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The road to incorporating Scottish pelagic industry data in science for stock assessments

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Fisheries data collection through industry-science partnerships have significant potential to support stock assessments and sustainable management, but few studies have described the steps taken *en route* to a successful partnership. This paper describes the development of the Scottish Pelagic Industry-Science Data Collection Programme; why and how it started, and what it has taken to develop a routine and consistent voluntary sampling regime of sufficient quality to become the main source of biological data on pelagic fish catches in Scotland. Using our experience, we emphasise the importance of establishing procedures that ensure the quality of methods and results, of working with institutions responsible for provision of national data, and of actively engaging with the International Council for the Exploration of the Sea (ICES) workshops and working groups on data quality, stock assessment and stakeholder engagement. The development of the programme has been, and remains to be, a mutual learning process which is reflected upon from our different institutional perspectives. The experience gained during this work has built knowledge useful for practitioners in other situations. Specifically, we identify five transferable design principles that we believe have been essential to success so far. Finally, we look at the steps ahead in our efforts toward continuous improvements.

KEYWORDS

collaborative research, stakeholder engagement, participatory research, fisheries science, data collection, co-creation, science-industry research collaboration, pelagic fisheries

1 Introduction

Strengthening the involvement of the fishing industry in the provision of data and experiential knowledge to support fisheries management is vogue (Stephenson et al., 2016; ICES, 2019; Steins et al., 2020; Holm et al., 2020; De Boois et al., 2021; Garmendia et al., 2021; Hart, 2021, Mangi et al., 2018; Steins et al., 2022). While the topic is far from new (Johannes, 1981; Neis, 1992; Neis et al., 1999; Neis and Felt, 2000; Haggan et al., 2007; Hind, 2015), recent proliferation in applications and debates is fuelled by new demands for

information to service the ecosystem approach, as well as professionalisation of the industry and moves toward more inclusive governance approaches in science and management.

In Europe, there has been a subtle, but important, shift in the language of Europe's Maritime Fisheries and Aquaculture Fund, where recent revisions opt for knowledge-based, rather than evidence-based, science and management (EU, 2021[1]). It is here where advocates for systematic inclusion of experiential knowledge and data provided voluntarily by the fishing industry (e.g. Mackinson, 2022a; Steins et al., 2022) find a natural home supportive of strengthening Science-Industry Research Collaboration (SIRC, *sensu* Steins et al., 2020). But the subject of how to operationalise a more knowledge-based approach frequently exposes concerns around the themes of legitimacy and credibility; including how potential conflicts-of-interest may influence the integrity of scientific and management processes and the quality of scientific information itself (e.g. Dickey-Collas and Ballesteros, 2019; Steins et al., 2022; Ballesteros and Dickey-Collas, 2023).

The work described here has been propelled by a growing momentum for strengthening stakeholder participation in science and management in the UK (Defra, 2011; Scottish Government, 2020; Seafood 2040, 2021), and internationally (Dörner et al., 2015; Thompson et al., 2019; Holm et al., 2020; Steins et al., 2022), with doors now more frequently open to collaborative science-industry initiatives. In particular, the Scottish Government Future of Fisheries Management Strategy 2020 - 2030 (Scottish Government, 2020) states:

> "Our overarching aim is to focus on collaboration and cooperation, not conflict and controversy….
> One of the ways we can do this is by increasing our openness and transparency around data, improving our evidence base and taking account of the range of knowledge that exists, in particular valuing the knowledge of fishers and others who work at sea, and using this to help."

This approach echoes the ambitions expressed across the UK in the recent Joint Fisheries Statement (Defra, 2022), which describes a vision for Participatory Decision Making:

> Section 3.4.1. "Our future vision is that industry should take a greater, shared responsibility for sustainably managing fisheries, while making a greater contribution towards the costs. This can include, for example, work to develop new management practices and contributing to fisheries science, being more actively engaged in fisheries management decisions, and co-designing future policy".
> And section 4.1.12, "A move to a more collaborative approach to fisheries management, as noted in section 3 above, will enable the fishing sector to contribute its information on activities and impacts to help co-design management actions. In taking such an approach, the fisheries policy authorities and fishing industry can work collectively to contribute to the delivery of the fisheries objectives."

For some scientists, eNGOs and managers, efforts to enhance industry's responsibility for science evidence provision are seen as an integral stepping-stone in the evolution of co-management initiatives because they build skills and capacity relevant to specific management needs (FitF, 2022a; Martin, 2022). However, UK government policies toward co-management (Defra, 2011; Scottish Government, 2020; Defra, 2022) will have a bearing on the appetite for, and speed of progress, in these developments.

The pelagic industry's motivation for a deeper and more systematic engagement with science stems from several related concerns and perspectives on the use of scientific information. The most pressing of these is the prospect of precautionary management[2] being applied when information on stocks is considered poor or insufficient to achieve a good quality stock assessment. For instance, the western herring stock (International Council for the Exploration of the Sea (ICES) divisions 6.a and 7.b-c) is a good example where, until recently, lack of information on stock identity meant ICES' precautionary approach was applied, resulting in a zero catch advice. Highly uncertain assessments, resulting from, for example, limitations in data availability or knowledge of stock structure, are intuitively associated with poor quality scientific advice, and not trusted. Quality and reliability of stock assessments also becomes a concern for industry when changes in scientific advice do not appear to match perceptions of changes observed at sea (e.g. Fishing News, 2021). Both of these situations lead to questions about the availability and quality of data, and how they are used to assess stock status. To help avoid limitations in data and make continuous quality improvements, the pelagic industry is supportive of maximising the use of all available data, whether collected by scientific institutes or by themselves (SPFA, 2019). As regular observers of changes at sea, fishers believe that their observations can serve as early warning indicators of change that could aid in the planning of scientific surveys and offer prior knowledge for stock forecasts that depend upon assumptions about current state.

Other, non-scientific, factors related to the business of pelagic fishing also play a role in motivating industry engagement with

1 The term knowledge-based is used in:-**Recital 25** "The European Maritime Fisheries and Aquaculture Fund should support an effective knowledge-based implementation and governance of the Common Fisheries Policy under direct and indirect management through the provision of scientific advice, regional cooperation on conservation measures, the development and implementation of a Union fisheries control system, the functioning of Advisory Councils and voluntary contributions to international organisations.-**Article 14**. Specific Objectives: (d) Fostering efficient fisheries control and enforcement, including fighting against Illegal Unreported and Unregulated fishing, as well as reliable data for knowledge-based decision-making.

2 A precautionary approach: as information becomes increasingly limited, more conservative reference points should be used and a further margin of precaution should be adopted when there is limited knowledge of the stock status.

science. Since the UK became an independent Coastal State in 2020, zonal attachment (the principle allocating quota according to the share of the stock residing within a particular country's economic zone) has become an important feature in negotiations regarding fishing access agreements in the Northeast Atlantic. Therefore, the need to be able to provide high quality evidence on stock structure and distribution is of immediate concern to fishers to help secure an equitable division of fishing quota (e.g. Gatt, 2019). Reputational issues are also an important driver for industry, including the understanding that involvement in scientific data collection is an outward demonstration of their sustainability credentials and support for responsible stewardship of pelagic fisheries.

Our contribution to the rapidly evolving topic of science industry research collaboration focusses on the development of the Scottish Pelagic Industry-Science Data Collection Programme, initiated by the Scottish pelagic industry. The principal driver for this was, and remains to be, industry's motivation to contribute to improvements in the quality and reliability of information used to support scientific advice on pelagic stocks in the Northeast Atlantic. Thus, the main purpose of the programme has been to enable fishers to be active contributors to a process of continuous improvement in the data and evidence that is used by ICES to assess and advise on the state of pelagic fish stocks. It relies on the voluntary participation of the Scottish pelagic trawler fleet; large (~75m), state-of-the-art vessels which mainly target herring, mackerel, and blue whiting, and comprises two parts. The first part, the *self-sampling scheme*, piloted from 2018-2021, requires vessel crews to sample fish from every haul of every trip. Fish length and weight data are collected as the fish are pumped onboard, and haul information is recorded to connect the biological sample data to the location and date/time of the catch, and other operational and environmental parameters. The second part, the *co-sampling scheme*, piloted in 2020, requires samples of fish to be frozen and brought ashore for biological sampling by scientists at the laboratories of Marine Scotland Science (MSS) and Shetland-University of Highlands and Islands (SUHI). This paper largely focusses on the details and development of the self-sampling scheme.

While our example is specific to the Scottish pelagic fishing industry, which operates within internationally managed fisheries, it is a case study where practitioners in other worldwide fisheries can recognise many transferable processes and areas of good practice. Our aim is to use this example to communicate the practical and social dimensions of an industry-science initiative, with the intention to facilitate better understanding of many of the 'why and how to' aspects that are less well documented and remain somewhat 'mysterious' for collaborating partners across different science and industry sectors. In particular, we cover why and how it started, what it has taken to develop a routine and consistent voluntary sampling regime that provides quality data, and what is required to bring the data to the attention of potential end users. To identify critical processes and transferrable lessons that could help expedite other initiatives, we describe how the quality and results have evolved through a mutual learning process, and reflect on our different institutional perspectives on what so far have been the most challenging obstacles, and the routes to overcoming them. Finally, we look at the steps ahead in our efforts toward continuous improvements.

The development of this sampling programme was, and continues to be, an iterative process. To provide clarity on the path taken to transition from the idea of an industry-science collaboration to its physical implementation, the descriptions of methods and results include statements on the background and motivation behind decisions.

2 Methods

2.1 Inception

The work began in July 2016, when the Scottish Pelagic Fishermen's Association[3] (SPFA) appointed Dr. Steven Mackinson as its Chief Scientific Officer, with responsibilities for developing and implementing a long-term strategy for professionalising its contributions to science (see Figure 1 for programme development timeline from inception through to current status). The overall theme however, was conceived long before, with the SPFA (like other industry sectors in the UK) being actively engaged in following the process of fish stock assessments and advice from ICES, and regularly accommodating scientists in their work, either onboard or onshore since the 1970s. As early as 2004, the SPFA was pro-active in discussions about how to improve engagement of the fishing industry in science, particularly in relation to the incorporation of additional information from the fishing industry into stock assessments and research (ICES, 2004; ICES, 2007; ICES, 2008).

In 2016, discussions with pelagic industry members during an SPFA board meeting highlighted industry concerns and perspectives on the use of scientific information described above, catalysing development of a data collection strategy (SPFA, 2019). This includes a science plan (Figure 2) which has pelagic fishermen at its heart, with two key strands: a science engagement policy, with key elements of contributing to science, upholding scientific standards, collaboration with government and academic scientists, and raising awareness; and a data collection strategy, underpinned by data collection onboard vessels and in factories. This planning document led to the decision to develop a pelagic self-sampling scheme, aligned with the SPFA data collection strategy. Then followed two years of preparation and design (Mackinson et al., 2018) leading to a proposal to trial the scheme.

The foundations of the programme are based upon an understanding of the opportunities in which industry data can make a worthwhile contribution to information used in fisheries science and advice. Supplemental Table S1 identifies a broad suit of scientific applications where industry data collection programmes may have the potential to add value to improving data and knowledge on fish stocks and their fisheries, which while speculative, provides a basis for further consideration and discussion.

3 The Scottish Pelagic Fishermen's Association (SPFA) is a member association comprised of 20 (out of 21) owner/operators of Scottish pelagic vessels and 2 from Northern Ireland.

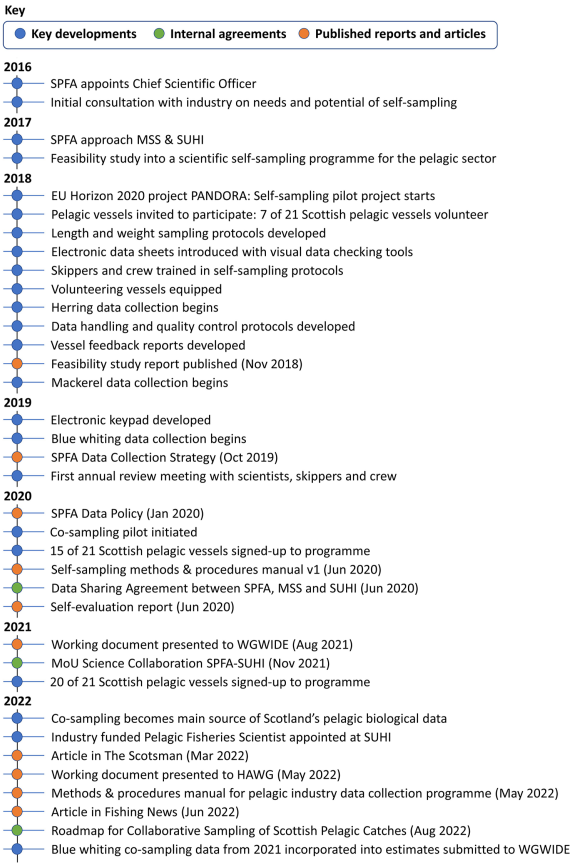

FIGURE 1
Timeline of events and milestone documents during development of the Scottish Pelagic Industry-science Data Collection Programme.

2.2 Collaborative approach

The programme has been developed by the Scottish Pelagic Fishermen's Association (SPFA – an association for the pelagic fishing fleet), Shetland UHI (SUHI - an academic partner of the University of Highlands and Islands (UHI)) and Marine Scotland Science (MSS - a division of the Scottish Government), with additional industry support from the Scottish Fishermen's Federation (SFF – an organisation that works for the collective interests of Scotland's fishermen's associations). From the very beginning, the approach has been to work in partnership with relevant national and international scientific and policy institutions, so that data provided by industry will be relevant, credible and trusted by the institutions that will use it.

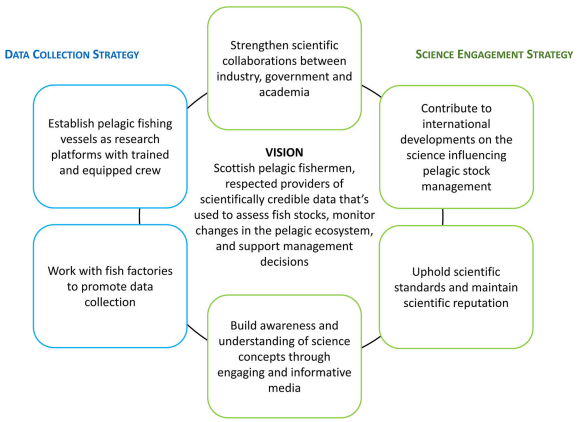

FIGURE 2
SPFA Science Plan (revised and updated from SPFA, 2019). The vision is enacted through the Data Collection Strategy and Science Engagement Strategy, which have defined objectives under which specific work activities occur.

Establishment of the pilot programme was made possible through the EU Horizon 2020 project PANDORA (pandora-fisheries-project.eu), which provided funding for dedicated staff time at SPFA, SUHI and MSS, as well as a commitment to report on the programme development.

Within the collaboration, each partner has specific roles that play to their strengths. The SPFA represents the Scottish pelagic vessels, with promotion and operationalisation of participation led by its Chief Scientific Officer. SUHI staff have worked closely with the SPFA throughout, providing the role of Sampling Coordinator and Data Manager, delivering training and ongoing regular communication with vessels. Over time, SUHI have developed a leading role in the day-to-day delivery of the programme. MSS works with the SPFA and SUHI to design sampling methods and protocols, and evaluate quality to ensure that the data collected meet required standards. Initially MSS' role was intended to be

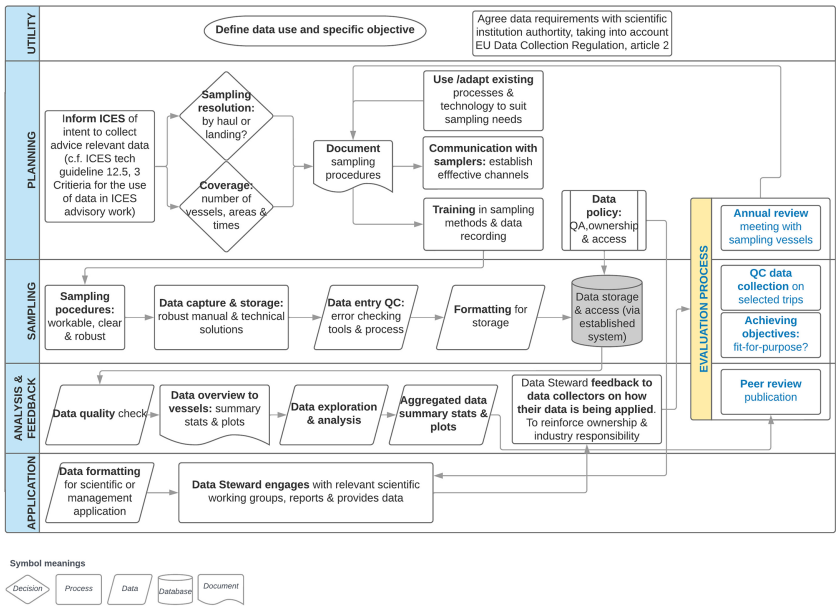

FIGURE 3
Generalized process plan for the Scottish Pelagic Industry-Science Data Collection Programme (revised from SPFA, 2019), indicating the components required to implement the self-sampling programme, moving through the stages of definition of utility, planning, sampling, analysis and feedback, through to application.

mostly advisory but, as the programme has developed, the role has evolved to full collaboration, focussed mainly on the co-sampling scheme and the requirements for provision of data to ICES. Laboratory sampling is undertaken by both SUHI and MSS. SFF provides logistical support to the sampling programme and contributes to the strategic work that seeks to see how lessons from the pelagic sampling might be translated to other sectors.

2.3 Practical implementation

The objective to provide data that can be used in fishery stock assessments to improve the quality of scientific advice has driven the design of each component of the programme. A generalized process plan for implementation was drawn up at the start of the process (Figure 3). The plan starts with the need to establish the utility by identifying information needs and corresponding objectives, which are essential in the planning stage. Implementation of data collection and its quality control in the sampling stage is followed by analysis and feedback to those involved in collecting the data. Finally, the data are prepared for application in relevant fora. While there are other research applications for the data collected under the Scottish Pelagic Industry-Science Data Collection Programme, these are not the key factors that influenced the design of the programme.

2.3.1 Developing methods and training

In 2018, member vessels of the SPFA were approached to participate in self-sampling. Upon joining the programme, each vessel was provided with a bespoke measuring board (Figure 4), sampling protocols, and data recording templates for haul and biological information (paper and electronic copies). Vessels use existing calibrated onboard weighing scales, which they use within their normal fishing activity to measure fish weights so that a price for their catch can be determined. Graphical sampling protocols were designed in consultation with MSS scientists and were kept to a single or two-sided A4 piece of paper. Information on the purpose of sampling and data collection is provided within the protocol. All the methods and protocols are documented in a sampling methods manual (Brigden et al., 2022) and additional detailed information on the programme development is reported in a PANDORA project technical report (Angus et al., 2021) and the PANDORA toolbox[4].

The initial focus of data collection was self-sampling of fish lengths and weights from all hauls during the fisheries for herring, mackerel and blue whiting. At first only herring was included, but the pilot was soon extended to mackerel later that same year (2018) and then blue whiting in 2019. Haul information is recorded to connect the biological data to the location and date/time of the catch and other operational and environmental parameters.

Prior to undertaking sampling, training sessions were provided to skippers and crew. Initially these were provided in groups (either at the factory or onboard a vessel), but an onboard one-on-one approach was soon adopted, with scientists joining vessels for

4 The PANDORA toolbox is an interactive website including a variety of resources ranging from simple meta-data and links to pre-existing tools to more complex, front-end platforms for displaying outputs from improved assessment and economic models (e.g. short- to long-term changes in distribution and/or productivity of fish stocks as well as economic trade-offs associated with different management strategies). https://www.ices.dk/PANDORA/Pages/default.aspx accessed 12/1/23.

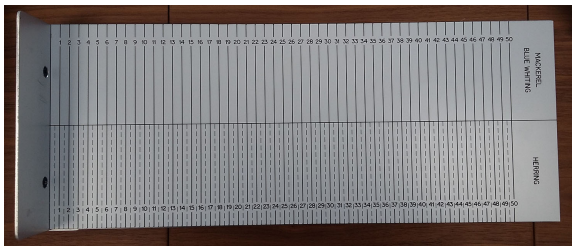

FIGURE 4
Bespoke measuring board, indicating the measurement intervals required for each species, provided to each vessel participating in the programme.

fishing trips or visiting vessels in port. While more time consuming, onboard training was more effective because processes could be demonstrated and tried by the crew using their own set-up. Accordingly, this meant that any questions and issues could be dealt with immediately and, importantly, that the scientists understood the operational conditions so that solutions could be tailored to individual vessels' needs. It was also vital in forming the personal foundations and means of contact necessary for good working relationships.

2.3.2 Quality control – documentation and data

A central part of establishing the programme was the development of reliable data handling and quality control measures, with fully documented processes and procedures, informed by published information on best practice. These serve to demonstrate that processes are scientifically rigorous and ensure the delivery of quality data. Providing full transparency of the programme, documentation is freely available on the SPFA website (https://scottishpelagic.co.uk/).

For the self-sampling data, which relies on crew collecting information onboard vessels, data checking tools were built into the electronic data recording sheet used by crew samplers to help identify data entry errors. These include summary statistics (maximum, minimum, and average length and weight values) and data plots that are automatically generated so that they can be used as immediate visual checks. As part of training, crews are taught how to read these plots and use them to recognise potential mistakes.

A data Chain of Custody is available for the self-sampling scheme, providing a stepwise guide of the QC processes at each stage of data handling, and the supporting documentation and tools required (Figure 5). Similar documentation is in development for the co-sampling scheme. The steps detailed in Figure 5 are applied to the self-sampling data, with each vessel providing two datasets (haul and length-weight) for every fishing season. Upon completion of each fishing season, the data are emailed or uploaded to an FTP site that is accessed by the programme data manager and saved to secure cloud storage. Data checking and quality control are undertaken by the data manager, which includes: ensuring that information matches between the length-weight and haul files so that information can be connected; checking for missing or erroneous information; checking that information is formatted correctly to be read in by data processing scripts. Data handling procedures are applied, and each step in the process is recorded by date in a log sheet. During data checking and quality control, the data manager will contact the vessel to query any issues if required. Further detail is given in a methods and procedures manual (Brigden et al., 2022). Following data checking and quality control, each vessel's self-sampling data are entered into new length-weight and haul data files before being appended into two pooled databases which contain the data for all vessels: a fish biological (length-weight) dataset and a haul dataset. The pooled length-weight and haul databases are used for reporting and are available for further analysis. Individual vessel data are also pooled to provide each vessel with all their fishery's data to date (see section *Communication and relationship building within the programme*). The processes for data re-formatting, entering, reporting and data pooling are each carried out using custom R (R Core Team, 2019) code, providing a consistent data handling approach that can be repeated for all vessels' data, at each processing step.

2.3.3 Technological evolution

To improve the sampling efficiency and minimise errors related to the paper recording and subsequent entry into a spreadsheet, efforts to develop a paperless system began in 2019. Several skippers had already taken it upon themselves to consider what type of system might work best, and, following a review and trials of various existing electronic recording systems (many of which were found to be over-engineered and overpriced for our needs), it was the skippers' idea for a simple keypad that was pursued. In collaboration with a local marine electronics supplier, a simple electronic keypad was designed and manufactured, along with bespoke software for live display, recording and reporting of sampling data (Figure 6). During development, feedback from skippers and crew on the design of a prototype keypad and software was crucial to making the system fit-for-purpose. The keypad is now installed in nearly all participating vessels and has the capability to record additional information on sex, maturity and fat content if needed. Some skippers are using the software's grading reports to provide their catch data directly to processors ahead of landing.

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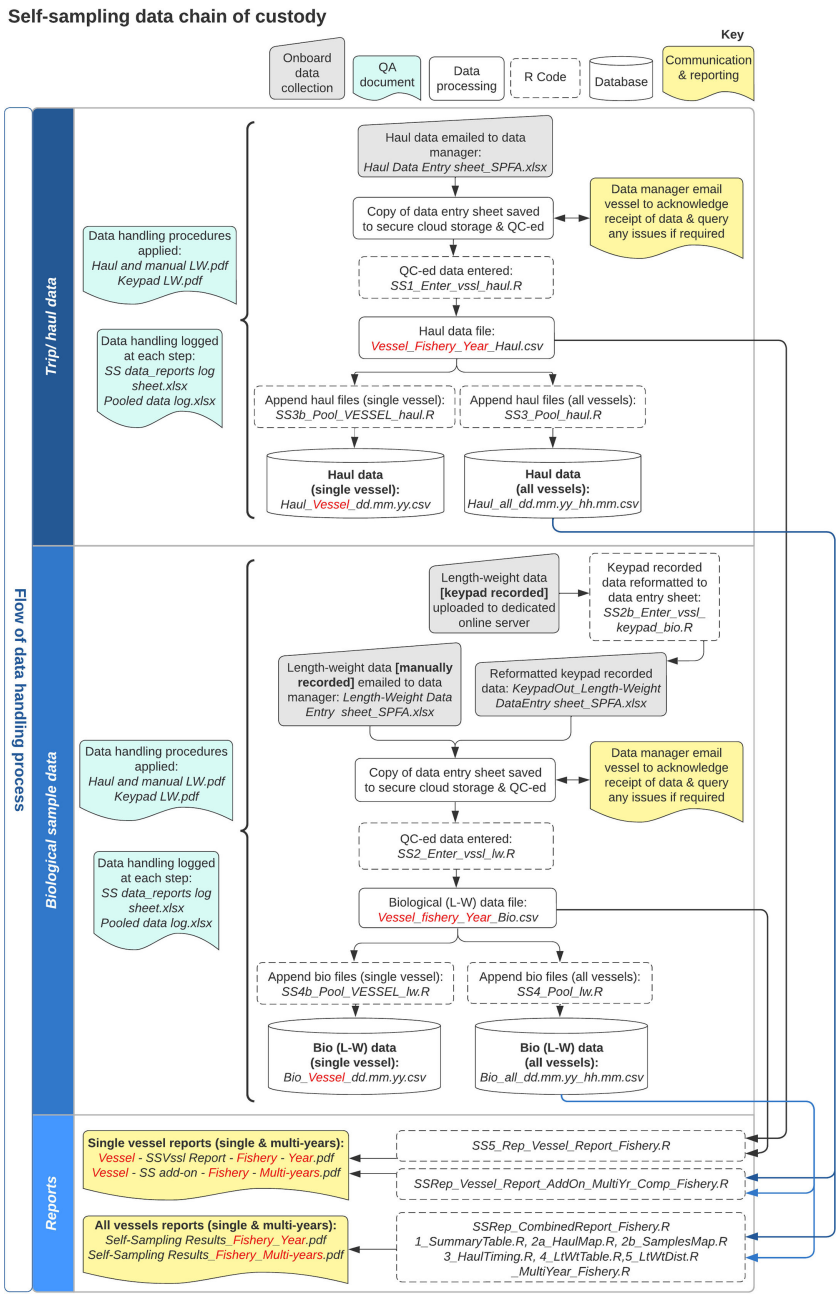

FIGURE 5
Self-sampling data chain of custody. Part of the programme documentation, providing a stepwise guide of the QC processes at each stage of data handling, and the supporting documentation and tools required. Notes: 1) Text in italics denotes file names; 2) Text in red italics ('Vessel', 'Fishery', 'Year/s') denotes the relevant vessel name, fishery and year/s (e.g. Altaire, Herring, 2020) 3) dd.mm.yy hh.mm denotes date/time labelling of file names relevant to processing date 4) QC=quality checked.

Samplers receive training on using the keypad at the time of installation, but in addition, a series of YouTube videos[5] have been distributed as an instructional aide, and to demonstrate the capabilities of the keypad system.

A key benefit of working with a local electronics supplier is that the company already provided services to many of the vessels and knew them personally. This made training and troubleshooting onboard easy and efficient, as well as providing a route for obtaining the feedback required to resolve any glitches and enhance capability, such as the recent development enabling direct upload of data from the keypad system to a dedicated online server.

2.3.4 Additional research

As part of the programme, specific experiments are being undertaken to assess any differences and determine any correction factors that may be required when fish are measured in either a fresh, chilled or frozen-thawed state. On-going

5 Example of instructional / information video for crew (accessed 10/3/23) https://youtu.be/WFbfVYY__Cs.

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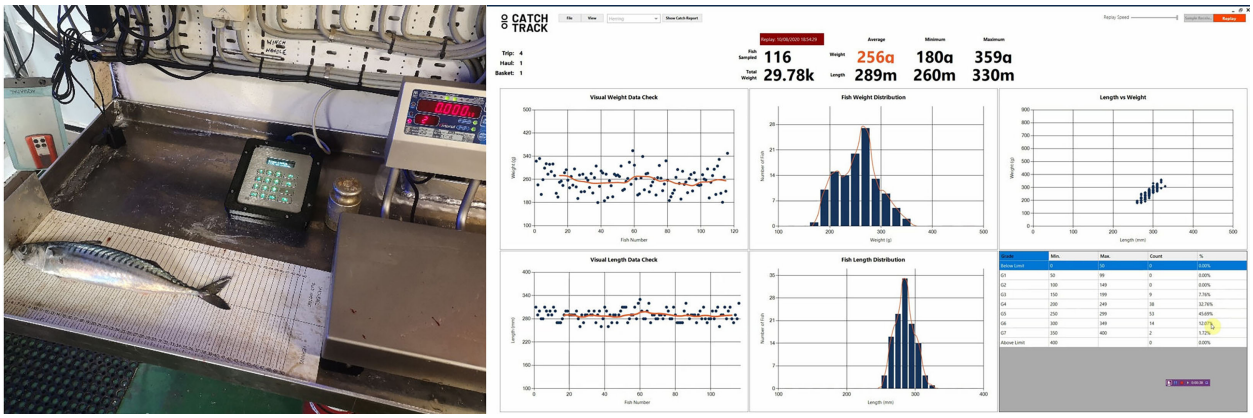

FIGURE 6
Electronic keypad for entry of fish length measurements, paired with weighing scales (left) and data visualisation and capture software on the bridge (right). The data visualisation provides real-time sample data and running average (left panels), size-frequency distributions (middle panels), tracking of the mean, minimum and maximum sizes (top values), a length-weight plot (top right) and percentage of samples in each user-defined grade category (bottom right).

Box 1. Key ICES workshops and working groups relevant to the development of the programme
Workshop on Science-Industry Initiatives (WKSCINDI; ICES, 2019)
Workshop on Data Standards and Guidelines (WKDSG; ICES, 2021a)
Workshop on Stakeholder Engagement Strategy (WKSHOES; ICES, 2021b)
Workshop to Evaluate the Utility of Industry-derived data for enhancing scientific knowledge and providing data for stock assessments (WKEVUT; ICES 2022a)
Working Group on the Governance of Quality Management of Data and Advice (WGQUALITY)
Working Group on Widely Distributed Stocks (WGWIDE)
Working Group on Commercial Catches (WGCATCH)
Herring Assessment Working Group (HAWG).

monitoring will continue to assess how data from samples collected onboard vessels compare with those collected elsewhere.

2.3.5 Data protection and sharing

The SPFA Data Policy (SPFA, 2020) describes the conditions and procedures regarding data access and use by the scientific community. All Data Products (data outputs resulting from aggregation of, or calculated from, underlying or aggregated data, and where individual vessel or personal data is not directly identifiable) are by default publicly available.

During the PANDORA project, a data sharing agreement between MSS, SPFA and SUHI, was established to enable all partners to access all data while ensuring compliance with the General Data Protection Regulation (GDPR) (EU, 2016). As part of the process, every individual vessel was required to give their written permission for the data on their catches collected by MSS to be shared with SUHI and the SPFA, the industry's representative association, because the data were being used for a purpose for which they were not originally collected. A data privacy notice (required under GDPR) and consent form were distributed to, and signed by, all relevant vessel owners.

The data sharing agreement includes descriptions of: the purpose, aims and benefits of the data sharing; limitations on the use of the data; the data to be shared; data required to match or link data sources; the process and basis of sharing; the information assurance and security for each institute; the Data Protection Impact Assessment and privacy notices; data retention and deletion, and management of the agreement. The data sharing agreement applies to data collected between 2018 – April 2022 (the end of the PANDORA project).

2.3.6 Communication and relationship building within the programme

Because the programme is reliant on the voluntary participation of each vessel, it is essential to maintain effective communication between all parties at different levels and for different purposes. This means thinking carefully about what information is needed by whom, when they need it, and in what format.

Using the SPFA's Chief Scientific Officer as a central point of contact, consultation with industry members on the needs and potential of the programme began in 2016, two years prior to its implementation. Since then, regular contact and the development of individual relationships with the skippers and samplers on each vessel has been pivotal in fostering understanding of the programme and the need to be consistent in providing high quality information.

Various means of communication are used depending on what best suits the different groups and individuals involved. Regular contact *via* phone call, WhatsApp, email, and visits to vessels ensures the flow of information in both directions (from scientists to industry and industry to scientists), helping to maintain the working relationships crucial for the programme's successful operation.

To demonstrate the value and utility of the information collected, programme participants receive a copy of their data and summary reports. An email is sent to each vessel at the end of every fishing season, including a standardised Excel file containing that vessel's data to date, and two reports displaying data summaries: (i) A season report provides information from the latest fishing season, including a map with haul locations, average length and weight per haul, length and weight distributions, length-weight relationship, and a comparison between the vessel's average fish weight and average weight of fish in the sample, (ii) A multi-season add-on report provides comparisons with previous years, regarding location, timing, and size of fish. At the end of each fishing season all participating vessel's data are combined and anonymised to provide a multi-vessel/multi-year report demonstrating the complete results of the industry sampling.

Establishing a close working relationship between scientists at the SPFA, SUHI and MSS has also been integral to the successful development and delivery of the programme. Bi-monthly planning meetings have been held and contact maintained throughout the development and implementation stages, with on-going consultation and review of the methods and data collected. It should also be noted that there has been continuity of personnel at all three organisations and this has helped maintain both stability and momentum.

Meetings involving all partners and participants are needed less regularly but are valuable occasions to provide and receive feedback. Since 2019 an annual review and planning meeting involving all participants and collaborators has taken place. In addition, quarterly SPFA directors board meetings provide regular opportunities for sampling to be discussed as needed.

2.3.7 Evaluation

Two years into the programme, a review of the first phase of the self-sampling scheme was undertaken by MSS. This self-evaluation applied published recommendations and guidelines to assess the self-sampling scheme in terms of sample sizes (Gerritsen and McGrath, 2007, Miranda, 2007; Schultz et al., 2016), sampling design (ICES, 2013; fishPi, 2016) and quality assurance (ICES, 2013; ICES, 2014; ICES, 2018a; ICES, 2018b). The report made specific recommendations aimed at minimising bias and ensuring data quality (see Annex 5 in Angus et al., 2021).

To assess the quality of industry self-sampling during the pilot period (2018-2021), data were compared with data collected through the long-established onshore sampling programme, co-ordinated by MSS and conducted under the EU Data Collection Framework (DCF) and its subsequent replacement in UK legislation. The full details of these comparisons are the subject for a paper currently in preparation.

2.3.8 Raising awareness

Beyond the efforts to promote the programme among pelagic fishers (including vessels outside the SPFA) the work has been promoted to other sectors of the Scottish and UK wide fishing industry *via* fishing and national press news articles (e.g. Fishing News, 2022; FitF, 2022b; Mackinson, 2022b) as well as through various industry forums, including: Seafish meetings, Fisheries Innovation Scotland, the Scottish Fishermen's Federation and Fishing into the Future[6]. Opportunities for knowledge exchange with other organisations involved in similar initiatives, and international engagement *via* academic conferences (e.g. World Fisheries Congress 2021 (Brigden et al., 2021), Marine Alliance Science Technology Scotland Conference 2019) have been valuable in programme development. But most important for building awareness of the programme and developing best practice has been participation in key ICES workshops and working groups (Box 1).

3 Results

3.1 Overview of self-sampling data

The growth and increased coverage of the programme over the first four years is shown in Table 1 and Figures 7, 8. Out of 20 Scottish SPFA member vessels, seven initially joined, the remaining vessels joining at various points over the following three years, as successful experiences of early-adopters built confidence in others. Full participation of Scottish SPFA member vessels was achieved in 2021. During the period of the development of the programme there was a simultaneous programme of vessel renewal within the fleet which contributed to the staggered participation. For example, the apparent dip in participation in 2019 compared to 2018 is due to the fact that some vessels participating in 2018 were sold and were not able to participate, while others started their sampling that year. To date, over 1700 hauls have been sampled, resulting in more than 190, 000 fish measured. The result of increased participation of the vessels was greater coverage of the full fleet activity in space and time of all the fisheries, which is highlighted in Figures 7, 8, which show how since the programmes start the overlap of sampling with the commercial fishing activity has developed from partial to complete coverage.

3.2 Evaluating the quality of self-sampling data

The self-evaluation report recommended developments to the sampling design and aspects of the quality assurance of the programme. To improve quality assurance it was recommended that additional clarifications and established quality indicators be added to existing documentation. The report also highlighted that potential bias in the self-sampling scheme would be reduced by implementing census or random sampling design of the full pelagic

6 Seafish – a public body supporting the UK seafood industry; Fisheries Innovation Scotland – a coalition of industry, government and experts driving strategic innovation in Scottish fisheries; Scottish Fishermen's Federation – an industry body to preserve and promote the collective interests of Scotland's fishermen's associations; Fishing into the Future – a UK-wide charity acting for sustainable and prosperous fisheries.

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TABLE 1 Number of unique vessels, trips, hauls (% valid), and total valid fish samples (length and weight), from a total of 20 SPFA member vessels.

	2018	2019	2020	2021
Herring				
No. vessels	7	5	15	16
No. trips	41	14	65	64
No. hauls (% valid)	88 (83%)	31 (97%)	153 (84%)	179 (83%)
No. fish (valid)	8017	3640	16754	20466
Mackerel (autumn)				
No. vessels	7	7	15	18
No. trips	29	20	67	67
No. hauls (% valid)	64 (83%)	47 (83%)	156 (85%)	189 (73%)
No. fish (valid)	6866	4577	16289	20281
Mackerel (winter)				
No. vessels	n/a	7	14	18
No. trips	n/a	23	45	67
No. hauls (% valid)	n/a	46 (91%)	95 (86%)	142 (97%)
No. fish (valid)	n/a	4862	9429	15977
Blue whiting				
No. vessels	n/a	1	5	9
No. trips	n/a	4	20	40
No. hauls (% valid)	n/a	29 (55%)	69 (100%)	136 (92%)
No. fish (valid)	n/a	1893	8002	15170

Samples are classified as valid (or invalid) during data checking and quality control undertaken by the data manager (see section Quality control – documentation and data). Only valid samples are used in further data analysis. n/a, not applicable for 2018 mackerel (winter) and blue whiting because the scheme was not yet operational in those fisheries at that time.

fleet. As a result of the evaluation, further effort was put into recruiting skippers, aiming to achieve full participation of the fleet. An advantage of undertaking the self-evaluation mid-way through the pilot phase was enabling the implementation of the recommendations in a timely manner.

The self-sampling scheme provides a finely resolved (haul level) dataset that covers the full spatial distribution of the fishery (Figure 7). It yields quality checked scientific data, and, where sampled trips coincide, is shown to have length distributions that are consistent with length distributions from MSS onshore sampling: the length distributions shown in Figure 9 demonstrate close similarity between the two datasets (onshore sampling and self-sampling), with the self-sampling dataset further resolved by length distributions at the haul level (black dotted line).

In addition, the programme includes additional information on fish weight to be combined with data on fish length, enabling seasonal and inter-annual variations in growth patterns of cohorts to be captured, which could potentially be incorporated into data submitted towards stock assessments. It also provides valuable data for research on species ecology. These data are commonly collected on scientific research surveys but were not previously routinely collected from commercial catches in Scotland. The example in Figure 10 indicates that the mean weight-at-length of mackerel of intermediate lengths observed from self-sampling data is greater than the mean weight-at-length predicted by the Length-Weight relationships used by MSS in spring 2021. In addition, the relationship appears to be more linear, rather than the exponential function assumed by the MSS weight-length relationship.

3.3 Extension to a new co-sampling scheme

Building on the at-sea success of the self-sampling scheme and mindful of the fact that stock assessment models require age data, the collection of otoliths (from which the ages of fish are determined) by crew onboard vessels was investigated by SUHI and MSS scientists in 2018. However, this was not deemed to be a feasible task for crew in the time they have available for sampling onboard, and alternative approaches were considered. This led to a trial in 2019, of the collection of frozen samples on selected trips, with scientists at MSS and SUHI laboratories carrying out the standard biological processing of these fish, namely the collection of information on age, length, sex and maturity. This is referred to as 'co-sampling', because both the industry and scientists take part in the collection of the data.

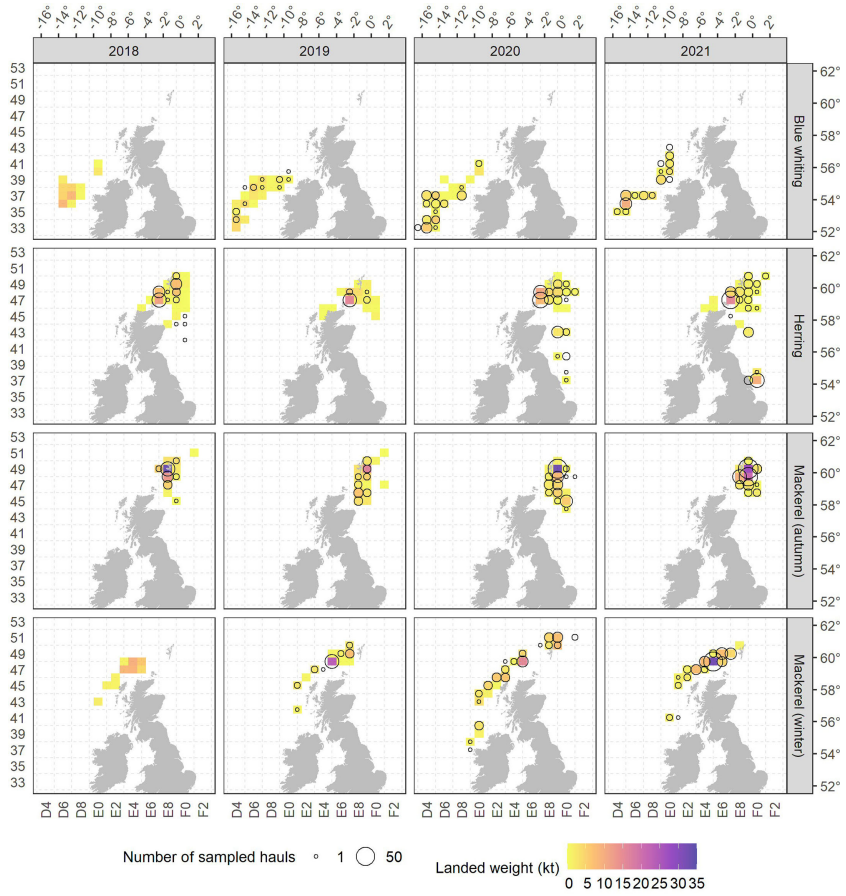

FIGURE 7
Total landed weight (kt) of commercial catches during the blue whiting, herring and mackerel fishing seasons per statistical square (colour scale) by the Scottish pelagic fleet (21 vessels) from 2018 to 2021, with the total number of individual hauls with valid samples collected through the self-sampling scheme (circles). Notes: 1) Samples are classified as valid (or invalid) during data checking and quality control undertaken by the data manager (see section Quality control – documentation and data). Only valid samples are used in further data analysis; 2) the plots in 2018 for mackerel (winter) and blue whiting do not include self-sampling data because the scheme was not yet operational in those fisheries at that time.

In 2020 the co-sampling trial evolved further to include the random selection of trips from which samples are taken, with SUHI or SPFA monitoring fleet activity and notifying vessels to take samples when their trip is randomly selected. In 2020 and 2021, co-sampling was undertaken alongside the MSS onshore sampling programme, providing comparative biological samples. Following this comparison period, in January 2022, co-sampling was adopted under Scotland's national sampling programme to become the main mechanism for collecting biological data on the catches of pelagic fish to be used in stock assessment.

4 Discussion

4.1 Benefits and good practice

The purpose of developing the Scottish Pelagic Industry-Science Data Collection Programme has been to enable fishers to be active contributors to the data and evidence that is used by ICES to assess and advise on the state of fish stocks and the marine environment. Over the course of 2018 - 2022, sampling and data collection by industry rapidly accelerated to become an established collaborative programme covering the whole fleet, with data being used in the ICES 2023 pelagic stock assessments by HAWG and WGWIDE. The success of this initiative has been recognised publicly through two awards: the Fishing News Sustainability Award in 2019 and the Marine Stewardship Council Ocean Leadership Award in 2022[7].

The data generated from the programme offer several benefits and opportunities in efforts to ensure continuous improvements in the quality of stock assessment and ICES advice for each of the pelagic species. There are several aspects of particular importance to data quality, as illustrated in Figures 7–10. First, sample coverage is representative of the activities of the whole fleet because even vessels that land overseas can sample their catches. Second, every haul of every trip is sampled, thus providing an accurate representation of the true catch composition, resolved finely both spatially and temporally. Thirdly, measurements of both the weight and length of fish provide important information on changes in fish growth; and avoid the need to rely on length-weight relationships to

7 Fishing News Sustainability Award: https://fishingnews.co.uk/2019-fishing-news-awards-winners/#sustainability.Marine Stewardship Council Ocean Leadership Award 2022: https://www.msc.org/uk/msc-uk-awards.

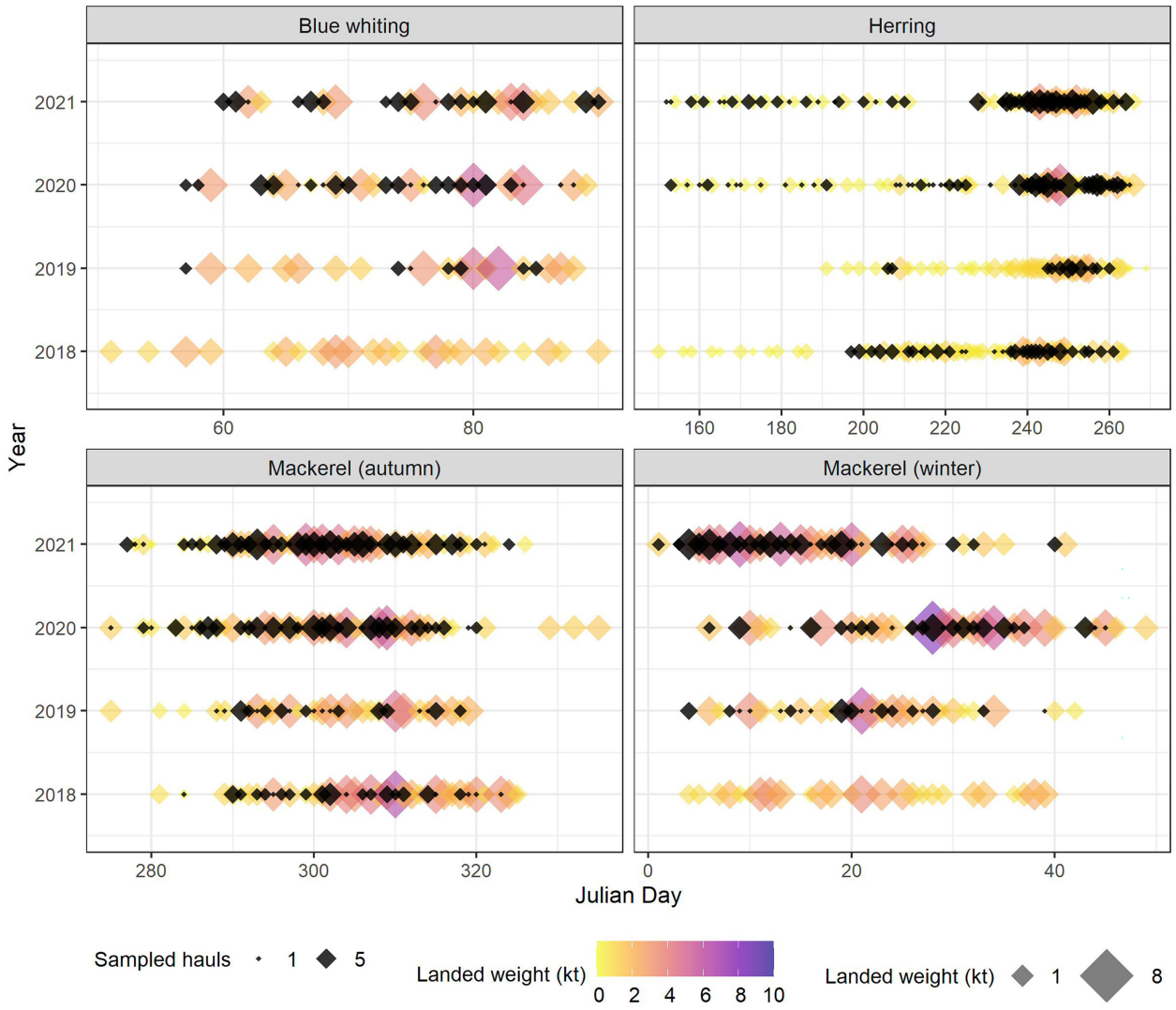

FIGURE 8
Total number of self-sampled hauls undertaken per day from fishing trips during the blue whiting, herring and mackerel fishing seasons (black diamonds), with the total commercial landed weight per day (coloured diamonds) by the Scottish pelagic fleet (21 vessels) from 2018 to 2021. Note: the plots in 2018 for mackerel (winter) and blue whiting do not include self-sampling data because the scheme was not yet operational in those fisheries at that time.

estimate fish weight data inputs to assessments, as was the case in the MSS onshore sampling programme.

From January 2022, co-sampling was adopted under Scotland's national sampling programme to become the main mechanism for collecting biological data on the catches of pelagic fish to be used in stock assessment. The main driver for this was the success of the self-sampling scheme, including almost the whole fleet, and showing that fishers could be relied upon to provide data and samples according to agreed protocols.

The core design principles that we believe have been essential to the success so far are not unique to the pelagic sector, therefore we believe they are transferrable to other sectors. They include:

i. Identifying where there is both opportunity and utility in information that fulfils a need expressed by industry or science.
ii. Always being open and honest with others and understanding that participation is better when fishers have a sense of ownership. The approach has focussed on engaging fishers on the scientific issues relevant to them, and importantly, encouraging an attitude where fishers want to provide data. Fundamental to this is the need for openness and transparent communications, because they help to build trusting and productive working relationships, where everyone can gain the confidence they need to do their job well and with pride. In the case of the sampling programme, we see the advantages, whereby skippers and samplers can - and do - contact programme scientists directly when they have questions or concerns.
iii. Creation of effective feedback mechanisms between scientists and the skippers and crew involved in

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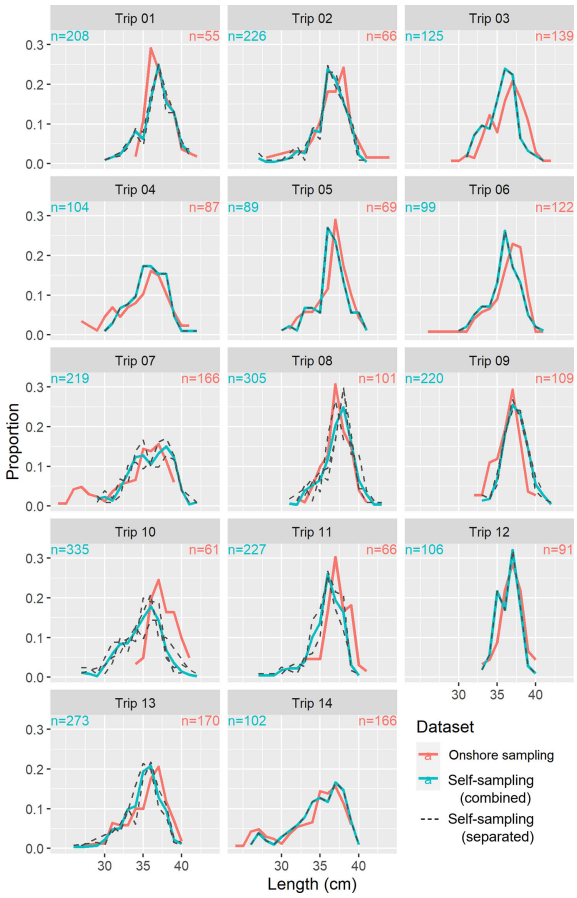

FIGURE 9
Length distributions from mackerel winter fishery trips in 2021, plotted by dataset (colours). Pink line=MSS onshore sampling (one sample in a single trip). Blue line=self-sampling (multiple samples in a single trip, combined). Black dotted line=self-sampling (multiple samples in a single trip, separated).

sampling. The purpose of these mechanisms is to provide the participants with information from which they can assess whether their efforts are rewarded with something of value to them (i.e. the 'what's in it for me?'), as well as to understand each other's roles and to provide opportunities for scientists to listen to operational needs so that they can adapt processes to be fit-for-purpose.

iv. Establishing transparent quality assurance and quality control processes and documentation that serve to assure data users that they can be confident that the information they receive is an accurate representation of the fishery catches.

v. Constructively engaging, challenging and supporting necessary developments in national and international institutional processes that determine whether data from industry programmes have the chance to be applied in stock assessments.

4.2 Perceptions, perspectives and priorities

Though this programme emerged from an industry initiative in the pelagic sector, represented by only one industry body, and comprising a series of seasonal single-species fisheries, its development has not been straightforward. Undoubtedly it is less challenging than developing a sampling programme with, for example, a large fleet of vessels operating in a multi-target mixed-species fishery and with multiple industry representatives. While successful so far, its development has been, a mutual learning process in which, at times, challenges and tensions have had to be navigated.

While these examples are specific to our study, they are the types of issues that would undoubtedly arise in other similar initiatives during their development phases. Being aware and prepared for these types of issues will allow others to develop mitigation measures and strategies from the outset. Applying our different institutional perspectives, we reflect below on six areas where challenges and sensitivities needed to be overcome.

4.2.1 Initial perceptions

While the industry (SPFA scientist and members) felt that being proactive to contribute to pelagic data collection would be welcomed, it perceived the reception from MSS as reticent and reluctant. However, this perceived reluctance was simply an awareness of the challenges that might be faced in trying to integrate a new data source into existing stock assessment models

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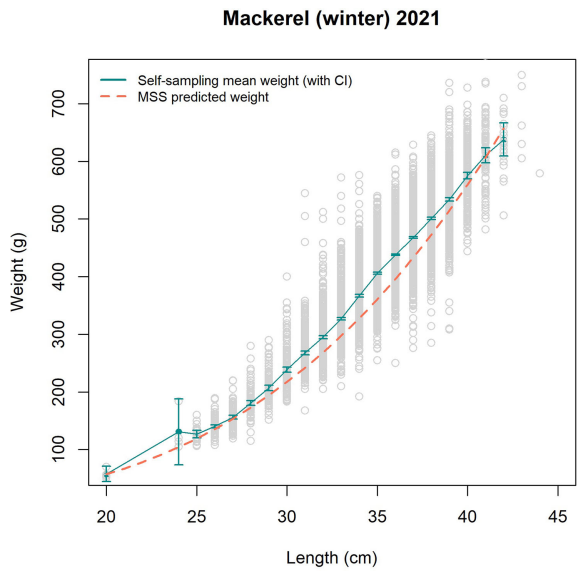

FIGURE 10
Fish length-weight relationship for mackerel 2021 (winter, Jan/Feb) plotted by dataset (colour and line type). Lengths are rounded down to the nearest 0.5 cm. Pink line=MSS predicted weight-at-length currently used by MSS for provision of data to ICES (W=0.003001*L^3.29). Blue line=self-sampling mean weight-at-length with confidence intervals (CI). Grey circles=self-sampling length-weight data (n=15,822 [Jan n= 15,259, Feb n= 563]).

(expanded upon in *Quality and continuity of data* below), and that such a change could need the agreement of other ICES scientists and was not necessarily within the gift of MSS scientists. However, as the industry have taken requirements onboard and addressed them, initial concerns of government scientists have been allayed, and similarly, industry have seen government scientists welcome the industry contribution and endorse the quality of the data.

The partnership between MSS, SPFA and SUHI became organised through engagement in the pilot phase funded as part of the PANDORA project, marking a key milestone in the development of the programme. This involved defining the aims and scope of a pilot study and the roles that each partner would play, which created a task-focussed structure for enabling conversations. The co-development of sampling protocols and joint participation in training actions during early stages were both important to alleviate the initial concerns and to build a starting point from which to expand up on. These provided a framework for everyone to start to navigate and address relevant issues on a case-by-case basis, rather than being overwhelmed by the whole task.

4.2.2 Opening the gate

For the SPFA and SUHI, recognition that government scientists are an institutional bedrock of ICES scientific assessment and advisory processes meant that there was a perception that, without MSS engagement in developing a collaborative approach, the chances of industry making a contribution to the scientific information used in ICES seemed slim. The reason for this is that while, in theory, industry derived data can enter the ICES system independently, the infrastructure and processes in ICES are not yet ready to facilitate that. Furthermore, the industry realised that trying to establish a pathway for industry to 'go it alone' could come across as confrontational and risk being seen as less than helpful. It soon became clear that including industry in the provision of data required by the current stock assessment model was the most efficient way to begin the process, while more speculative approaches, such as developing new assessment methods, would take longer. This meant the development of a more collaborative approach to the collection of age data, and hence to the development of the co-sampling scheme.

The decision to use industry samples as the main source of information for pelagic assessment was made by MSS in 2021. The reason for this was three-fold. Firstly, the pilot had successfully demonstrated the reliability of the industry to be responsible for collecting samples and data to a high standard. Secondly, the almost complete participation of the fleet (Table 1) meant that co-sampling presented an opportunity to facilitate random sampling of all landings, including catch landed abroad. Thirdly, the success of the co-sampling pilot meant that MSS resources were over-stretched when handling samples from both the co-sampling scheme and the existing MSS onshore sampling programme. Together, these reasons meant that the decision to concentrate effort on the co-sampling scheme became clear.

Even though SUHI, MSS and SPFA have been collaborating for several years, with the end of the PANDORA project there is a need for a new formal written agreement underpinning the arrangements (see next section). Despite the high-level UK policy statements suggesting that collaboration is now the *modus operandi*, first it has been necessary for the foundations of trust and confidence to be built between individuals. This has been achieved after several years of successful collaboration.

4.2.3 Quality and continuity of data

As the main responsible authority for scientific data on the key UK pelagic stocks, MSS has a responsibility to provide high quality data. Changes to the data collection methods, even when they improve the data, have the potential to create a step-change in the time series of data provided to ICES, and was thus a legitimate concern for MSS. This concern was understood, and to some extent shared, by SPFA and SUHI because during the early stages of the pilot phase the success of the engagement, willingness and ability of crews to take on new work was yet to be tested. A shift to greater collaboration with the fishing industry requires a continued commitment from participating vessels for a minimum of several years; something that is now close to being formalised under the planned Memorandum of Understanding (MoU) on science collaboration between the partners (SPFA, MSS and SUHI), which will complement existing MoUs between MSS and SUHI and SUHI and SPFA. The commitment for a shared MoU is expressed in a roadmap for collaborative sampling of Scottish pelagic catches established in August 2022.

The consequences of using a new data source needs to be fully considered, because the inclusion of new biological data into an existing time series has the potential to cause a shift in the data that

could be spurious and misinterpreted as a change in the structure of the stock. Thus, prior to the introduction of any new data, examination of the resulting effects on estimates would be required. Having knowledgeable staff within MSS that are directly involved in ICES working groups on assessments, catch data, quality assurance and regional database development has been important to ensure that such evaluations have taken place and the programme is fit-for-purpose. Similarly, the engagement of SPFA and SUHI in relevant ICES assessment and quality working groups as well as workshops on industry-science initiatives has been important in this respect.

Concern for the quality of scientific sample data itself has been less of a worry to industry than the perception that their new role in the co-sampling scheme might be driven more by the government's wish for a cheap source of sampling, rather than a wider commitment toward enhancing scientific engagement with the industry. The concern of being a cheap source of sampling cannot, however, be justified because of the similar workload and costs compared with the onshore sampling programme.

4.2.4 Reputational concerns

Combined with concern for the quality of science, MSS and SUHI take care to maintain their scientific integrity and independence so there is no cause for real or perceived conflict of interest coming from external sources. Such concerns might be assumed not to apply to the industry, but this is not the case. The risks of reputational damage from failing to act professionally and live up to expected standards are keenly felt there too because it has a bearing on industry's sustainability credentials and thus their social licence to fish.

Transparency, documentation and communication have been key to mitigating possible reputational concerns from internal or external sources. Throughout, the collaborators have worked on a series of public and scientific communications that explain the aims, plans and operational details of the pelagic sampling programme. Quality assurance documentation and public access to it has also been important in this regard. A particularly important document is the Data Sharing Agreement. This document is explicit about the conditions and processes for sharing the detailed data necessary for scientific collaboration, and, not being our personal area of expertise, the drafting of it was a challenging process. The experience of having to consider such details has been fundamental to build trust and assure each collaborator that safeguards are in place.

Reputational concerns remain present and come to the fore from time to time. Being mindful of them ensures that the collaborators continue to make considered efforts to demonstrate and maintain the credibility of the work as well as the integrity of the institutions and individuals involved.

4.2.5 Pace of change

One of the challenges that has been particularly difficult to manage from the industry side is balancing the pace of progress with expectation. Some participating vessels have regularly expressed frustrations that progress toward integrating industry sampled data into assessments was slower than they expected. This is despite the fact the pilot study was planned to take 3 years, without any plans for data to be used in assessments within that time frame (SPFA, 2019). When industry decides to make changes to any operation, skippers are quick to mobilise crew and apply them, so it is hard for them to understand why change cannot be so immediately implemented elsewhere. At times, the frustration has led to an imminent risk of people pulling out of the (voluntary) programme. A combination of very active personal engagement from SPFA and a dedicated member of SUHI staff responsible for the day-to-day operations of the programme, has been fundamental to prevent this, as well as capitalising on the peer pressure among the fleet. It was also beneficial that the recruitment of new vessels in the first year was relatively slow because it gave time to implement procedures that worked well, thus avoiding the risk of vessels becoming disengaged if processes were not fit-for-purpose.

From the MSS scientists' point of view, however, the pace of change has been faster than planned and required a flexible approach, both with the roll-out of the initial self-sampling pilot, and with the inclusion of additional trials, in particular the co-sampling trial, which resulted in a rapid increase in the workload of scientific samplers. This increase in workload was not fully anticipated, and was not sustainable longer term, thus stimulating efforts on the design of new sampling arrangements. Furthermore, additional infrastructure, for example, the data sharing agreement (specifying what shared data can be used for), databases, and code, needs to be updated to keep pace with these changes.

Naturally, there are also differences in the time each partner has available to work on the programme over the course of a year, with some partners being employed to focus on the work, while others have limited resource to allocate to development work on top of their other commitments and are not able to reprioritise their work in response to the demands of the programme. These differences in the timing and overall time available of each partner to work on the programme leads to differences in the pace and timetable of output that can be achieved. Expectations are managed during monthly meetings, using time management techniques of setting realistic time scales for individual tasks and prioritising them, so that there is greater alignment and improved understanding in the timing of delivery.

4.2.6 Communication

At the start of the programme all meetings were chaired and minuted by the same partner. After some confusion about actions agreed at an earlier meeting, a meeting protocol was agreed, key points of which included rotation of management of the meetings between institutes, a review of agreed actions and conclusions during the meetings, and a specified date for all participants to review and agree the final meeting minutes. Establishing this meeting protocol has been helpful in reducing misunderstandings between partners.

Since 2020 all meetings between SPFA, SUHI and MSS have been held online. Although this has the advantage of easier access to meetings for all, this does lead to reduced interaction between individuals which may have impacted on a sense of team building. It

is expedient to prioritise areas of disagreement during focussed online meetings, but these offer less opportunity to appreciate mutual agreements and successes that might be afforded by unstructured social time spent together.

Where differing perspectives, priorities and ways of working clash it can be characterised as conflict. Although at times difficult to navigate, it is also worth acknowledging the benefits that these sometimes-opposing forces bring. For example, ambition to move the work forward at pace, taking the time to consider all the details, questioning the relevancy of certain aspects of the work. At times, these themes have been experienced as friction, however, ultimately these different points of view also provide a focus for discussion on how to deliver a better programme.

5 Conclusion and future

Over a relatively short period of time, industry sampling and data collection has been implemented and is now routine within the Scottish pelagic fishing industry. There are a number of factors that have enabled this to occur, principally the willingness and drive of all concerned and, the staff time and financial resources to enable it to happen. All parties have already demonstrated their commitment to continued collaboration on pelagic science and data collection. The Scottish pelagic industry have demonstrated their commitment to the continuation of the programme from 2022-2026 with the establishment of a Memorandum of Understanding between the SPFA and SUHI and creation of a new industry funded Pelagic Fisheries Scientist post based at SUHI. Further evidence of industry's commitment is visible among new vessels that have chosen to install scientific grade echosounders and sampling equipment, and even build specific spaces onboard dedicated to scientific sampling activities. Similarly, the commitment from MSS is clear through the winding down of their onshore sampling programme. As ever, a collaborative approach will be adopted because for industry sampling data to be used, both industry and relevant national administrations responsible for data submissions will need to commit to working toward this objective. Our foundation for this will be a 3-way MoU that helps formalise operational plans, agreements and policies to help ensure scientific integrity of the data and the institutions. Continued engagement with ICES is also necessary to ensure that the apparatus of the receiving system is in place to accommodate the data. This includes addressing issues regarding data access, use, delivery and formats needed to meet the requirements of emerging tools (e.g. ICES Regional Database and Estimation System (RDBES) (ICES, 2022b)) and processes (e.g. Quality Assured Assessment Framework) necessary to facilitate the use of industry data.

Our example provides valuable lessons for others in terms of both the practical and social dimensions of collaborative research endeavours. It offers a partial 'roadmap' for others considering self- and co-sampling initiatives that are underpinned by a shared objective to continuously improve the science that supports long-term sustainability of fisheries.

Data availability statement

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

Author contributions

All authors were involved in the editing and revision process, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1075345/full#supplementary-material

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