity Return/Shellfish E-log trial	Record activity and catch of under 10-m potting and netting vessels with shellfish licences	A lack of reliable data supporting stock assessment and management	2006—ongoing; All vessels on a month by month basis; detailed catch and effort	£60k per year from Defra; Defra, MMO, IFCA

Role of fishers	Industry incentives	Objectives met and why?	Impact	Link to management and decision-making	Reference
Sign voluntary agreement/fit VMS, record catch and effort data	Improved port facilities/ access to their data/ access to market (20% premium)/free equipment	Yes—developed and tested a data collection template for inshore fishers	Medium–data collection is ongoing post project and data used by IFCAs	Provision of catch data and location. Mechanism for compliance and monitoring fishing around sensitive reef areas	Woo et al. (2013)
Fit iVMS/record catch and effort data by string. Provide a daily landed weight	High-quality data feeding into policy/free equipment/build-up track record	Yes—collected and analysed high-resolution CPUE	High—Data have fed into Whelk consultation and systems to be introduced to nationally	Provision of data towards consultation on sustainable management measures for the Welsh whelk fishery	Rossiter (2016)
Collect data daily via paper log-sheet and carry observers on occasion for validation	Better data provided to scientists; daily rate	Yes—compiled a data set with total catch from inshore fleet	The trial demonstrated that validated self-sampling by under 10-m skippers is potentially, an efficient way of collecting commercial fishery data.	Approaches for fully documented fisheries in the inshore fleet	Mangi et al. (2016)
Sampling catch, sorting, record volumes and label discard sample to be handed over to discard officer	Better data/natural interest and £25 payment per sample taken	Yes—data gathered and compared. Fishers were well trained and supported.	Low as the initiative stopped at the end of the project but did show what could be achieved	Monitoring of discarding and retention by trawl fisheries in Western Waters by the use of Fisher Self Sampling.	Caslake, Kingston, Lart, and Searle (2002)
Carry observers and undertake self-sampling	Better data feeding management/improved quality and prices/ engagement with industry	Yes—sufficient resource on the ground and all fishers engaged	Provided a baseline for the fishery. Improved quality standards. Has been subsequently used by science and in policy	Resources and outreach—all fishers were contacted	Combes and Lart (2007)
HFIG tendered for project and fishers involved in designing of surveys	Baseline to negotiate mitigation/ compensation	Yes—buy-in from both sides	Provided a means of resolving potential conflicts and measuring future change	Data accepted by both Dong Energy and HFIG and provided basis for improved relations	https://plus.google.com/+HfigOrgUk
Fishers identified areas of cod abundance, which were then analysed by scientists	Additional days at sea	Yes, in terms of days at sea: unclear in terms of reduction in mortality	Difficult to judge given large areas involved	Encouraged industry to become more selective	Needle and Catarino (2011)
To carry the CCTV equipment and fish more selectively for cod	Uplift in quota based on historic discard levels	Yes—The motivation and incentives for fishers were sufficient and the technology fit for purpose	Reduced cod discards to around 1% from a normal level of 40%	Accuracy in catch monitoring tools	MMO, (2013)
To carry the CCTV equipment and sort place discards and present them to the camera	Uplift in quota based on historic discard levels	Yes—powerful tool for corroborating self-reporting data	Much improved data on discards and evidence to support claim of low discard levels	Use of remote electronic monitoring (REM) to corroborate self-reported discard data	Roberts et al. (2015)
Management board/data collection and cooperation with scientists	Self-management	Work in progress but positive steps forward being made.	Deemed a successful local co-management initiative with overwhelming support	Management and regulation of shellfish within Shetland's six mile limit	https://www.ssmo.co.uk/
Fishers carried out surveys	Possibility of influencing policy, for example MPAs	Baseline established due to sufficient resources being available.	Too soon to determine	Establishing baseline data	Kenny Coull, Project Manager, Personal communication
Record perceived order of magnitude of changes in stock abundance	Improved assessments from ICES corresponding to fisher's experiences	No—timetable to feed into ICES altered, scientists unhappy with qualitative nature and low level of responses	Limited	Changes over time	https://www.nafc.uhi.ac.uk/research/fisheries/fishers-north-sea-stock-survey
Legally required to complete the forms and provide accurate details	Improved scientific basis for management decisions.	No—a lack of compliance from industry underpinned by little or no motivation as uses of the data not been witnessed.	Limited other than to demonstrate that method of data collection has not been effective	Collecting of critical catch and effort data	Bell (2013)

(Continues)

TABLE 2 (Continued)

	Project	Objectives	Driver	Date, scale and data required	Source of funding and research partners
14	Fishface	To test the feasibility of using recreational waterproof cameras to collect footage of commercial fishing activity on inshore vessels for the purpose of monitoring	A lack of reliable data supporting stock assessment and management	2013–14; <10 vessels; continuous capture of video around the vessel while active	Private, Fishface; fishers and Fishface
15	Shark By-Watch UK 1	Improve knowledge of shark and ray bycatch and discarding in the inshore fisheries.	Categorization as data-limited stock resulting in quota restrictions and fishing opportunities	2011; Southern North Sea, Greater Thames Estuary; Abundance, spawning and nursery areas	£80,000 from EFF; Cefas, <10 fishers
16	Shark By-Watch UK 2	Minimize bycatch of sharks and rays	Understanding bycatch and discards of elasmobranchs in UK waters:	2015; Bristol Channel, Greater Thames Estuary, The Wash; Level of bycatch and discarding/survival	£250,000 from EFF, Defra, Morrisons; Cefas
17	National Evaluation of Populations of Threatened and Uncertain Elasmobranchs (NEPTUNE) shark, skate and Ray Scientific By-catch Fishery	Increase the understanding of the levels of bycatch and on-deck vitality for porbeagle, spurdog & common skate in Celtic Sea	Listing of porbeagle, spurdog & common skate as 0-TAC or prohibited during 2009–11.	2012 - 2013; Celtic Sea; catch rates, abundance, on-deck vitality, long-term discard survival.	Defra; Cefas, fishers

2.2.5 | Objectives met and why

These varied on a case-by-case basis. Some of the consistent reasons for (i) success include objectives were clear and achieved, fishers were involved from the beginning, there was clear leadership and ongoing support, short-term benefits were identifiable and good communications to manage expectations. ii) failure include objectives were not met because there was lack of consultation with fishers, objectives were poorly defined and too large scale, lack of perceived benefits (no feedback), lack of leadership and support, too many diverse interests involved and fishers "fatigue".

2.2.6 | Impact, strengths, weaknesses, opportunities and threats

In general, the technical impact of the data collected has been relatively low. However, much has depended on how the objectives were defined. For instance, in the Conservation Credits initiative the impact on cod (*Gadus morhua*, Gadidae) mortality was low but the project benefited some fishers through the extra days at sea. Due to the innovative and investigative nature of many of the projects, they often meet the objectives. The strengths therefore vary greatly from project to project, but in cases when there is buy-in from fishers, costs were low, and benefits were high. Strong leadership (preferably from both fishers and scientists) is also a key strength is some of the projects, while a feeling of common ownership and goals among fishers and good communications are positive features of others.

The weaknesses also vary greatly, but the most significant ones relate to a top-down approach; no perceived benefits either during or after the project; too many interests involved; no leadership or resource to maintain momentum; and poor communication with the fishers on an ongoing basis. The most common opportunities identified include the possibility of creating a time series once baselines have been established. Securing such opportunities in some cases, however, was hampered by participant "fatigue" and funding issues. The possibility of developing communications to increase wider buy-in to the idea of industry collection of data was also identified as a key opportunity. In the face of reducing public funding for data collection, it is important that alternative ways to collect data are pursued and promoted. Equally some of the projects identified the opportunity of technology to automate the data collection process and reduce the burden on the fishers, using them as vessels of opportunity rather than research laboratories. One threat identified as substantial was trust—where fishers feared that their data will be used against them. There is a perception that this has happened in the past.

2.3 | Summary of lessons learnt from past initiatives

The literature review on the most important attributes of an industry-led data collection initiative was used to identify the "must have" or "must avoid" points from across all the initiatives investigated. These were kept at a broad level to make it easier to communicate. The following aspects are considered fundamental ingredients of successful industry-led data collection initiatives as distilled by the authors. Many of these are similar to the good practice messages produced by the GAP (bridging the gap between science and stakeholders) project (Mackinson, Neville, Raicevich, & Clausen, 2008; Mackinson, Raicevich, Kraan, Magudia, & Borrow, 2015).

2.3.1 | Industry participation

It may seem obvious, but on-the-ground support must be present for an initiative to succeed. The core idea should originate within the fishing community and normally in response to some issue or challenge. Ideally, the industry group should lead or at least share the project lead throughout. An interesting observation was that the most successful projects have a strong shared interest or "glue" within the

Role of fishers	Industry incentives	Objectives met and why?	Impact	Link to management and decision-making	Reference
Install, operate, maintain the camera system and download the data on a regular basis	Better data feeding management, improved quality and prices	Yes—the quality of the images was excellent and the cameras generally did collect the required data.	Limited to date but has shown what can be achieved at a low cost on small-scale vessels	Data storage/transfer. Low-cost high-quality images	MacGarvin (2014)
Tagging and recording information, self-sampling	Improved knowledge and data available to fishers	Yes—knowledge gathered and shared through website	High impact through excellent stakeholder engagement and media campaign	Involvement and use of local knowledge to improve communications and trust between fishermen and scientists	www.sharkbywatch.org
Data collection	Improved evidence base leading to more fishing opportunities	Partial—focus too large	High excellent stakeholder outreach through dedicated comms team.	Species subject to small or zero TACs, such as spurdog, could become choke species under CFP	Hunter et al. (2016)
Self-sampling after training trips	Improved evidence base to feed into scientific assessment	Overall objective was not met as mechanisms on who and where the data should be used were not identified.	Some of the data were used by a subsequent programme in a proposal to STECF for the Spurdog By-catch Avoidance Programme.	Increased data collection to improve robustness of available data	Ellis et al. (2015)

industry group well before the initiative begins. Consequently, this explains why small-scale local initiatives tend to be more successful than larger projects. The pre-existing shared interest enables the group to stay focused in the face of inevitable challenges and issues. The smaller scale may also ensure that the share of responsibility and effort is verifiably equal which tends to enforce the group value of the project.

2.3.2 | Trust and understanding

An important attribute found consistently among the successful projects was having a shared goal that was both easy to recall and explain and ultimately communicate. It was observed and commented that if the goals are complicated or unclear, the initiative will fail as all the parties will be aiming for different outcomes. As well as undermining the aims of the initiative, there is less acceptance of the results under these circumstances, as participants feel betrayed and trust is lost. Trust is all too often hard won and easily lost. As with most projects requiring a voluntary contribution, there is a period of selling the idea. This can be reduced/facilitated by demonstrating how project participants will work together effectively and respectfully. It is critical that during this process, expectations are managed, and unrealistic promises are avoided. Furthermore, it is extremely important that the project team do exactly what they say they will. Minor instances such as not returning a call in a timely manner or forgetting to share a document can become a catalyst for the unravelling of a project.

2.3.3 | Incentives

Investigating and presenting the incentives for collaboration is an important step for all successful projects to undergo. The incentives should be clear for all parties and not just fishers. They must also be realistic and deliverable. The incentives to cooperate can take many forms. For instance, in the SESAMI project a daily rate was paid to skippers for recording data from their fishing operations (Mangi et al., 2016). It is worth noting that economic incentives do not have to be monetary. Several of the initiatives actively sought to avoid such monetary incentives as it may promote short-term thinking, while the goals are often long term. Many found that this created a conflict among fishers and scientists, and had the effect of eroding trust, while indirect economic benefits such as provision of equipment or an uplift in quota were deemed to be more appropriate and consistent with the aims of industry-led data collection. To this end, the majority of the initiatives studied report that the assurance of better data and evidence being incorporated into science and management is the single most important incentive to participants.

2.3.4 | Leadership

There are many facets of leadership, but in terms of industry-led data collection initiatives, the most important was having the drive to make things happen. This role is difficult for a working fisher to fulfil and requires a person with strong administrative skills. It may be feasible for a project to be front loaded with support and training. However, experience has shown that there is need for a local activator throughout the lifetime of the initiative. Small technical issues or points need to be addressed quickly, and without the intervention of a local trusted actor the responsibility falls upon the fishers to contact often unknown individuals who are unavailable when fishers have the time and inclination to pursue the issue. Experience from past and ongoing projects has shown that this person can also fulfil the role of communicator and assist in maintaining motivation among fishers, while providing any necessary support.

2.3.5 | Resources

The move towards increased industry-led data collection is partly driven by the reduction in funding and personnel resources in the face of a growing requirement to provide robust evidence to support appropriate management and market requirements. Here, there is usually an expectation of a significant return on investment, but for small fisheries, this may be difficult to find. Fishers collecting data will certainly improve the efficiency of the process and data quality. However, resources are required in training and validating the data so that its quality is known. Consequently, industry-led data collection should not be seen as free science as this could underestimate the true cost and the value added by the fishers. On the contrary, industry-led data collection projects must therefore be properly resourced if they are to deliver the benefits they set out.

2.3.6 | Feedback

A common perception of fishers following engagement with data collection is that the process is "down to them," and afterwards, they are left in the dark as to the outcome and value of their participation. Most successful initiatives have invested considerable time and money into the feedback process, ensuring that fishers get something out of it and that there is an appreciation of their contribution. Fishers need to hear and see that something is happening with their data. There is an innate suspicion that nothing will change, but by demonstrating that their data means something, it gives fishers hope and motivation to undertake and sustain their efforts.

3 | MATCHING DATA NEEDS AND CAPACITY TO COLLECT THE DATA

3.1 | Stakeholder interviews

The transition towards ecosystem-based management necessitates a broader perspective of sustainability, requiring approaches for managing through ecosystem change and strategies for mitigating societal impacts—in particular for those whose livelihoods depend on the sea. These needs demand engagement and collaboration between sectors and across borders (Apitz, Carlon, Oen, & White, 2007; Borja, 2005; Ducrotoy & Elliott, 1997; Elliott, Fernandes, & de Jonge, 1999; Read, Elliott, & Fernandes, 2001). For instance, in fisheries management, most people agree that there are weaknesses in ICES stock assessments that could be solved with more or better data (Apitz et al., 2006), and that the fleet of fishing vessels at sea presents an opportunity to collect additional data (Graham et al., 2011; Mangi et al., 2015, 2016). However, realizing the potential to join up "need" and "capacity" is something that is difficult to achieve. As the literature review has demonstrated, the fishing industry has been collaborating with scientists and regulators in projects to collect fisheries and environmental data with some success. These projects, while producing useful information and demonstrating that the fishing industry can add value to research survey work, often have had a short life and rarely have been adopted as a routine model. These issues and related constraints need to be addressed to ensure that industry–science projects can collaborate and share knowledge.

To identify opportunities where marine monitoring need and opportunity can be matched, a stakeholder survey was conducted. The objective was to identify the most useful data and the challenges the fishing industry face when contributing to the stock assessment process. Through contacting UK marine monitoring authorities (MMA), environmental non-governmental organizations (eNGOs), fish processors and retailers, and fishers we aimed to: (i) identify gaps in monitoring data for assessment needs; (ii) canvass opinion on whether these data gaps could be filled by fisheries-dependent data; (iii) identify capacity or expertise within the fishing industry to collect data; and (iv) describe difficulties of data users in incorporating the information in assessments and characterize the potential pitfall faced by the industry in collecting such information.

3.2 | Data collection and analysis

A technical assessment questionnaire was developed and published through the Survey Monkey (www.surveymonkey.com) online portal. Participants were only shown questions relating to their specific activity in the monitoring and assessment process to ensure relevance and to minimize the time needed to complete the survey. A branched survey design was used with questions being dependent on previous answers (Figure 1). The questionnaire asked respondents to state the focus area of their current employment, classifying themselves as interested in fisheries data/assessments, ecology and biodiversity data/assessments, hydrographic and water quality data/assessments, or other environmental data/assessments. Fishers were asked what data types they could supply information on while data users (MMA, eNGO and fish processors) were asked what data they would be interested in obtaining with assistance from the fishing industry.

The survey was circulated to a list of 42 "targeted" stakeholders identified by the Celtic Seas Partnership (CSP www.celticseaspartnership.eu/) via a URL link copied into an e-mail invitation. Targeted stakeholders included fishing industry representatives, environmental NGOs, individual experts, statutory nature conservation bodies, fisheries managers (MMO, Defra) and scientists. These were identified through a series of stakeholder workshops under the Celtic Sea Partnership project. Because of the limited number of invited participants and the uncertainty regarding the likely number of targeted responses, the same survey was also made available to anyone interested in responding. Potential "general" participants were made aware of the public survey through (i) requesting "targeted" respondents to forward the survey link to others that they felt might be interested; (ii) circulating the link to the CSPs Fishing for Data (F4D) Group (The fishing 4 data group is a collaboration between fishing industry, eNGOs, retailers and scientists whose overarching goal is to see data gaps preventing effective fishery and conservation management addressed); and (iii) through publicizing the survey link via a blog on the Cefas website (www.cefas.co.uk), which explained the purpose of the research and included a link to the general survey. The Cefas twitter account periodically advertised the blog.

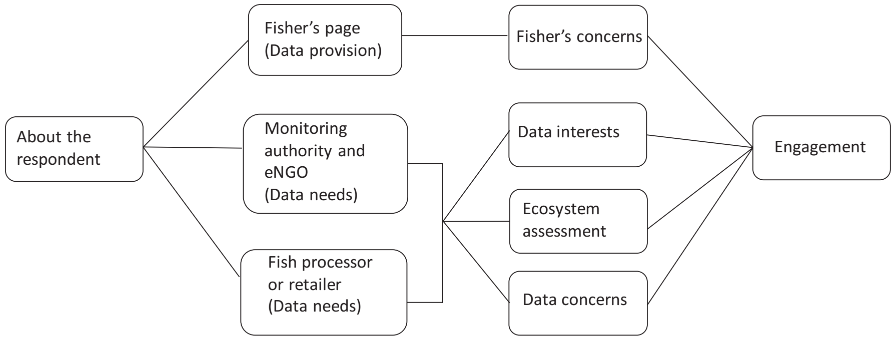

FIGURE 1 Schematic of the branched online survey identifying the questions the respondent had to answer to which determined the path through the survey

Composition of respondents was monitored throughout, and e-mails were sent to encourage specific categories of respondents to participate to balance the coverage across potential data providers and various data users. Two separate URL survey links were circulated, one to targeted stakeholders and another to the general respondents. The links led to the same survey, but the data generated were stored separately allowing for the groups to be analysed separately. The survey was conducted during November and December 2016. Respondents were contacted by phone or e-mail where details were provided if their answers required clarification or further detail was needed to aid the interpretation.

Overall 49 individuals responded to the online survey made up of 16 from the target group and 33 from the general group (Table 3). A total of 23 fishers/vessel owners responded, six respondents were from eNGOs, 19 were from marine monitoring authorities, and only one fish processor or retailer completed the survey. Fishers were well represented in both the targeted and general group, making up 35% and 53% of respondents, respectively. Monitoring authority respondents comprised 46% of the general group and 25% of the targeted group. Five of the six eNGO respondents were part of the targeted group. The fish processor who responded was part of the targeted group.

TABLE 3 Composition of target and general group divided by employer and topic focus as inferenced by respondent's employment details

Employment focus	Target respondent	% of target	General respondent	% of general	Total
Fish processor or retailer	1	6%			1
Fisheries data or assessments	1	6%			1
Fisher/vessel owner	6	35%	17	53%	23
Fisheries data or assessments	5	29%	16	50%	21
Hydrographic and water quality data or assessments	1	5%	1	3%	2
Marine monitoring authority	4	24%	15	47%	19
Fisheries data or assessments	4	24%	10	31%	14
Hazardous substances			1	3%	1
Hydrographic and water quality data or assessments			3	9%	3
Impact of fishing on conservation features			1	3%	1
Non-Governmental organization	5	29%	1	3%	6
Ecology and biodiversity data or assessments	2	11%	1	3%	3
Fisheries data or assessments	2	11%			2
Hydrographic and water quality data or assessments	1	6%			1
Total	16		33		49

3.3 | Data opportunities and need

Results indicate that 77% of respondents focused on fisheries-related data or stock assessments. These were mainly fishers and fish processors. Most monitoring authority respondents (74%) specialized in fisheries data, but other specialities were represented, with 16% focussing on hydrographic and water quality data. Two monitoring authority respondents did not focus on any of the provided options and selected the "other" option describing themselves as focusing on hazardous substances and impact of fishing on conservation features. The focus of the eNGO respondents was broader with 40% focusing on fisheries data/assessments, 40% on ecology and biodiversity data/assessments and 20% on hydrographic and water quality data/assessments.

Offers and requests for fisheries information dominated the data needs. Of the 23 fishers, 17 indicated they could provide data on fish stocks, 16 for fisheries data, 11 for biodiversity from fishing activity and 16 for acoustic information making up 85% of the data offers. The fish processor requested only information related to fisheries data, whereas MMAs and eNGOs showed an increasing interest in general environmental information, but still <50%.

The results suggest that the greatest opportunity to involve fishers in data collection is in relation to information directly related to fishing activities. Information on fish stocks (proportion retained and discarded) and fisheries activities (gear types, fishing location, depth) ranked highest in the opportunities (from fishers) and need (from management authority and eNGOs) in substantial numbers. This information is practical to collect as it is most aligned with fishing activities so is likely to have minimal impact on fishing operations. There are wide-ranging environmental uses for these data from stock assessments of interest to the fishery itself to biodiversity and habitat information.

Acoustic information can also be made available by many fishers, but there were fewer respondents expecting to use this information. Our survey treated these data as a distinct entity belying the fact that it has the potential to be highly informative on stock abundance, but advice users may not fully understand the relevance at the assessment level. Nevertheless, acoustic information and diversity information from fishing activity present good opportunities for cooperation. Because such information is currently poorly represented in assessments, it may well have a greater effect in improving assessments than additional information on fish stocks and fisheries activity.

3.4 | Concerns of fishers

Twenty of the 23 fishers had at least one concern regarding the provision of data with five fishers having the maximum of three concerns. The remaining three fishers had either no concerns or skipped this question. The greatest concerns were that data would be used against fishers (13 responses) followed by concerns over diversion of activity from fishing to monitoring. There were no concerns voiced regarding the use of the data by authorities (Figure 2). No participating fisher registered a concern that authorities may gain information regarding their activities. In part, this is because inspections already extensively supervise the industry, sea observer programmes and vessel monitoring systems provide data on fishers' activity and behaviour. Few fishers thought they had the time or opportunity to collect information in areas other than fishing grounds. The proportion of the time at sea spent on fishing grounds is relatively large, and few vessels can afford to be at sea conducting activities other than fishing. The whole point of involving fishers in data collection is to make efficient use of time spent at sea for different purposes, so it does not seem sensible to divert vessels from their primary activity, but opportunities may still exist on transits between port and fishing grounds.

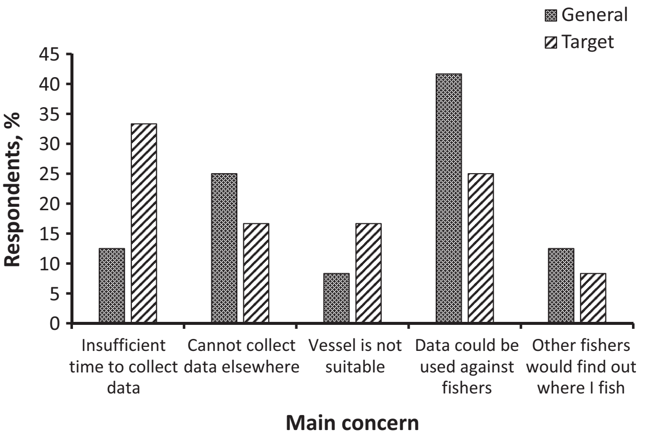

FIGURE 2 Responses registered by fishers regarding concerns with data collections showing the proportion (%) for the target and general group

The concern from fishers that the information would be used against them varied between the target and general groups. Fewer number of respondents from the target group indicated this as a major concern compared with those from the general group. If this is a real difference between the groups, it is not clear whether this is due to the targeted group having been involved in the discussions as part of the Fishing 4 Data group (having gained some trust) or whether they simply were more likely to participate in the process because of less concern. The survey did not specify what constituted "against the fishery." With hindsight, this is an important distinction worthy of future exploration. If fishers are concerned that their data may lead to reduced catches to maintain sustainability, then this will inevitably lead to conflict. Improvements in precision and accuracy are largely independent of the likely change in status outcome which must be accepted prior to participation in data collections. This relates to managing expectation, better data and better management decisions does not mean better fishing opportunities, at least in the immediate/short term, it can mean more restrictions. Interpretation of the data out of scientific context, with the intent to support a particular view or ambition (pseudoscience), must be avoided. Clarifying and discussing these risks is necessary to avoid the erosion of trust and to ensure the longevity of what is a worthwhile and efficient means to improve our understanding of fish, fisheries and the marine environment.

3.5 | Concerns of data/advice users

Concerns over using data directly collected by fishers are surprisingly similar across the different data sources and uses. Encouragingly, and in contrast to optional survey comments made by fishers, government and eNGOs are generally positive about the data. Only roughly 10% of respondents indicated that data were inherently untrustworthy and therefore not suitable for assessment purposes. Roughly 30% responses suggest that the data could be used with few or minor changes to the assessment methodology, implying that there should be some quick wins. Responses suggest, for most assessments, around 40% of the concerns could be overcome with some investment from the fishing industry, such as quality of data, reliability of long-term availability and methodological protocol. The remaining 20 to 30% of responses indicated that the information from fishers is likely to have spatial, temporal or technical biases. These problems are specific to the intended use of the data and would require additional work by stock assessment scientists in conjunction with the industry to ensure that the biases in the new data sources can be appropriately accounted for in the assessment.

Overall, the results are very positive with majority of the problems resolvable, though in most cases at additional cost. Depending on the objective, industry–science data collection schemes are likely to require a long-term commitment and more thought needs to be put into how such activities can be funded. As commented in the survey, collecting data that is not used presents no benefit. At the same time, it must be clear that in stock assessments, in particular, short time series tend to have little effect in changing assessment outcomes, and in many cases, they cannot be used until a long enough time series exists.

3.6 | Engagement

Thirty-four of the 49 respondents replied to the question regarding their willingness to help develop means to overcome issues that hinder the use of fishing vessels as platforms for data collection, all but two of them positively. It is not clear why the other 15 respondents did not want to answer the question. Four fishers, four MMA and three eNGO employees were unconditionally willing to participate. This demonstrates that there are both fishers and data users interested in making industry–science data collection work. Over half of the fishers and data users were interested in further efforts to resolve the issues highlighted in this survey. Those responding positively to this question from the MMA group were almost exclusively those with a focus on fisheries. When willing to work on other data sources, participants did so only in conjunction with fisheries information indicating that for industry-led data collections, the most likely starting point will be working together on fisheries issues.

3.7 | Summary of matching needs and capacity to collect data

The Celtic Seas Partnership (CSP) requested a survey of its members to assess what steps they could take to develop a strategy for industry-led data collection in the context of fisheries and environmental monitoring for the Celtic Seas ecoregion. The limited number of potential respondents (targeted participants) within the group meant that a generalization of the responses was difficult particularly as the CSP sees the interaction between industry, scientists and management as one of its major ambitions thus potentially predisposing their membership to views not representative of the view of the entire industry. The study therefore attempted to test the wider utility of the lessons learned by also canvassing industry participants from a more independent pool and initially treating the responses separately to investigate whether there were differences in the views of the two groups. Responses from both groups were entirely voluntary and made up of small sample sizes with relatively little power to detect differences among the groups. While these shortcomings are not desirable, the information generated has highlighted areas of opportunity where fishers could cooperate in the collection of data towards a comprehensive monitoring programme designed to assess the environmental condition of the seas. Fishers indicated that they are capable and willing to collect a variety of marine environmental information identified as a need by management authorities and eNGOs such as biodiversity observations (marine mammals and birds), marine litter, water quality (hydrographic information), and information directly related to the fishery such as fish stocks, biodiversity from fishing activities and fisheries acoustics. Given that available resources are a limiting factor to improved assessments and the need to maximize the impact of industry-led data collection programmes, we suggest prioritizing effort in areas where the assessment focus of government scientists and the data opportunities provided by fishers overlap. Data-limited species are attracting more attention because advice is needed but difficult to develop (ICES, 2017). For example, many elasmobranch stocks are data-limited and legislative collections are kerbed due to the relatively small proportion of these species in landings (McCully, Scott, Ellis, & Pilling, 2013; Simpfendorfer et al., 2011). However, they are considered ecologically important and several species have restrictive fishing opportunities, and so could easily become choke species as the landing obligation is phased in (Rochet, Catchpole, & Cadrin, 2014). Better data are likely to lead to improved confidence in status assessments, which would make the resulting management measures easier to communicate to stakeholders.

There is also a focus on wide-ranging species especially where their distribution has changed from historic conditions (Christensen et al., 2003; Perry, Low, Ellis, & Reynolds, 2005). There are many such stocks (e.g. cod and anglerfish), but localization of fisheries means that there may be limited opportunities for additional, short-term data collection to influence legislative requirements for many demersal species. The real opportunity for additional information that could make a difference to fishers is probably in the pelagic sector, where a better understanding of the stock distribution and its change over time has the potential to lead to more informed decision-making for managers and policy. In contrast, for many age-based demersal stock assessments more of the same data would likely lead only to more precise assessments. There will potentially be some gains in fishing opportunities, because as in data-limited stocks, more precision means less precautionary management is needed. It is unlikely to fix concerns over bias, persistent under- or overestimation of stock dynamic parameters. To address such issues, new or different data are needed to correct for biases in the assessment such as changes in productivity or natural mortality. Such changes in stock size due to causes other than exploitation are poorly understood, but recent data on environmental conditions are difficult to relate to these historic changes (Sheltona & Marc Mangela, 2011), so that improvements in environmental data collection are unlikely to improve assessments in the short term.

Fishing industry interest, understandably, is likely to focus on traditional stocks such as haddock (*Melanogrammus aeglefinus*, Gadidae) cod, sole (*Solea solea*, Soleidae) and plaice (*Pleuronectes platessa*, Pleuronectidae). If it is decided to make species such as these the focus of data collection efforts because a broader range of fishers would likely benefit, then it is important to manage the expectations. More substantial and longer-term commitments are necessary to make progress for traditional demersal species. Fisheries data collection methods are already standardized and developed to be suitable for use on fishing vessels. Technological developments have largely focused around automating the electronic data capture/evaluation process. Specific methodologies can only be considered once it is clear specifically what data are needed for a particular stock. In the next section, we look at guidelines for industry–science data collection that support the development of industry-led initiatives from the bottom-up, as well as top-down initiatives from managers and scientists.

4 | DATA COLLECTION PROTOCOL

4.1 | Guidelines for industry–science data collection

Results from the stakeholder survey on matching the need and capacity to collect data show that some data users have legitimate concerns regarding the ability of the fishing industry to provide quality-controlled data in a form that is accessible and useful for generating the scientific evidence for advice in management. There are concerns also about the governance of the scientific process and what partnerships with industry mean for the integrity of scientific institutions. Fishers also have their concerns, particularly those that perceive that management bodies are not committed to make use of their data, or management does not react quickly enough on their information. If they do not understand clearly how science is generated and used in management, it can exacerbate their frustration with management, potentially leading to poor compliance with regulation (Mackinson, Mangi, Hetherington, Catchpole, & Masters, 2017).

Working in partnership therefore benefits both industry and science because the value of science to management is better understood and accepted when the scientific knowledge is co-created (Dickinson et al., 2012; Schläppy et al., 2017). The stakeholder interviews, and review of past and ongoing data collection initiatives also indicate that many fishers are keen to contribute data from their fisheries as scientific evidence to help improve management and stock assessments. Individual motives for this may be complex, but most fishers agree on the long-term goal of securing access to fishing opportunities. Their interest in science is also deeply rooted in a genuine curiosity to know and understand more about what is happening underwater. While the specific details will vary for each fishery, the common features for successful industry–science data collection initiative can be defined (Mackinson et al., 2017).

Based on a series of workshops (http://www.fishingintothefuture.co.uk/industry-data-collection-strategy-and-issues), reviews, conversations with key personnel and relevant agencies, and experiences from past projects (e.g. GAP2), Mackinson et al. (2017) developed a step-by-step guidance to gathering useful and useable scientific information. The aims were to (i) provide a reference tool to initiate and execute industry–science data collection initiatives, which have the highest chances of success; (ii) help scientists understand how to work with industry to enhance scientific knowledge and data; (iii) help fishers understand and contribute to the scientific evidence base for management; and (iv) support manager's need for salient evidence upon which to develop management measures that benefit the sustainability of fisheries. The guidelines support the development of industry-led initiatives from the bottom-up, as well as top-down initiatives from managers and scientists, and everything in-between.

The whole process is broken down in to five stages (Figure 3), each prompted by a single question. Stage 1 initiates the data collection process, convening people around the task of specifying the problem and what needs to be achieved to solve it. The data collected must relate directly to a clearly identified management need from the outset. It is advisable to carefully plan for this stage as all subsequent steps will be greatly informed by it. Stage 2 involves the practical planning of the data collection through co-design. Stage 3 involves collecting data on the water and considering survey issues and data analyses. Stage 4 considers how the knowledge gathered can be applied to achieve the desired impact of the study. Stage 5 involves critical evaluation, drawing out lessons for the future. For more details on each stage see the full report at www.fishingintothefuture.co.uk/industry-science-and-data/survey-protocol-guidelines/.

The detailed guidelines are presented as series of questions relevant at each stage in the data collection. When the guidance is employed in a practical workshop setting, the questions are used to facilitate planning through open discussion pertinent to the problems at hand. Drilling down, more detailed questions can serve as a checklist of items to be reviewed and considered where relevant.

One key aspect in designing and delivering industry–science data collection programmes is having the right tools to assist scientists in making the most out of the information available to them to generate

	1. Initiation by co-creation	2. Planning by co-design	3. Survey and analysis	4. Applying the knowledge	5. Evaluation
	What do we want to achieve?	The evidence we need and how to get it	Gathering evidence and making the most of it.	How do we make the knowledge count?	Did it achieve what was expected?
Science questions to consider	- What is the problem and why does it need to be solved? - Who wants to solve it and what outcomes do they expect? - What are the aims for the project? - Who are the gatekeepers that will influence how the evidence will be applied? - What is the scope, scale and timing of the project? - Are the outcomes achievable?	- What objectives are needed? - What information is needed for it to be fit for purpose? - Critical needs and constraints to address? - What is needed to make the data robust scientifically? - What skills and training are required? - What are the resource implications? - Who owns the data and what access will they require?	- What on-board procedures are needed to make the data collection work? - How will the work be managed to ensure quality control? - How will the team and others be kept up to date with progress? - How will data be analysed and interpreted?	- What routes lead scientific data to being used as evidence and applied? - What format does the data need to be in for a quality review? - What's required to justify any proposal based on the findings?	- Has the aim been achieved? - Do the benefits outweigh the costs? - What worked well and what can be improved? - What strategic actions need to occur for this to continue?
Collaboration questions to consider	- Who are the end-users and knowledge providers that need to be involved? - What understanding and expectations do people have? - Is the aim agreed and understood? - What core values are needed to make the collaboration work? - Who needs to be on the project team?	- How to motivate industry's participation? - Who needs to be involved and how? - What feedback mechanisms are needed? - What working practices can meet the needs of the science? - What research tools might help co-delivery? - What communications will strengthen collaboration?	- How can we build shared knowledge and skills? - Why is it a good idea for scientists to be on-board fishing vessels whenever possible? - How do we keep a focus on getting the job done to the required standard?	- How do we gain the support of relevant managers and other stakeholders? - What needs to be communicated about the process and outcomes? - Why is important to give visibility to fishermen's contributions and how they have been used?	- How did the collaboration process go? - What was the value and benefit of co-construction? - Why should we give credit where it is due? - What should the group do next?

FIGURE 3 Summary overview of the step-by-step data collection protocol showing the parallel science and collaboration processes, accompanied by the key questions to consider at each stage [Colour figure can be viewed at wileyonlinelibrary.com]

robust scientific evidence, but also to empower fishers to collect relevant data. Industry–science data collections also need to portray the full spectrum of potential contribution ranging from fishers providing information to scientists, to collaboration in research, through to governance arrangements in which fishers contribute knowledge and actively participate in research and management (Mackinson & Middleton, 2018; Mackinson, Wilson, Galiay, & Deas, 2011; Mackinson et al., 2017; Stephenson et al., 2016). The data collection protocol describes the essentials of what it takes to co-design and co-deliver industry–science initiatives, helping to identify those people and institutions that should be involved, and the roles they need to play. Consideration should be made on how to motivate people's participation by identifying the drivers and incentives that resonate with them. The step-by-step process also involves planning for joint learning and training activities that develop shared understanding, and getting the support of managers and other stakeholders, and making effective communication with a wider audience. The evaluation phase (Stage 5) is meant to look critically at the results and the process and use this learning when planning new initiatives. While focusing on fisheries data collection, the guidance is not restricted to the process of gathering scientific information required for stock assessment. It is equally relevant to research on understanding the biology and ecology of species and behaviour of fisheries.

4.2 | Applying the data collection protocol

To demonstrate how the stages from the data collection protocol can be applied to collect data and feed into a management system, the scientific and governance pathways, developed by the Spurdog By-catch Avoidance Programme, were applied retrospectively (Figure 4). Other examples are provided in the data collection protocol (www.fishingintothefuture.co.uk/industry-science-and-data/survey-protocol-guidelines/). The Spurdog By-catch Avoidance Programme was a science-industry trial to monitor, avoid and reduce spurdog bycatch. Its objective was to develop and evaluate an alternative option to the prohibition of spurdog and prevent a "choke" to UK fisheries under the CFP landing obligation. Although spurdog is a prohibited species, it is caught in demersal trawl and gillnet fisheries within European waters. Due to its status, current catches of spurdog are discarded, although the extent of this problem is unknown. The new CFP introduced a landing obligation with a phased implementation from 2015. Previously, spurdog was a zero TAC species, meaning it had the potential to become choke species in mixed fisheries, whereby it forces fishers to stop fishing altogether and tie-up their vessels in areas where spurdog is caught as bycatch. The recent (2017) addition of spurdog to the prohibited species list has prevented it from becoming a choke species, in effect opting out of fisheries legislation, ensuring that discarding can continue. However, this is not in the spirit of the landings obligation, as it does not contribute to the reduction in fishing pressure of the stock and does not address wasteful dead discarding.

Based on fisheries-dependent scientific evidence (Bendall et al., 2014; Hetherington et al., 2016), a collaborative research partnership between government policy advisors, scientists, the fishing industry and an environmental non-governmental organization (eNGO) informed the development and trial of the real-time avoidance of

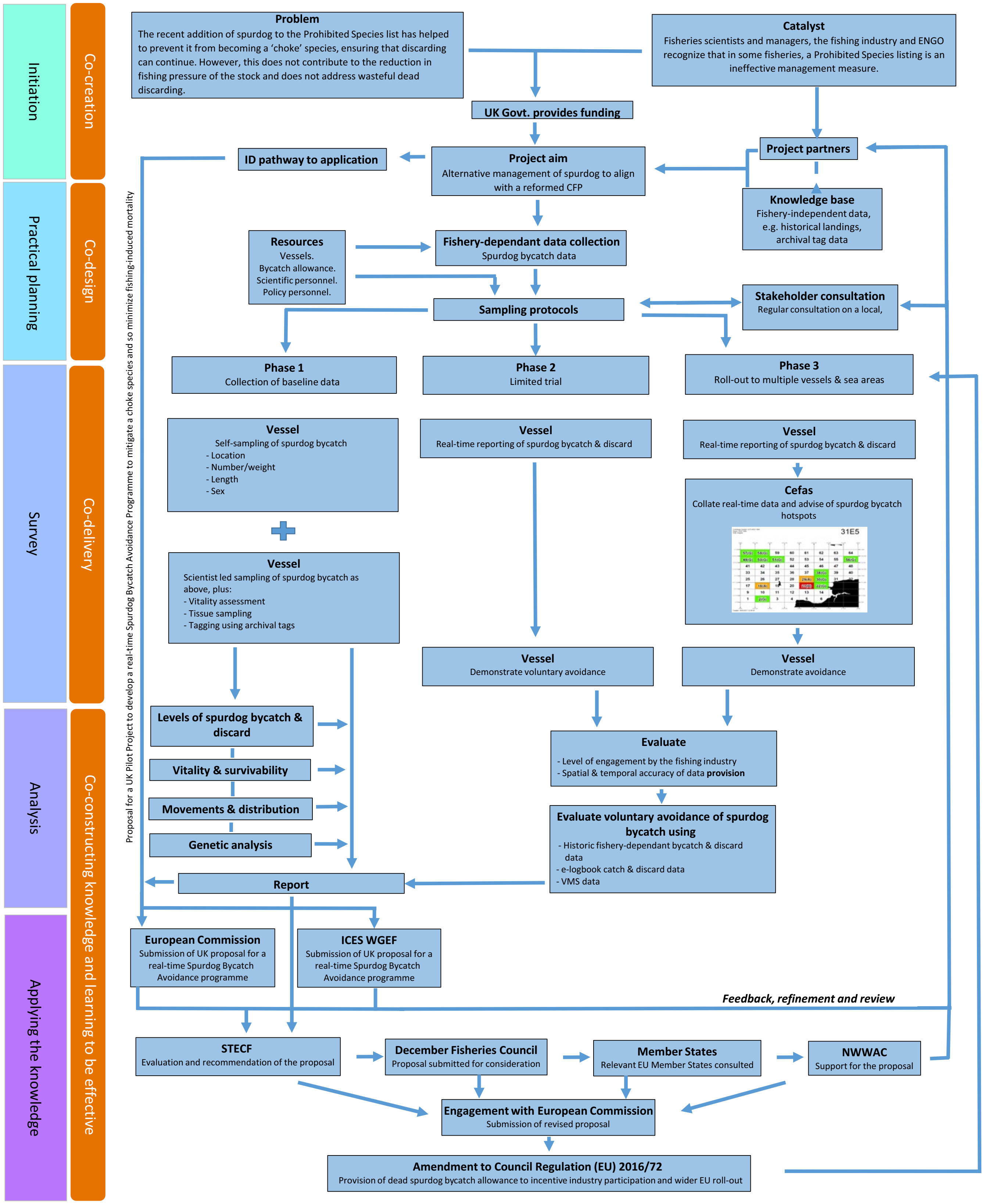

FIGURE 4 Architecture of the development, trail and evaluation of the real-time Spurdog bycatch avoidance programme demonstrating how the data collection guidelines can be applied to generate data and information for management [Colour figure can be viewed at wileyonlinelibrary.com]

spurdog. Through an ArcGIS online portal, fishers self-report their bycatch in real time by area. This information is compiled and reported back to fishers using a traffic light system with red (high risk of spurdog bycatch), amber (medium risk of significant bycatch) and green (low risk of significant bycatch). This empowers the fishers to make informed fishing behaviour decisions in real-time, enabling active avoidance of recent bycatch “hotspots,” reducing spurdog bycatch, reducing fishing mortality and prevent choking the fishery. By utilizing data collected directly by the fishing industry, fishers are more likely to adapt their fishing behaviour to avoid spurdog bycatch as the evidence provided is based on their own observations. While the stakeholder engagement helps underpin future decisions on avoiding bycatches in key “hotspot” areas, facilitating a real-time understanding of the interaction between fishers and this threatened stock, the programme is assessing the feasibility of devolving management of spurdog bycatch to the fishing industry.

The initial phase of the programme has successfully demonstrated that a real-time spurdog bycatch reporting tool, together with a small dead spurdog bycatch allowance, offers a real and probable alternative to an immediate Prohibited Species listing for spurdog, thereby providing a pragmatic solution to align spurdog with the CFP landing obligation (Hetherington et al., 2016). Through continued positive engagement with the European Commission, a strong UK Government policy lead, supported by two positive, but cautious reviews of the Spurdog By-catch Avoidance Programme by Scientific, Technical and Economic Committee for Fisheries (STECF) (STECF, 2014, 2015) led to fishing vessels participating in the project to land limited quantities of dead spurdog, with a precautionary annual limit of 270 tonnes (UK allocation of 100 tonnes), with a vessel monthly limit of 2 tonnes. This incentivized industry participation in the programme, allowing for a comprehensive trial for evaluation.

5 | HOW UK PROGRESS COMPARES TO OTHER COUNTRIES

While the tide is slowly turning to be more supportive of industry–science initiatives in the UK, there is no overarching policy from science, management or end users that seeks to create and promote the conditions to initiate and implement such activities. What exists is a collection of learning-by-doing cases, each seeking to solve locally relevant issues. Systematic and institutional support for industry–science needs to come from the organizations that have statutory responsibility for collected data, its quality control and application (Mackinson & Middleton, 2018). Such a situation is better reflected in East coast USA, and in New Zealand and Australia where dedicated programmes for industry–science initiative fall under the auspices of science and management agencies. For example, the NOAA Fisheries National Cooperative Research Program was set up through congressional funding to provide a means for commercial and recreational fishers to become involved in the collection of fundamental fisheries information to support the development and evaluation of management options. Through this programme, the industry and other stakeholders can partner with NOAA fisheries and university scientists, in all phases of the research programme, including survey/statistical design, conducting of research, analysis of results, and communication of results (https://www.st.nmfs.noaa.gov/cooperative-research/index).

Similarly, in New Zealand the Trident Systems, a limited partnership funded by its partners together with Seafood Innovations Limited, aims to provide high-quality research services supporting the effective and efficient management of New Zealand’s fisheries for long-term sustainable use. Trident Systems’ research and development programme focuses on the delivery of stock-specific services with the work carried out in collaboration with several independent research providers including the Ministry for Primary Industries (http://www.tridentsystems.co.nz/). Its purpose is to (i) develop innovative systems and processes, including for efficient data collection for fisheries management, especially from inshore finfish fisheries; (ii) apply these systems and processes to provide stock and/or fishery-specific research services that support timely and efficient fisheries management decision-making; (iii) carry out these activities in a manner that efficiently utilizes industry resources, and supports industry involvement in fisheries management processes; and (iv) ensure a broad base of industry commitment to the development of its systems and processes, and the utilization of the results of applying these systems and processes.

In Australia, the Fisheries Research and Development Corporation (FRDC) is a co-funded partnership between the Australian Government and the fishing and aquaculture sectors (http://www.frdc.com.au/About-us). It was formed as a statutory corporation in 1991, under the provisions of the Primary Industries Research and Development Act 1989 and is responsible to the Minister of Agriculture and Water Resources. The FRDC’s role is to plan and invest in fisheries research, development and extension activities and provide leadership and coordination of the monitoring, evaluating and reporting including facilitating dissemination, extension and commercialization. Although FRDC works with a diverse and geographically dispersed group of stakeholders, the key ones are aquaculture, commercial fishing, indigenous fishing and recreational fishing sectors.

In Europe, The Netherlands, Denmark and Norway have ongoing programmes where scientists are working closely with industry on routine data collection programmes. For example, the Dutch self-sampling programme coordinated by the Institute for Marine Resources and Ecosystem Studies (IMARES) undertakes discards monitoring in close collaboration with the Dutch fishing industry (Kraan et al., 2013). Within this project, a reference fleet of vessel owners, willing to participate in a self-sampling programme, has been recruited to provide key evidence to support management of discarding practices. In 2013, the reference fleet consisted of 23 vessels. Similarly, the Norwegian reference fleet, funded through an annual quota set aside for the Institute of Marine Research (IMR), comprises of 20 vessels in the coastal demersal, 11 vessels in the offshore demersal, two vessels in the coastal pelagic and five vessels in the offshore pelagic fisheries that systematically delivers assessment ready data on a range of stocks (Bowering et al., 2011; Nedreaas, Borge, Godoy, & Aanes, 2006; Pennington & Helle, 2011). The Norwegian reference fleet is a source of information and data to a range of stakeholders including the Institute of Marine Research (IMR), the Ministry of Fisheries and Coastal affairs (FKD), the Directorate of Fisheries (FDIR), the National Institute of Nutrition and Seafood Research (NIFES), the International Council for the Exploration of the Sea (ICES), and the Norwegian Fishermen Organization (Norges Fiskarlag).

Recent appointments of former government scientists by the demersal and pelagic industry sectors from several EU countries and Norway demonstrate industry's commitment to professionalism in undertaking their role within the established systems that collect and make use of scientific data. For instance, in a landmark development, the representative association for Scotland's mackerel and herring fishers appointed a chief scientific officer to spearhead marine research to boost understanding of key pelagic fish stocks and improve their management (http://www.scottishpelagic.co.uk/). This appointment by the Scottish Pelagic Fishermen's Association (SPFA) represents an innovative new approach to fisheries management where fishing vessels will play a significant role in collecting and disseminating scientific information on fish stocks.

The programmes and initiatives described above demonstrate how global marine environmental governance and the management of fisheries during the last decade have been building opportunities for scientists, fishers, policymakers and stakeholders to communicate, negotiate and work together (Johnson, 2007; Neis & Felt, 2001; Reid & Hartley, 2006). They also indicate growing efforts in the mainstreaming of fishing industry generated data for fisheries and marine science evidence and decision-making. While the objectives of the initiatives vary, they all endeavour to provide legitimacy and equitable management, cost-efficient research, and more efficient enforcement due to higher legitimacy among stakeholders. The expansion of the programmes shows that it takes a structured and balanced approach to mobilize key actors by matching their strategic interests and indicates that collaborative research is one principle route to providing data and information for evidence-based decision-making. These initiatives encompass a model for data provision that could be routinely adopted to overcome some of the funding limitations and short-term nature of current industry-led data collection projects.

6 | CONCLUSION

This study was undertaken to address the increasing need for a strategic approach to industry–science data collections in the face of reducing resources and growing need for evidence in fisheries management and marine environmental monitoring. The aim was to evaluate progress in the development of plans and procedures that can be employed to collect, record and use fishing industry knowledge and data in the evidence base for managing fisheries and marine ecosystems. Here, opportunities where fishers could cooperate in the collection of data towards a comprehensive monitoring programme have been identified and matched with the needs of monitoring agencies. Further, guidelines for data collection, as well as the management and administration of the use of the data (i.e. storage, ownership and accessibility of the data) that is subsequently collected have been described. There are still barriers to achieving a routine industry–science data collection scheme that feeds data into stock assessment and management advice. These include cultural challenges (e.g. where monitoring schemes and stock assessments are not yet flexible enough to utilize fisheries-dependent data) and lack of resources (both financial and organizational) to adequately fund and run such programmes and uncertainty around the long-term commitment to collecting these data. However, the research conducted here has addressed some of the technical and capacity barriers to enable the fishing industry to perform a key role in addressing data gaps in the science and management of fisheries. If fishers can be supported to collect the right data, about the right fisheries, and in the right way, then current data shortages could be overcome.

Our research also addresses issues of fishers-science interactions, engagement and collaborative efforts that could be used to improve trust and relationships. The need for collaboration as well as addressing the practical aspects of data collection mean that the roles people play and the way they interact with one another are key to determining success in industry–science initiatives. At the same time, the twin processes of developing the scientific rigour and content are inseparable. These twin-strands of practical science (i.e. defining the aims, requirements, design and process for the actual data collection) and the collaborative process (i.e. establishing a framework for how the industry and scientists will work together to co-create, co-design, co-deliver and con-construct the knowledge harvested from the research) are mutually supportive. Indeed, the engagement process is unique to collaborative industry–science research while the practical design is relevant to any kind of data collection, and therefore, the two processes should run in parallel. Careful attention is therefore needed on how to work together effectively and respectfully.

A wide range of scientific information that could reasonably be collected by the fishing industry within their normal activities has been identified and matched with advice/policy data needs. For each of the suggested data types, there were fishers able to provide such information and data users interested in obtaining the said information. The industry proposed to assist in collection of most if not all data types, but information directly related to the fishery such as fish stocks, biodiversity from fishing activities, fisheries activity and fisheries acoustics was readily obtainable by many of the fishers. Opportunities to maximize the impact of industry–science data collection scheme in the areas of fisheries mean much more detailed discussions between specific fisheries and stock assessment scientists are necessary. Advice could focus on areas of high assessment priority which could also have a beneficial outcome for the industry. These include data collections on data-poor species managed on a highly precautionary basis, especially those that may act as choke species as the landing obligation is further implemented. Widely distributed species with changing distributions that complicate the attribution of landings to stock and areas provide further opportunities. In contrast to stock assessments, environmental assessments are less specific. Such data collections could be applied more generally across an ecoregion with fewer concern over the appropriateness of the spatial range of collections and differences in fishing practices.

ACKNOWLEDGEMENTS

This research was funded by the (i) Celtic Seas Partnership (CSP) through the Fishing-4-data initiative on informing the scope of the Celtic Seas fishery stakeholder data collection strategy; (ii) Department of Environment, Food and Rural Affairs (Defra) through the Fisheries Science Partnership (FSP); and (iii) Fishing into the Future (FITF) through a grant from the Seafish Strategic Investment Fund (SIF). We would like to thank the Scottish Pelagic Fishermen's Association (SPFA) for supporting one of the authors. Special thanks to the respondents who took part in the online survey and the workshop participants for their thorough, productive and engaging discussions.

ORCID

Stephen C Mangi http://orcid.org/0000-0001-8233-2612
Dale Rodmell http://orcid.org/0000-0002-0879-7822
David Righton http://orcid.org/0000-0001-8643-3672

REFERENCES

Agardy, T., Bridgewater, P., Crosby, M. P., Day, J., Dayton, P. K., Kenchington, R., … Peau, L. (2003). Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *13*, 353–367. https://doi.org/10.1002/aqc.583

Anseeuw, D., Moreau, K., Vandemaele, S., & Vandendriessche, S. (2008). *Discarding in beam trawl fisheries: quantification and reduction (preliminary results).* ILVO Report, Oostende, Belgium.

Apitz, S. E., Carlon, C., Oen, A., & White, S. (2007). Strategic frameworks for managing sediment risk at the basin and site-specific scale. *Sustainable Management of Sediment Resources*, *3*, 77–106. https://doi.org/10.1016/S1872-1990(07)80064-X

Apitz, S. E., Elliott, M., Fountain, M., & Galloway, T. S. (2006). European environmental management: Moving to an ecosystem approach. *Integrated Environmental Assessment and Management*, *2*, 80–85. https://doi.org/10.1002/ieam.5630020114

Armstrong, M. J., Payne, A. I. L., Deas, B., & Catchpole, T. L. (2013). Involving stakeholders in the commissioning and implementation of fishery science projects: Experiences from the UK Fisheries Science Partnership. *Journal of Fish Biology*, *83*, 974–996. https://doi.org/10.1111/jfb.12178

Bell, E. (2013). *Under-10 m automated shellfish data collection pilot study.* MF1226 Cefas Report, 15 pp.

Bendall, V. A., Carson, N., Cragg, A., Hetherington, S. J., McGregor, K., O'Brien, C., … Rendall, J. (2014). *Proposal for UK Pilot Project to develop real-time Spurdog By-catch Avoidance Programme to mitigate choke species and so minimise fishing induced mortality.* Working document submitted to the Scientific, Technical and Economic Committee for Fisheries (STECF) – 47th Plenary Meeting.

Borja, A. (2005). The European Water Framework Directive: A challenge for nearshore, coastal and continental shelf research. *Continental Shelf Research*, *25*, 1768–1783. https://doi.org/10.1016/j.csr.2005.05.004

Bowering, R., Storr-Paulsen, M., Tingley, G., Bjorkan, M., Volstad, J. H., Gullestad, P., & Lorentsen, E. L. (2011). *Evaluation of the Norwegian Reference Fleet*. Retrieved from http://www.imr.no/filarkiv/2011/10/evaluation_of_the_norwegian_reference_fleet_final_report_august_2011_final_rev_logo.pdf/en

Caslake, R., Kingston, A., Lart, W., & Searle, A. (2002). *Monitoring of discarding and retention by trawl fisheries in Western Waters by the use of fisher self-sampling*. MF806 Defra Report, 32 pp.

Catchpole, T. L., Enever, R., Maxwell, D. L., Armstrong, M. J., Reese, A., & Revill, A. S. (2011). Constructing indices to detect temporal trends in discarding. *Fisheries Research*, *107*, 94–99. https://doi.org/10.1016/j.fishres.2010.10.012

Catchpole, T. L., Revill, A. S., & Dunlin, G. (2006). An assessment of the Swedish grid and square-mesh codend in the English (Farn Deeps) *Nephrops* fishery. *Fisheries Research*, *81*, 118–125. https://doi.org/10.1016/j.fishres.2006.08.004

Catchpole, T. L., Ribeiro-Santos, A., Mangi, S. C., Hedley, C., & Gray, T. S. (2017). The challenges of the landing obligation in EU fisheries. *Marine Policy*, *82*, 76–86. https://doi.org/10.1016/j.marpol.2017.05.001

Christensen, V., Guénette, S., Heymans, J. J., Walters, C. J., Watson, R., Zeller, D., & Pauly, D. (2003). Hundred-year decline of North Atlantic predatory fishes. *Fish and Fisheries*, *4*, 1–24. https://doi.org/10.1046/j.1467-2979.2003.00103.x

Combes, J., & Lart, W. (2007). *Clyde Environment and Fisheries Review and Sustainable Supply Chain Project Report*. Clyde Fisheries Development Group, 202 pp.

Depestele, J., Polet, H., Van Craeynest, K., & Vandendriessche, S. (2008). *A compilation of length and species selectivity improving alterations to beam trawls.* ILVO Report, Oostende, Belgium.

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Jason, M. J., … Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*, 291–297. https://doi.org/10.1890/110236

Dorner, H., Graham, N., Bianchi, G., Bjordal, A., Frederiksen, M., Karp, W. A., … Gudbrandsen, N. H. (2015). From cooperative data collection to full collaboration and co-management: A synthesis of the ICES symposium on fishery-dependent information. *ICES Journal of Marine Science*, *72*, 1133–1139. https://doi.org/10.1093/icesjms/fsu222

Ducrotoy, J. P., & Elliott, M. (1997). Interrelations between science and policy-making: The North Sea example. *Marine Pollution Bulletin*, *34*, 686–701. https://doi.org/10.1016/S0025-326X(97)00118-5

EC (2008). *European Commission Council Regulation (EC) No 199/2008 of 25 February 2008 concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy.*

Elliott, M., Fernandes, T., & de Jonge, V. (1999). The impact of recent European directives on estuarine and coastal science and management. *Aquatic Ecology*, *33*, 311–321. https://doi.org/10.1023/A:1009960706750

Ellis, J. R., Bendall, V. A., Hetherington, S. J., Silva, J. F., & McCully Phillips, S. R. (2015). *National Evaluation of Populations of Threatened and Uncertain Elasmobranchs (NEPTUNE).* Project Report (Cefas), 105 pp.

Enever, R., Revill, A. S., Caslake, R., & Grant, A. (2010). Discard mitigation increases skate survival in the Bristol Channel. *Fisheries Research*, *102*, 9–15. https://doi.org/10.1016/j.fishres.2009.09.013

Frid, C. J. L., Paramor, O. A. L., & Scott, C. L. (2006). Ecosystem-based management of fisheries: Is science limiting? *ICES Journal* *of Marine Science*, *63*, 1567–1572. https://doi.org/10.1016/j.icesjms.2006.03.028

Graham, N., Grainger, R., Karp, W. A., MacLennan, D. N., MacMullen, P., & Nedreaas, K. (2011). An introduction to the proceedings and a synthesis of the 2010 ICES Symposium on Fishery-Dependent Information. *ICES Journal of Marine Science*, *68*, 1593–1597. https://doi.org/10.1093/icesjms/fsr136

Greenstreet, S. P. R., & Rogers, S. I. (2006). Indicators of the health of the North Sea fish community: Identifying reference levels for an ecosystem approach to management. *ICES Journal of Marine Science*, *63*, 573–593. https://doi.org/10.1016/j.icesjms.2005.12.009

Hetherington, S. J., Nicholson, R. E., & O'Brien, C. M. (2016). *Spurdog By-Catch Avoidance Programme*. Final report. 52 pp.

Hoare, D., Graham, N., & Schon, P. J. (2011). The Irish sea data-enhancement project: Comparison of self-sampling and national data-collection programmes – results and experiences. *ICES Journal of Marine Science*, *68*, 1778–1784. https://doi.org/10.1093/icesjms/fsr100

Holm, P., Hadjimichael, M., Linke, S., & Mackinson, S. (Eds.) (2018). *Collaborative research in fisheries: Co-creating knowledge for fisheries governance in Europe*. Berlin, Germany: Springer Books (in Press).

Hunter, E., Hetherington, S., Ross, E., Scutt Phillips, J., Nicholson, R., Borrow, K., … Bendall, V. (2016). *Shark By-watch UK 2. Understanding by-catch of elasmobranchs in UK waters: A nationwide programme, a regional approach*. Final project report.

ICES (2017). *Report of the ICES Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3–6* (WKLIFEVI), 3–7 October 2016, Lisbon, Portugal. ICES CM 2016/ACOM:59. 106 pp.

Jennings, S. (2005). Indicators to support an ecosystem approach to fisheries. *Fish and Fisheries*, *6*, 212–232. https://doi.org/10.1111/j.1467-2979.2005.00189.x

Johnson, T. R. (2007). *Integrating fishermen and their knowledge in the science policy process: case studies of cooperative research in the North-Eastern U.S.* Dissertation: Rutgers University.

Johnson, T. R., & van Densen, W. L. T. (2007). The benefits and organization of cooperative research for fisheries management. *ICES Journal of Marine Science*, *64*, 834–840. https://doi.org/10.1093/icesjms/fsm014

Kraan, M., Uhlmann, S., Steenbergen, J., Van Helmond, A. T. M., & Van Hoof, L. (2013). The optimal process of self-sampling in fisheries: Lessons learned in the Netherlands. *Journal of Fish Biology*, *83*, 963–973. https://doi.org/10.1111/jfb.12192

Large, P. A., Agnew, D. A., Pérez, J. A. A., Frojána, C. B., Cloete, R., Damalas, D., Dransfeld, L., …. González, F. (2013). Strengths and weaknesses of the management and monitoring of deep-water stocks, fisheries, and ecosystems in various areas of the world - a roadmap toward sustainable deep-water fisheries in the Northeast Atlantic? *Reviews in Fisheries Science*, *21*, 157–180. https://doi.org/10.1080/10641262.2013.785475

Littell, J. S., McKenzie, D., Kerns, B. K., Cushman, S., & Shaw, C. G. (2011). Managing uncertainty in climate driven ecological models to inform adaptation to climate change. *Ecosphere*, *2*, 1–99. https://doi.org/doi:10.1890/es11-00114.1

Lordan, C., Cuaig, M. O., Graham, N., & Rihan, D. (2011). The ups and downs of working with industry to collect fishery-dependent data: The Irish experience. *ICES Journal of Marine Science*, *68*, 1670–1678. https://doi.org/10.1093/icesjms/fsr115

MacGarvin, M. (2014). *Project Fishface*. Modus Vivendi Report, 26 pp.

Mackinson, S., Mangi, S., Hetherington, S., Catchpole, T., & Masters, J. (2017). *Guidelines for Industry-Science Data Collection: Step-by-step guidance to gathering useful and useable scientific information*. Fishing into the Future report to Seafish. 65p.

Mackinson, S., & Middleton, D. (2018). Evolving the ecosystem approach in European fisheries: Transferable lessons from New Zealand's experience in strengthening stakeholder involvement. *Marine Policy*, *90*, 194–202. https://doi.org/10.1016/j.marpol.2017.12.001

Mackinson, S., Neville, S., Raicevich, S., & Clausen, W. L. (Eds.) (2008). *Good practice guide to participatory research between fisheries stakeholders and scientists*. GAP project deliverable 1, 23 pp.

Mackinson, S., Raicevich, S., Kraan, M., Magudia, R., & Borrow, K. (Eds.) (2015). *Good practice guide: Participatory Research in Fisheries Science*. Retrieved from http://gap2.eu/outputs/pr-handbook/

Mackinson, S., & Wilson, D. C. K. (2014). Building bridges among scientists and fishermen with participatory action research. In J. Urquart, T. Acott, D. Symes & M. Zhao (Eds.), *Social issues in sustainable fisheries management* (pp. 121–137). Dordrecht, The Netherlands: Springer. https://doi.org/10.1007/978-94-007-7911-2

Mackinson, S., Wilson, D. C., Galiay, P., & Deas, B. (2011). Engaging stakeholders in fisheries and marine research. *Marine Policy*, *35*, 18–24. https://doi.org/10.1016/j.marpol.2010.07.003

Mangi, S. C., Dolder, P. J., Catchpole, T. L., Rodmell, D., & de Rozarieux, N. (2015). Approaches to fully documented fisheries: Practical issues and stakeholder perceptions. *Fish and Fisheries*, *16*, 426–452. https://doi.org/10.1111/faf.12065

Mangi, S. C., Smith, S., & Catchpole, T. L. (2016). Assessing the capability and willingness of skippers towards fishing industry-led data collection. *Ocean and Coastal Management*, *134*, 11–19. https://doi.org/10.1016/j.ocecoaman.2016.09.027

McCully, S. R., Scott, F., Ellis, J. R., & Pilling, G. M. (2013). Productivity and susceptibility analysis: Application and suitability for data poor assessment of elasmobranchs in northern European seas. *International Commission for the Conservation of Atlantic Tunas (ICCAT)*, *69*, 1679–1698.

MMO (2013). *Catch Quota Trials 2012:* Marine Management Organisation Final report. Retrieved from www.marinemanagement.org.uk/fisheries/management/quotas_cqt.htm

MRAG (2010). *Towards sustainable fisheries management: International examples of innovation* (p. 93). London: MRAG Ltd.

Nedreaas, K. H., Borge, A., Godoy, H., & Aanes, S. (2006). *The Norwegian reference fleet: co-operation between fishermen and scientists for multiple objectives*. ICES CM 2006/N: 05 12 pp.

Needle, C. L., & Catarino, R. (2011). Evaluating the effect of real-time closures on cod targeting. *ICES Journal of Marine Science*, *68*, 1647–1655. https://doi.org/10.1093/icesjms/fsr092

Neis, B., & Felt, L. (2001). *Finding our sea legs: Linking fishery people and their knowledge with science and management*. St. John's: ISER Books.

Parkes, G., Young, J. A., Walmsley, S. F., Abel, R., Harman, J., Horvat, P., … Nolan, C. (2010). Behind the signs - a global review of fish sustainability information schemes. *Reviews in Fisheries Science*, *18*, 344–356. https://doi.org/10.1080/10641262.2010.516374

Payne, M. R., Barange, M., Cheung, W. W. L., MacKenzie, B. R., Batchelder, H. P., Cormon, X., … Paula, J. (2016). Uncertainties in projecting climate-change impacts in marine ecosystems. *ICES Journal of Marine Science*, *73*, 1272–1282. https://doi.org/10.1093/icesjms/fsv231

Pennington, M., & Helle, K. (2011). Evaluation of the design and efficiency of the Norwegian self-sampling purse-seine reference fleet. *ICES Journal of Marine Science*, *68*, 1764–1768. https://doi.org/doi:10.1093/icesjms/fsr018

Perry, A. L., Low, P. J., Ellis, J. R., & Reynolds, J. D. (2005). Climate change and distribution shifts in marine fishes. *Science*, *308*, 1912–1915. https://doi.org/10.1126/science.1111322

Pikitch, E. K., Santora, C. E., Babcock, A., Bakun, A., Bonfil, R., Conover, D. O., … Sainsbury, K. J. (2004). Ecosystem-based fishery management. *Science*, *305*, 346–347. https://doi.org/10.1126/science.1098222

Pilling, G. M., Apostolaki, P., Failler, P., Floros, C., Large, P. A., Morales-Nin, B., … Tsikliras, A. C. (2008). Assessment and management of data-poor fisheries. In A. Payne, J. Cotter & T. Potter (Eds.), *Advances in fisheries science: 50 years on from Beverton and Holt*

(pp. 280–305). Hoboken, NJ: Blackwell Publishing. https://doi.org/10.1002/9781444302653
Pita, P., Fernández-Vidal, D., García-Galdo, J., & Muino, R. (2016). The use of the traditional ecological knowledge of fishermen, cost-effective tools and participatory models in artisanal fisheries: Towards the co-management of common octopus in Galicia (NW Spain). *Fisheries Research*, *178*, 4–12. https://doi.org/10.1016/j.fishres.2015.07.021
Read, S., Elliott, M., & Fernandes, T. (2001). The possible implications of the water framework directive and the species and habitats directive on the management of marine aquaculture. In R. Pea (Ed.), *The implications of directives, conventions and codes of practice on the monitoring and regulation of marine aquaculture in Europe (MARAQUA)* (pp. 58–74). Aberdeen (UK): Fisheries Research Services.
Reid, A. N., & Hartley, T. W. (Eds.) (2006). *Partnership for a common purpose: Cooperative Fisheries Research and Management*. *American Fisheries Society Symposium 52*. Proceedings of the Symposium Fisheries Society/Sea Grant Symposium Partnerships for a Common Purpose: Cooperative Fisheries Research and Management held in Anchorage, Alaska, U.S.A., 13–14 September 2005. Bethesda: American Fisheries Society.
Revill, A., Dunlin, G., & Holst, R. (2006). Selective properties of the cutaway trawl and several other commercial trawls used in the Farne Deeps North Sea *Nephrops* fishery. *Fisheries Research*, *81*, 268–275. https://doi.org/10.1016/j.fishres.2006.06.017
Rice, J. (2005). Bringing experiential knowledge into fisheries science advisory processes: Lessons learned from the Canadian experience of participatory governance. In T. S. Gray (Ed.), *Participation in fisheries governance* (pp. 249–268). Dordrecht, The Netherlands: Springer. https://doi.org/10.1007/1-4020-3778-3
Roberts, J., Course, G., Pasco, G., & Sandeman, L. (2015). *Catch Quota Trials - South West Beam Trawl*. Marine Management Organisation Report, 22 pp.
Rochet, M.-J., Catchpole, T., & Cadrin, S. (2014). Bycatch and discards: From improved knowledge to mitigation programmes. *ICES Journal of Marine Science*, *71*, 1216–1218. https://doi.org/10.1093/icesjms/fsu039
Roman, S., Jacobson, N., & Cadrin, S. X. (2011). Assessing the reliability of fisher self-sampling programs. *North American Journal of Fisheries Management*, *31*, 165–175. https://doi.org/10.1080/02755947.2011.562798
Rossiter, T. (2016). *Fully Documented Fisheries Pilot Project - Welsh whelk fishery*. Welsh Government Report, 14 pp.
Sale, P. F., Cowen, R. K., Danilowicz, B. S., Jones, G. P., Kritzer, J. P., Lindeman, K. C., ... Steneck, R. S. (2005). Critical science gaps impede use of no-take fishery reserves. *Trends in Ecology and Evolution*, *20*, 74–80. https://doi.org/10.1016/j.tree.2004.11.007
Sampson, D. B. (2011). The accuracy of self-reported fisheries data: Oregon trawl logbook fishing locations and retained catches. *Fisheries Research*, *112*, 59–76. https://doi.org/10.1016/j.fishres.2011.08.012
Schläppy, M.-L., Loder, J., Salmond, J., Lea, A., Dean, A. J., & Roelfsema, C. M. (2017). Making Waves: Marine citizen science for impact. *Frontiers in Marine Science*, *4*, 146. https://doi.org/10.3389/fmars.2017.00146
Sheltona, A. O., & Marc Mangela, M. (2011). Fluctuations of fish populations and the magnifying effects of fishing. *PNAS*, *108*, 7075–7080. https://doi.org/10.1073/pnas.1100334108
Sherman, K., Sissenwine, M., Christensen, V., Duda, A., Hempel, G., Ibe, C., ... Zwanenburg, K. (2005). A global movement toward an ecosystem approach to management of marine resources. *Marne Ecology Progress Series*, *300*, 241–296. https://doi.org/10.3354/meps300275
Simmonds, E. J., Doring, R., Daniel, P., & Angot, V. (2011). The role of fisheries data in the development evaluation and impact assessment in support of European fisheries plans. *ICES Journal of Marine Science*, *68*, 1689–1698. https://doi.org/10.1093/icesjms/fsr067
Simpfendorfer, C., Cortés, E., Heupel, M., Brooks, E., Babcock, E., Baum, J., ... Soldo, A. (2011). *An integrated approach to determining the risk of over-exploitation for data-poor pelagic Atlantic sharks*. Report of an expert working group held June 3–6 2008 in Washington DC. 15 pp.
STECF (Scientific, Technical and Economic Committee for Fisheries) (2014). *47th Plenary Meeting Report (PLEN-14-03)*. Publications Office of the European Union, Luxembourg, EUR 26944 EN, JRC 93037, 138 pp.
STECF (Scientific, Technical and Economic Committee for Fisheries) (2015). *50th Plenary Meeting Report (PLEN-15-03)*. Publications Office of the European Union, Luxembourg, EUR 27602 EN, JRC 98672, 90 pp.
Stephenson, R. L., Paul, S., Pastoors, M. A., Kraan, M., Holm, P., Wiber, M., ... Benson, A. (2016). Integrating fishers' knowledge research in science and management. *ICES Journal of Marine Science*, *73*, 1459–1465. https://doi.org/10.1093/icesjms/fsw025
Stram, D. L., & Ianelli, J. N. (2015). Evaluating the efficacy of salmon bycatch measures using fishery-dependent data. *ICES Journal of Marine Science*, *72*, 1173–1180. https://doi.org/10.1093/icesjms/fsu168
Thompson, S., & Stephenson, R. L. (Eds.) (2016). *Canadian Fisheries Research Network*: Final report of NSERC Strategic Network Grant NETGP 389436-09.
Tully, O., Robinson, M., O'Keefe, E., Cosgrove, R., Doyle, O., & Lehane, B. (2006). *The Brown Crab (Cancer pagurus L.) Fishery: Analysis of the resource in 2004–2005*. Fisheries Resource Series, 4. Irish Sea Fisheries Board, 48 pp.
Uhmann, S. S., Bierman, S. M., & van Helmond, A. T. M. (2011). A method of detecting patterns in mean lengths of samples of discarded fish, applied to the self-sampling programme of the Dutch bottom-trawl fishery. *ICES Journal of Marine Science*, *68*, 1712–1718. https://doi.org/10.1093/icesjms/fsr066
Woo, J., Rossiter, T., & Woolmer, A. (2013). *Lyme Bay Fully Documented Fisheries Trial*. Blue Marine Foundation report, 105 pp.

How to cite this article: Mangi SC, Kupschus S, Mackinson S, et al. Progress in designing and delivering effective fishing industry–science data collection in the UK. *Fish Fish*. 2018;00:1–21. https://doi.org/10.1111/faf.12279