FISH and FISHERIES

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Approaches to fully documented fisheries: practical issues and stakeholder perceptions

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Abstract

The Common Fisheries Policy (CFP) reform sets out a move to a land-all catch policy in European Union waters with a requirement for full reporting of fishing and on-board processing activity. We explore the merits, stakeholder perceptions and applicability of different technology and approaches to the full documentation of fisheries that might be considered in the context of implementing the CFP reform. While recent efforts have focused on demonstrating how remote electronic monitoring (REM) systems can be utilized in fully documented fisheries (FDF), other technologies and approaches such as reference fleet and self-sampling exist that could contribute to delivering FDF. Perceptions of fishers show that they would prefer using a reference fleet or self-sampling to REM systems as a future method of implementing FDF. In general, there is support from the fishing industry for data collection and enhancement, but there remains some mistrust concerning the use of the data. Findings show that the most appropriate means and methods of FDF will depend on the circumstances and objectives for full documentation whether in enforcing a discard ban, documentation of total catch or data enhancement. We conclude that any technology or approach that will be used to deliver the monitoring requirements for FDF needs to make practical and commercial sense at the fishing vessel level.

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Introduction

The European Union has agreed to reform the Common Fisheries Policy (CFP) with a package of measures that include a staged move to a land-all catch policy with a requirement for full reporting of fishing and on-board processing activities (EC 2013). The timetable specifies changes to take place in pelagic targeted fisheries by January 2015, and in whitefish, flatfish and *Nephrops* fisheries by way of a phased implementation approach starting in January 2016 and fully in place by January 2019. Under the reformed CFP, all fish caught must be retained and landed (discard ban), except where the fish will be used for live bait, have good survival rates when discarded, or are not allowed to be landed. In some circumstances, a *de minimis* level of up to 5% of total catch of regulated species may be discarded if there are disproportionate costs handling and storing the fish on board (EC 2013). The CFP reform proposal further indicates that fishers will be accountable for their total catches and not only the part of the catch that is landed. There is therefore a need to implement an accounting system for EU fisheries that gives comprehensive, complete and reliable documentation of all catches including discards. This has commonly been referred to as having fully documented fisheries (FDF). The CFP reform proposal further suggests that in order to achieve the obligation to fully document fishing activities, vessels need to be appropriately equipped with the necessary technologies for data acquisition.

It is important to recognize that what constitutes FDF has yet to be defined. Here, we use the term FDF to refer to the collection of catch data needed for science and management purposes to demonstrate full documentation of fishing activities. We recognize FDF as having the potential for fishers to provide data for multiple uses including: (i) science, by supplementing traditional sources of scientific information such as market sampling, observer trips, catch and log-book returns; (ii) management, including for monitoring and enforcement; and (iii) for the fishing industry themselves to demonstrate compliance with management measures, potentially leading to exemption from restrictive management measures or access to fishing opportunities. We therefore sought to identify the widest possible range of benefits that FDF could bring to science, management and the fishing industry.

A wide range of tools and approaches are now available and have been applied to monitor and collect catch data that could support the fishing industry meet the CFP obligations. These include vessel monitoring systems (VMS) that record the location of the vessel in time and space (Aanes *et al.* 2011; Skaar *et al.* 2011), electronic logbooks that store catch and effort information as well as other technical characteristics of the fishery (Gallaway *et al.* 2003), and remote electronic monitoring (REM) techniques such as closed circuit television (CCTV) that provides video surveillance of areas of the vessel where fish are handled for fish detection, identification and measurement (McElderry *et al.* 2003). The use of fisheries observers on-board vessels is also one of the methods of collecting high-quality data at-sea during fishing operations since observers can record a wider range of data on more species than fishers (Faunce 2011; Fernandes *et al.* 2011). The question then is which one(s) of these is appropriate to deliver the monitoring requirements for FDF and how can it be applied to fisheries with different characteristics? The suitability and applicability of each technology or approach will differ due to the range of species, vessel sizes, types of fishing gear, handling practices and other variables associated with each fishing activity.

In this article, we explore the applicability of different technology and approaches to the full documentation of catch for various types of fishing that might be considered in the context of implementing the CFP reform. This includes evaluating whether the technologies and approaches can deliver the information required, including the practical considerations that need to be taken into account, and the drivers and incentives that are required by the fishing industry to deliver FDF. This information is needed for the successful translation of the CFP reform policy objective into practice. We address the fishing industry approaches to FDF by asking the following three questions:

1. What are the relative merits of different approaches and technologies to collect catch data?
2. How is fully documentation of fisheries and the available tools and approaches perceived by stakeholders?
3. What are the practical issues and opportunities towards FDF?

Merits of technologies and approaches in documenting total catch

Literature review

In order to provide a baseline understanding of the technologies and approaches that could be applied to document catch in fishing operations, a search strategy was developed that included all the key terms related to technologies (e.g. REM/CCTV) and approaches (e.g. reference fleets, self-sampling) identified from discussions between scientists and fishers' representatives. The search terms were then used to search databases (e.g. Science Direct, Web of Science), Internet search engines (Google, Google Scholar) and Governmental and Inter-governmental science agency websites (including those of Cefas, Marine Scotland, Ifremer, DTU Aqua and ICES). The search identified 56 articles that comprised 22 technical reports, 25 peer-reviewed papers, five conference presentations and information from four websites (Table 1).

SWOT analysis is a structured planning framework used to identify and analyse the strengths,

Table 1 Articles used in the literature review to assess the merits of each technology and approach in fully documented fisheries.

Technology/Approach	Technical report	Peer reviewed	Conference presentation	Website	Total
Automated sampling	1	3			4
Catch documentation				4	4
Fisheries observers	1	7	1		9
Onshore sampling	3	1			4
Reference fleet	2	2			4
Remote Electronic Monitoring/CCTV	10	3	4		17
Self-sampling	4	9			13
Multiple technologies	1				1
Total	22	25	5	4	56

weaknesses, opportunities and threats involved in a project or business venture (Cowx *et al.* 2010). As an assessment tool, SWOT analysis helps in exploring current constraints and future possibilities of any sector through a systematic approach of introspection into both positive and negative concerns. By assessing the strong and weak points, the potential threats that may become an obstacle for the implementation of the project can be identified and planned for to enable success of the project. The process involves a qualitative analysis that encourages the development of opportunities to build on strengths of the sector to overcome weaknesses while at the same time utilizing sectoral strengths to minimize vulnerability to threats (Cowx *et al.* 2010). The SWOT analysis was used here as an ideal way of providing a critical review of the strengths and opportunities, as well as to generate a deeper understanding of the weaknesses and the threats that need to be managed or eliminated to ensure the successful application of each of the technology to FDF.

Each of the 56 articles pertinent to the review was therefore examined for key information including (i) the characteristics of the fishery or fisheries used in the article; (ii) the types of data that were gathered; (iii) the use made of the data, e.g. in science and/or management; (iv) whether the data gathered were verified including the approach used to verify the data; and (v) the costs of data capture and verification. This information was organized into a SWOT matrix, where

1. Strengths included coverage, cost, industry buy-in, simplicity.
2. Weaknesses included cost, bias, representativeness, time, technology failure.
3. Opportunities included simplification, reduced regulation, automation.
4. Threats included low level of participation, falsification, non-representativeness.

Below, we discuss the key findings from this literature review and outline the applicability of each technology and approach in implementing FDF.

Remote electronic monitoring

The overwhelming focus of catch documentation efforts in recent years has been on the development and application of cameras and associated electronic monitoring technologies. In Europe, this has been as part of catch quota trials which aim to record all of the catch of specified species, whether they will be retained or discarded. REM systems work by integrating video cameras, gear sensors and geographical positioning system (GPS) to record and log all fishing activity for review and verification onshore. The recorded video footage allows the catch in most cases to be identified to species level, and is used to monitor retained and discarded catch. The electronic monitoring log can be used on two levels; either as a census where all footage may be viewed and catch monitored directly, or as a system of audit where a proportion of the video footage is reviewed for consistency with self-reported catch.

Literature shows that REM/CCTV has been used to record total catch within a fishery as a substitute for human observers where they may be impractical, or in order to provide greater observer coverage in a more cost efficient manner (McElderry *et al.* 2003; Ames *et al.* 2007; Evans and Molony 2011;; Dalskov 2013; Ruiz 2013). REM systems have also been deployed to monitor the capture of protected or vulnerable species and efforts are under way to relate fishing activity and VMS position data so as to gain further insights into spatial patterns of fisheries (McElderry *et al.* 2007). In EU fisheries, the application of REM to monitor fishing activity is a relatively recent development. Trials have been conducted in Denmark (Kindt-Larsen *et al.* 2011), Scotland (Scottish Government 2011) and England (MMO 2012) with otter trawlers, gill netters, seine netters and beam trawlers participating in catch quota trials for cod (*Gadus morhua,* Gadidae) in the North Sea, and for common sole (*Solea solea,* Soleidae), plaice (*Pleuronectes platessa,* Pleuronectidae) and anglerfish (*Lophuis piscatorius, L. Budegassa,* Lophiidae) in the Western English Channel. Around the world, however, REM systems have been tested on various fisheries over the past decade, with 33 pilot studies and operational systems in eight fisheries. These include the British Columbia hook and line groundfish fishery principally targeting halibut (McElderry *et al.* 2003), the tropical tuna purse seine fishery (Ruiz 2013), the Bering Sea flatfish trawl fishery (McElderry *et al.* 2008), the inshore set net and trawl fishery off the Canterbury coast, New Zealand (McElderry *et al.* 2007) and in the Australian gill net fishery (Evans and Molony 2011). In the case of the British Columbia halibut line fishery, REM is now used to deliver complete coverage with approximately 200 vessels, 1200 trips and 10 000 days at sea monitored annually (Archipelago Marine Resource Ltd. 2013).

REM systems, however, face a number of challenges including a lack of support from skippers and crew as it is seen to intrude on their privacy (Table 2). A recent attitude survey reported by Baker *et al.* (2013) reveals that a large proportion of the fishing industry (64%) in the US South Atlantic is not supportive of the use of REM. REM systems also do not perform well in large volume fisheries especially where species identification is required. For example, it is difficult to distinguish between sand sole (*Pegusa lascaris*) and common sole (J. Roberts, Marine Management Organization, personal communication). The large volume of fish that enter the conveyor belt at once also result in a large portion of the fish hiding under the top layer (Ruiz 2013). The quality of the image is also sometimes limited by external factors (scales, water drops) and the quality of the cameras themselves. Analogue cameras are sturdy but of relatively low resolution while digital cameras have much higher image resolution and frame rates, but are associated with higher data storage costs (Ruiz 2013). An independent validation process is also required such as cross-checking with on-board fisheries observers (Table 2). Other weaknesses include the practicalities of operating the equipment on small-sized vessels, equipment failure and cost. Costs include not just of the equipment, which in Danish trials was estimated at approximately US $13 000 per vessel (Kindt-Larsen *et al.* 2011), but also the ongoing monitoring and maintenance programme which requires a detailed implementation programme, including training and quality checking of the data analyses with considerable annual costs (McElderry 2008). The full costs estimated in the British Columbia hook and line fishery were around US $8100 per vessel for a 10% audit of video footage, which can range between 1 and 20% of landed value. These costs comprised 20% for equipment, 45% for field services and 35% for data services (Stanley *et al.* 2011). A comparative analysis of the costs of fisheries observers and REM in a Scottish case study, however, showed that costs for REM were high in the first year but vastly reduced in the second year, while costs for observers were low in the first year but increased in the second (Dinsdale 2013). Dinsdale (2013) concludes that although costs vary greatly depending on the numbers of analysts, equipped vessels and observers, the cost per haul is cheaper when using REM than when using on-board observers.

Fisheries observers

On-board observers have formed a major part of fisheries data collection programmes in the EU since 2002 (EC 2008). Observers collect data on quantities of retained and discarded species, including biological data (e.g. length frequency of retained and discarded fish) and fishery data (e.g. fishing effort and location). Information collected by observers has been used extensively in stock assessments and the provision of management advice (Faunce and Barbeaux 2011). Observers can provide a strong direct link between fishers and science thereby promoting good communication (Cotter and Pilling 2007).

The cost for 100% observer coverage is very high (Table 2) and most observer programmes therefore only provide a sample of fishing activity (Benoît and Allard 2009), though there are some exceptions where 100% observer coverage is mandatory such as in the North Atlantic Fisheries Organization's Regulatory Area. Target sample rates within the EU are set out in the Data Collection Framework (EC 2008) and generally cover 1–2% of fishing trips per fishery. The deployment of observers is therefore a balance between the number of samples necessary to meet the objectives of the programme and cost. Evans and Molony (2011) estimate the equivalent observer time to ensure the coverage of a REM system at $49 000 compared to $20 000. Another weakness of fisheries observers is the potential for biased data as a result of the non-random distribution of observers among fishing vessels (e.g. due to logistical constraints) and changes in fishing practice or location when observers are on-board (observer effects) (Benoît and Allard 2009; Faunce and Barbeaux 2011). The use of observers to sample fisheries also necessitates their separation from enforcement activities to ensure that samples collected are not biased (Cotter and Pilling 2007). This suggests that observers could not perform a role in consistently fully documenting catches at the vessel level without considerable cost and change in emphasis. Such a change would need to be considered in relation to the objectives of an observer programme. An enforcement or control scheme will likely provide very different information from a scientific programme and further, the

Table 2 Summary of the strengths, weaknesses, opportunities and threats for each of the technologies and approaches identified in the literature in delivering FDF.

Approach	Description	Examples of application	Strengths / Opportunities	Weaknesses / Threats	References
Remote electronic monitoring	Monitoring of catch on fishing vessels through integration of video cameras, gear sensors and GPS to record and log fishing activity for monitoring and review onshore	Several examples of operational monitoring Over 33 pilot trials in fisheries globally	Flexible, tailored application Tested and proven to be successful in monitoring fishing activity and distinguishing retained and discarded catch in several fisheries Can provide complete coverage or limited risk-based coverage Increased selectivity in fishing operations through behavioural change Improved economic performance (landing all catch) More cost-effective than observers if good coverage is required	Cannot provide some biological information on catch, e.g. maturity stage, otolith samples Requires significant support to install, maintain and manage equipment Reviewers require training and auditing Concerns about privacy Requires observers to validate and collect biological information Cost can be considerable	Kindt-Larsen *et al.* (2011), Scottish Government (2011), van Helmond *et al.* (2012), Stanley *et al.* (2009, 2011), McElderry *et al.* (2003, 2007, 2008), Evans and Molony (2011), Ames *et al.* (2007), MMO (2012), Ruiz (2013), Baker *et al.* (2013), Dinsdale (2013), Dalskov (2013)
Observers	Scientific observers on board fishing vessels to collect data on quantities of retained and discarded species, including biological data and information on fishing activity	Widespread use in fisheries around the world Forms a large part of EU data collection since 2002	High confidence in data collected Precision levels can be controlled and CVs estimated Provides robust, scientifically rigorous data on total catch Provides strong links between fishers and scientists	Coverage limited by high cost Possible observer effect on catching and sorting behaviour Possible deployment effect due to logistical constains If required to fulfil enforcement role, observer data would likely be biased and unrepresentative Not possible on some vessels because of, e.g. size and space restrictions Limited by EU Working Time Directive	Evans and Molony (2011), Cotter and Pilling (2007), Catchpole *et al.* (2011), Allard and Chouinard (1997), Benoȏt and Allard (2009), Faunce and Barbeaux (2011), Coull (2013)
Onshore sampling	Onshore observers vising ports to collect data on age, length, catch composition and area fished	Widespread use in fisheries around the world Runs alongside observer programme as part of EU data collection since 2002	Provides robust, scientifically rigorous biological data Provides data on species that may not be sampled at sea by observers	Logistics of reaching remote minor ports Estimating total catch when catch is partially retained on board or split between different markets / processors	Allard and Chouinard (1997), Mayfield (2010), ICES (2010, 2012, 2013)

Table 2 Continued.

Approach	Description	Examples of application	Strengths / Opportunities	Weaknesses / Threats	References
Self-sampling	Can be classified as follows: self-collection of discard sample material for analysis by laboratories self-collection of data by fishers self-reporting of catch and activity	Irish Sea and North Sea *Nephrops* fisheries Norwegian purse-seine fishery Oregon trawl fishery	Provides detailed information on catch and activity Provides wider sampling coverage than observers because smaller samples can more easily be collected from several vessels Has been shown to provide high-quality data consistent with observer sampling which can be used in stock assessments Strong industry support and sense of data ownership	Requires strict protocols for data collection Voluntary participation leading to concerns about sampling bias May not work well for contentious, rare or protected species where there might be an incentive to misreport Rapid decline of enthusiasm if expected benefits are not realized Requires verification and auditing to maintain data quality Extensive training for fishers may be required	Lordan *et al.* (2011), Hoare *et al.* (2011), Uhlmann *et al.* (2011), Pennington and Helle (2011), Bellail *et al.* (2008), Sampson (2011) Roman *et al.* (2011), Bowering *et al.* (2011), Starr (2000)
Reference fleet	A group of vessels that serves an enhanced data collection role, with the vessels considered sufficiently representative of the activity of that fishery for the data to be raised to the level of the fishery as a whole.	Norwegian reference fleets New Beford offshore otter trawl groundfish fishery	Provides high resolution data on fishing location and fleet behaviour Provides a sampling platform to gather data representative of fishery May be funded from existing quotas Good support from industry and sense of ownership in data Promotes good contact between fishers and scientists Can provide additional information on wider evironment and other marine species	Voluntary nature can lead to sampling bias Needs careful sampling design to ensure the fleet is representative of the wider fishery Cannot be used in isolation – needs validation through observers and market sampling to ensure data are representative Requires considerable support (e.g. for training, validaton)	Bowering *et al.* (2011), Roman *et al.* (2011), Nedreaas *et al.* (2006), Pennington and Helle (2011)
Automated species identification and measurement	System for automatic species identification, length measurement and weight estimation from a calibrated camera system	Scientific trials Operational system trialled in Azores, Portugal	Shown to have a high level of accuracy in scientific trials for a limited number of species Fishmetrics has produced consistent sampling for a large number of fish in trials Potential link with REM which would increase sampling coverage	Limited seagoing trials under commercial conditions with range of similar species System requires careful calibration to ensure good quality of data	Strachan *et al.* (1990), Strachan (1994), Storbeck and Daan (2001), Storbeck and Dann (1991), APEM (2013), Scantrol (2013)

Table 2 Continued.

Approach	Description	Examples of application	Strengths / Opportunities	Weaknesses / Threats	References
At-sea weighing equipment (scales, codend weigher)	Platform-mounted scales which can quickly measure bulk weights (including boxes, baskets) of fish or crane codend weighers (load bearing scales attached to net)	Motion compensated scales in large vessels in whitefish fisheries Bench and crane scales trials in Scottish squid fishery, North Sea pair trawlers	Motion-compensating scales can provide accurate reading of bulk weight of catch Tested crane scales give accurate weight estimation within 3% of compensated scales Can provide quick method for accurate recording of bulk weights, or individual species depending on requirements. Wide range of options available depending on accurancy required and cost	Requires regular and accurate calibration, e.g. to take account of net weight Catch needs to be sorted to required level of reporting Can range in cost from $150 to $ 15 500	Caslake (2011), Seafish (2010)
Catch documentation tools	Wheelhouse tools for effective recording of activity, environmental conditions and catch information including e-logs	E-log books on >15 m vessels in EU Wheelhouse-based monitoring systems employed in many fisheries within the United Kingdom	e-logs provide method for recording discards Larger vessels operate systems with equipment recording environmental variables associated with activity	Concerns about equipment failure and data ownership Concerns about non-reporting and unverified entries Difficult for skippers to provide good estimates of discarded amounts	Walsh *et al.* (2002), OLRAC (2013), Absolute Software (2013)
Onshore grading equipment	Shore-based equipment for grading and sorting fish.	Lorient fish market Trialed in southwest UK	Fish markets may have opportunity to sell length data to scientiifc agencies Automated measurement would free scientific staff for other tasks, e.g. otolith collection Measurements within 2.5 cm possible	Small fish still require grading by hand Development required for higher accurancy	Ashworth *et al.* (2012)

coverage and design of such a programme would need to reflect risk tolerance based on the objectives of FDF.

Onshore (port) sampling

Portside monitoring programmes have become mandatory in many fisheries. They are used to verify the size of fish in landings and to collect data necessary for stock assessments and biological investigations (Allard and Chouinard 1997). Onshore observers collect data on age, length, landings composition, maturity and length-weight relationships. In the EU, onshore sampling programmes are used to compliment on-board observer programmes as part of the EU's data collection framework with the results from the two programmes usually combined to provide the data for ICES stock assessment and other science and management uses.

Similar to on-board observers, a key weakness of onshore observers is the necessity to subsample from the commercial landings, and therefore making it difficult to achieve an adequate, representative catch sampling especially in fisheries that comprise numerous fleets fishing over large spatial areas, where there is high variability among catches and where a proportion of the catch may be discarded. Challenges in utilizing this approach in FDF therefore include considerations of the logistics of sampling in remote minor ports, how total catches will be estimated when only some of the catch is retained on-board or the landings may be split between different markets / processors, and in some cases, landings may be offloaded directly from the fishing vessel to a lorry or landings of different vessels may be mixed.

Self-sampling

Self-sampling can be considered as (i) the self-collection of discard material by fishers for processing by scientists such as in the Irish Sea Nephrops fishery (Hoare *et al.* 2011; Lordan *et al.* 2011), the North East English coast Nephrops fishery (E. Bell, Cefas, personal communication), the boarfish fishery (Lordan *et al.* 2011), and the Dutch beam trawl fishery (Uhlmann *et al.* 2011); or (ii) the self-collection of data by fishers such as in the Norwegian purse seine fishery (Pennington and Helle 2011), the North East American groundfish fishery (Roman *et al.* 2011), the French Celtic Sea cod fishery (Bellail *et al.* 2008) and the Bengweulu swap fishery (Ticheler *et al.* 1998); or (ii) the self-reporting of catch and activity such as in the Oregon trawl fishery (Sampson 2011) and the New Zealand lobster fishery (Starr and Vignaux 1997).

Self-sampling can be used in the collection of biological samples, e.g. length-frequency of retained and discarded fish where it provides a higher sample rate than can be provided by observers (Table 2). Self-sampling also provides wider sample coverage than observers and has been shown to produce high-quality data that is consistent with observer sampling (Starr and Vignaux 1997; Roman *et al.* 2011), and useful in stock assessments (e.g. Hoare *et al.* 2011). In the majority of cases, data are collected to supplement observer and market samples, but in some, such as the Norwegian system, self-sampling has become the single source of biological information from the fisheries (Bowering *et al.* 2011). The self-reporting of catch has also taken place in some fisheries and in these circumstances, acts as a 'reference' or 'study' fleet that involves a number of vessels from the fishery collecting detailed information on catch composition, length-frequency of the catch and information on fishing operations such as location and technical characteristics of the gear.

Self-sampling programmes, however, have generally been voluntary leading to concerns about sampling frame bias (Roman *et al.* 2011) and short natured with declines in enthusiasm over extended periods (Starr 2000; Lordan *et al.* 2011). Concerns have also been raised about potential bias or non-adherence to protocols, particularly through the removal of larger individuals from unsorted catch (Lordan *et al.* 2011), and in some cases, the falsification of data (Ticheler *et al.* 1998) (Table 2). While such problems are not unique to self-sampling (Graham *et al.* 2011), such concerns are significant when considering self-sampling as, e.g. a means of fleet-wide discard sampling for full documentation of individual vessel's catch. The accuracy of the catch gathered through self-reporting projects without some means of verification has been questioned (Sampson 2011) leading to conclusions that self-reporting will not work well for monitoring contentious, rare or protected species (Starr 2000).

Reference fleet

A reference or study fleet is a group of vessels that serve an enhanced data collection role, with the vessels considered to be sufficiently representative of the activity of that fishery such that the data collected can be raised to the fishery as a whole. Examples include the Norwegian reference fleet comprised 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 (Bowering *et al.* 2011); and the New Bedford offshore otter trawl groundfish fishery (Roman *et al.* 2011). In 2009, the number of vessels in the Norwegian reference fleet comprised 1% of the coastal fleet and 15% of the offshore gillnet fleet, whereas the New Bedford offshore otter trawl study fleet comprised 25% of the vessels and 29% of landings from the fishery.

In the Norwegian reference fleet, the vessels are required to collect detailed information on total catch (landings and discards) including sampling the length-frequency of catch (generally one sample per day) (Nedreaas *et al.* 2006), and other biological data (e.g. collection of otiliths, genetic and stomach samples) as well as providing detailed information on fishing activity and encountered marine mammals and seabirds. Vessels are compensated through a set aside proportion of the Norwegian quota for relevant species, which covers both additional quota for the vessels in the scheme and the running costs of the scheme (administration, equipment and direct payment to the fleet). In the New Bedford offshore otter trawl fishery, vessels are required to estimate weight of retained catch by species, discards of commercial species partitioned into reasons for discarding (e.g. below minimum landing size, lack of quota) and also provide total weight of discards of non-commercial species. Length-frequency measurements are also taken for six specified commercial species with 100 retained fish and 100 discarded fish measured per specified species per fishing area per fishing trip. Vessels are compensated $400 a day for data collection, although they can be penalized if the data are of poor quality (Roman *et al.* 2011).

Data obtained from the Norwegian reference fleet have primarily been used for input to stock assessment models, including providing age-disaggregated catch from the fisheries. The information has also been used to provide detailed information on catch composition at a high spatial resolution and on technical development and fleet behaviour. The use of reference fleet as an approach for catch documentation has strengths in that reference fleet provides continuous samples at a high resolution giving detailed information on catch and also provides samples which are representative of the wider fishery (Table 2). However, the voluntary nature of the programmes has led to concerns about catch bias in both the Norwegian and the New Bedford offshore otter trawl reference fleets (Bowering *et al.* 2011; Roman *et al.* 2011). Further, although the data in the Norwegian reference fleet have been of a high quality, poor sampling design together with disbanding the port sampling programme has led to a reduced effective sample rate from the fisheries (Bowering *et al.* 2011; Pennington and Helle 2011), and its unknown whether the programme is representative of the wider fishery. For such reasons, Roman *et al.* (2011) recommend such a system to complement but not replace the current fishery-dependent data collection methods. In FDF, reference fleets could provide additional data but such data would need to be validated through a complimentary observer and port-based sampling programme to account for potential bias and unrepresentative sampling, suggesting that this approach may not be adequate in isolation as a monitoring system.

Automated species identification and measurement

Methods for automated species identification and weight estimation of fish have been in development since the early 1990s (Strachan *et al.* 1990; Storbeck and Dann 1991; Strachan 1994). The system involves attaching a camera and/or laser over a conveyer belt such that as fish pass through, key morphological features are recognized and the species is identified. Species length-weight relationships are later used to estimate total weight. More recent developments include camera-conveyor systems which allow manual sampling of fish lengths through virtual (i.e. desk-based) sampling of images either transmitted from landing ports or the vessels themselves (e.g. Fishmetrics) (G Menezes, Fishmetrics, Personal communication). Such systems rely on human identification and measurement through images, rather than automated computer-based systems. Whereas species identification and weight estimation has been demonstrated to have a high level of accuracy (>95%) in trials (Storbeck and Dann 1991; Storbeck and Daan 2001), these have generally been for a limited number of species and have not been under commercial conditions where there may be high volumes of fish, and where the cost of the equipment and the calibration of the system would need to be carefully controlled, particularly for weight estimation to take account of changes in fish condition. Currently, automated systems of species identification and measurement are not widely or systematically used as a sampling tool, though Fishmetrics has been successfully deployed in a number of fish markets in Azores, Portugal where the geography makes effective market sampling more challenging (G Menezes, personal communication).

Other supporting systems for fish measurements include electronic measuring boards such as Scantrol FishMeter and Electronic Data Capture (EDC) which provide an electronic board for measuring length (from 1 mm to 2 m), weight and inputting sex of fish (Scantrol 2013; Cefas 2013). The system consists of a waterproof display unit connected to a measuring board that can read, store and display all recorded data. One hundred different species can be selected from function keys on the measuring board and the system can record up to 40 additional parameters. This system includes computer compatible software package for transferring data and to convert recorded data to other formats such as Excel. Other systems that have been developed for digital aerial bird surveys could be reconfigured to recognize fish on a sorting belt (e.g. APEM 2013). In FDF, approaches for species identification and length-weight measurement could be combined with REM/CCTV. However, such an approach may require significant changes in working practices and application of such technologies would depend on the characteristics of the fishery (e.g. volume of fish, ease in distinguishing morphological features between species). It would need to be demonstrated that such a system can be automated providing repeatable and accurate measurements under working conditions at sea.

At sea scales and cod-end weigher

Supporting technology which may have potential application for FDF includes systems for more accurate weighing of catch, through either platform-mounted scales or cod-end weighers. Non-compensating and motion-compensating platform-based scales have been used by larger commercial vessels in some whitefish fisheries where motion compensation is favoured (Seafish 2010). The systems rely on boxes or baskets of fish being placed on the scales and measurements are transmitted to a recording system. These have been shown to provide accurate readings, and there are several commercial options currently available. Current costs vary from $750 for non-compensating bench scales to $15 000 for motion compensated bench scales with software (Seafish 2010).

In addition to bench mounted scales, crane scales have been tested on-board commercial vessels in a Scottish squid fishery, a pair trawler off North East England and a trawler in Bristol Channel (Caslake 2011). Crane scales measure the total weight of the cod-end as it is hauled on-board and remotely sends it to the wheel house for recording. The weight of retained fish is then subtracted from the total cod-end weight to estimate the bulk weight of discards. Field trials have shown crane scales to be accurate to within 3% when compared to motion-compensating scales (Caslake 2011). The cost of crane scales varies based on the weight the scales can take with simple crane scales costing around $150, while those capable of taking more significant loads at $1500–$3000. In FDF, at sea scales and cod-end weighers are not mutually exclusive and will need to be used together to gather useful data.

Catch documentation tools

The introduction of electronic log-books (e-logs) to all vessels >15 m in EU fisheries has provided a mechanism to record not only the landed portion of the catch but also the discarded weight. e-logs provide a useful mechanism for self-reporting that can easily be integrated into current technology. However, they have weaknesses including the potential for technological failure, non-reporting by skippers, industry concerns about data ownership and the fact that at present e-logs are only used on large vessels (Table 2). Entries onto the system are also unverified and at present are not always completed as part of the fishing activity records. Larger vessels have also been equipped with a range of technologies for monitoring environmental variables and bathymetric information. Such systems (e.g. Absolute Software 2013; OLRAC 2013) provide a potential mechanism for integration of technology into fishing operations.

Onshore grading machines

Another possible technology that could support full documentation and increase data availability on landings is shore-based equipment for grading and sorting fish. These require individual fish to be placed on a conveyer belt which pass over sensors and are weighed and sorted (Ashworth *et al.* 2012). Such a mechanism is already in place in some fish markets (e.g. Lorient, France), and has been trialled in Southwest England. Grading machines have the potential of monitoring the composition of landings for comparison with observer or reference fleet data as part of a risk-based strategy towards enforcing a discard ban (Allard and Chouinard 1997). At present, the technology can measure fish within 2.5 cm but cannot measure small fish, and would require higher accuracy for some species if the information is to be used in scientific assessments and fish marketing.

Summary of merits of different approaches and technology to FDF

This literature review shows that delivering FDF is not limited by technology. The technology to facilitate FDFs is present and can be used to enhance data collection for multiple purposes. The right technology will depend on the objective or set of objectives for the fishery. For example, REM/CCTV could provide a high level of confidence in monitoring and auditing a discard ban, but may be less useful currently for providing additional high-quality biological data owing to limitations of video footage. Further, technologies such as REM did not replace the need for independent validation and collection of data by fisheries observers, but rather support these methods enabling them to provide greater sampling coverage. Results of the SWOT analysis indicate that individually all the technologies have weaknesses implying that the most appropriate strategy to achieve a set of desired monitoring objectives for FDF in a fishery will be to combine them. For example, REM is an effective compliance tool, but in combination with an automated system for species identification and a system for length measurements, it could enhance the collection of data for scientific purposes as well. Similarly, all the approaches assessed have weaknesses and are therefore less effective in isolation and will need to be combined to allow verification and validation of the data. For example, combining REM and a self-sampling reference fleet may provide an effective system that delivers both increased confidence that total catch is accounted for, and more suitable scientific information. Similarly, under a land-all catch policy, REM with onshore grading could provide a risk-based approach to monitor the presence of discarding.

It is worth noting that several advances have been made on this front and the development of technologies for multiple data gathering is a rapidly growing area. For instance, inshore vessels taking part in the Recopesca project were fitted with a network of sensors that collected integrated data on fishing effort and physical parameters (temperature, salinity) allowing assessment of the biological resources as well as environmental quality of fishing grounds (Leblond *et al.* 2008). Findings from this review show that a number of technologies are already in use, particularly on larger vessels, which have potential benefits for science and management. In fact, fishing vessels already have a considerable amount of technology on board, and therefore efforts need to focus on the integration and cross-communication to ensure the technology enhances data collection rather than becomes a burden to skippers.

The success of any of these technologies and approaches in FDF will depend on the level of support from fishers, however. In the next section, we present the views from fishers and other key stakeholders towards the technologies and approaches for the full documentation of fisheries.

Perceptions of stakeholders towards FDF approaches and technologies

Case study interviews

In order to generate feedback on the feasibility of the different technologies and approaches, and to assess existing opportunities that would enable skippers and crew to fully document their catches during fishing operations, face-to-face interviews were conducted with skippers and managers of producer organizations (PO). Two case study fisheries in England and one in Northern Ireland were used to explore how useful the different technologies and approaches would be in different circumstances. The three case-studies were the southwest inshore trawl fishery, southwest offshore gillnet fishery and Irish Sea Nephrops trawl fishery. These case study fisheries were chosen because of the diversity of the species they targeted (from ultra-mixed to a few species), area fished (offshore and inshore) and gears used (trawls and nets) (Table 3).

A questionnaire was developed for the skippers, vessel owners and PO managers in each fishery. The questionnaire was designed to elicit respondents' views on the utility of approaches and technologies, including those discussed here, in delivering FDF. The questionnaire included open and closed-ended questions that were grouped into five broad sections as follows.

1. Section A required background information of the respondent and their fishery.
2. Section B explored the capacity, willingness and sampling frequency that the respondent perceived was manageable to collect data on fishing effort, retained catch, and discards of commercial and non-commercial species. Respondents were presented with specific measures of fishing location (latitude and longitude of haul, time of shooting, depth fished), discards of commercial species (weight of discards, number of discards, reason for discarding) and discards of non-commercial species (presence in haul, estimating weight and numbers); and asked to state what data they were capable or would be willing to collect during fishing operations. For each set of data, respondents were asked whether they would be willing to collect the data (yes/no), their capacity to collect them (easy/limited/not possible) and the sample size (all hauls/some hauls; by haul/by day/by trip).
3. Section C gathered views on the practicalities in data collection by skippers. Respondents were asked to explain whether and how current fishing practices might change if they had to collect their own data, any additional effort required and how weather conditions might affect data collection (including quantity and quality).
4. Section D explored whether incentives were needed to encourage full documentation of catches with respondents asked to state what

Table 3 Details of the three case study fisheries used during stakeholder interviews. The number of vessels and vessel lengths were extracted from UK fisheries activity database.

Fishery	ICES areas fished	Number of vessels in 2011	Average vessel length, m	Fishery description
Southwest <15 m trawl fishery	VII e, f, h	14	13.3	The south west trawl fishery is highly mixed targeting around 50% TAC species and 50% non-TAC species. Fishers expect to see a reduction in TAC and new technical measures but the fishery is relatively data deficient, and discards are largely regulatory in nature. Because of the mixed nature of the fishery, fishers fear that if blanket technical control measures are applied it could result in loss of valuable species.
Southwest >15 m gill and tangle net fishery	VII e, f, g, h, j	12	18.6	The southwest gill/tangle net fishery targets hake, pollack, monk and turbot. Fishers have issues with zero-TAC on non-target species and by-catch of spur dogs, porbeagle sharks, skate and undulate rays result in considerable discards. Fishers would like to improve data collection to inform science and management and validate compliance by developing a 'code of practice'.
Irish Sea >10 m Nephrops trawlers (vessels from Anglo-Northern Irish Producer Organization based on Kilkeel and Portavogie)	VII a	29	18.2	The Irish Sea Nephrops trawlers target only a handful of species. The fleet is subject to cod-recovery effort control restrictions despite claiming low cod by-catch. Skippers would like to demonstrate (through full documentation) low cod by-catch and provide a basis for dialogue over removal or relaxation of effort control measures.

would incentivize them to collect their own data during fishing operations. The respondent scored each incentive they provided on a scale of 1–5 to indicate whether the incentive has a small effect = 1 or large effect = 5 on them collecting their own data.

5. Section E gathered the respondent's perceptions on the strengths and weaknesses of the various approaches and technologies to fully document fishing activities. Respondents were asked to rank (using 1–10 where 1 = the most suitable and 10 = the least suitable) how they perceived that the different technologies and approaches could deliver FDF. The list included REM/CCTV, self-sampling, reference fleet, onshore grading machines, at sea scales, gear-in gear-out sensors, electronic log-books, net sensors and some blank cells to add any other approaches.

All skippers and PO managers in each case study fishery were invited to take part. One declined to participate in the interviews saying that he had filled in lots of questionnaires before and nothing had changed. A total of 26 responses were received comprised eight skippers and one PO manager from the southwest netters, seven skippers from southwest trawlers and nine skippers and one PO manager from the Irish Sea Nephrops trawlers. All data collection took place in November and December 2012.

Data analysis

The willingness, capacity and sample frequency to collect data for measures of fishing location, discards of commercial and non-commercial species were summarized based on the number of fishers who had responded to each category. Responses to the open-ended questions on the practical considerations on which or how fishing practices might change and on the additional fishing effort required for skippers to collect their own data were analysed for common themes or topics using text-mining. The responses were amalgamated, with similar words transformed to one consistent term and common stop words such as 'a', 'and' and 'the' removed, with the remaining text tabulated into a word-frequency using R package 'tm' (Feinerer *et al.* 2008). The words that appeared more than once were plotted with the size proportional to the frequency of occurrence of the word using word cloud (Fellows 2013). As a final step the resultant illustrations were cross-checked with the comments received in the questionnaires to ensure the meaning was not misconstrued in the process of transforming sentences to word clouds.

A list of all the incentives required to collect the data as provided by each respondent was developed and closely related incentives mentioned by respondents were merged. For instance, respondents who indicated direct payment, money for crew, money for scientific fishing, money and compensation as incentives were all merged into direct payment. Similarly, where the respondents mentioned additional quota, extra quota, quota and quota increases as incentives, these were merged into additional quota. The average score for each incentive was multiplied by the number of times that the incentive had been mentioned to calculate an overall score for each incentive. The mean, median and standard deviation of scores provided by respondents on the strengths and weaknesses for each technology and approach was plotted.

Stakeholder workshop

In addition to the fishers interviews in the three case study fisheries, a two half days stakeholder workshop was held to provide a focused discussion on the direction, challenges and opinions on the various technologies and approaches that have been used to document catch in the past or have the potential for this task in the future. The workshop also provided an opportunity to discuss relevant drivers and incentives necessary for the adoption of the methods that might help deliver and implement the requirement for FDF. Participants were drawn from fisheries science, management, policy, technology, fishers' organizations and retailers, and came from England, Scotland, Norway, the Netherlands and Canada. The stakeholder workshop included presentations on various current REM/CCTV trials, self-sampling, catch control systems, size sampling and discussions on the application of FDF and discard ban. We present findings from these stakeholder interviews and workshop below.

Willingness, capacity and sample frequency for collecting own data

The case study interviews indicate that fishers would be willing to collect further information on a range of fishing activities and catch (Table 4). Fishers indicated that the collection of fishing location, time, estimating weight and boxes of fish

Table 4 Summary responses from fishers and PO managers (n = 26) on their willingness, capacity and sample frequency for collecting data on fishing location, discards of commercial and non-commercial species showing the number of fisher who responded to each measure.

	Willingness		Capacity			Sample size				
Parameter	No	Yes	Easy	Limited	Not possible	All hauls	Some hauls	By haul	By day	By trip
Location										
Latitude and longitude of haul	3	18	18	3	1	15	5			
Time of shooting and hauling	1	20	19	3		15	6			
Depth fished	3	19	17	3	2	16	4			
Lengths of retained catch	19	3	2	3	17				1	1
Discards of commercial fish										
Estimated weight of discards	4	18	15	5	2			11	6	1
Estimated quantity of discards (no. of large fish, no. of baskets)	2	20	15	7				11	6	3
Measuring the sizes of a sample of discards	9	13	5	11	6			5	5	3
Reason for discarding		22	17	5				12	5	4
Discards of non-commercial fish										
Identifying non-commercial species	5	17	16	2	4			11	4	1
Presence of non-commercial species in haul	1	21	18	3	1			12	6	2
Estimated weight of non-commercial species discarded	6	15	10	5	6			10	3	1
Estimated quantity of non-commercial species discarded (no. of large fish, no. of baskets)	5	16	10	5	6			10	4	1
Measuring the sizes of a sample of non-commercial species discarded	10	11	4	8	9			3	6	1

discarded, reasons for discarding as well as identification of non-commercial species could be achieved easily. However, most felt that they were either limited or not capable of measuring the lengths of fish in the retained catch. They stated that this was due to a lack of time, and sometimes there were simply too many fish to measure. Some respondents felt that measuring lengths could be better achieved by fisheries observers. Some, however, expressed support for measuring lengths of a sample of discards, which they felt could be achieved when time permitted and subject to the amount of workload at the time. Some respondents indicated that it would be difficult to record the depth where fish were caught because depth varied considerably within a tow. The fishers also expressed interest in collecting other types of information such as rubbish (litter), survival of non-commercial species, cetaceans in the area and number of other vessels fishing nearby.

In terms of sampling frequency, the majority of respondents indicated that they were willing to record fishing location (position, time of shooting or hauling and depth fished) for all the hauls in the fishing trip (Table 4). For estimates of quantities, weights and species discarded as well as identification of non-commercial species, respondents indicated that these could best be collected for each haul. Fishers, however, added that the number of variables measured would depend on the workload at the time.

Advantages and disadvantages of data collection

When asked to provide advantages and disadvantages of collecting their own data during fishing operations, fishers stated that additional data would provide science and management with information that was of a greater resolution than currently collected on fishing activities and catches (Fig. 1a). Fishers also felt that the collection and use of such data would build trust with scientists, and potentially yield cost savings. Conversely, fishers felt that collection of any additional information would be time-consuming, create extra work and therefore would require additional crew (Fig. 1b). A need to control for bias so as to ensure consistency with the data was highlighted by respondents to the interviews as well as during discussions at the stakeholder workshop implying that mechanisms for effective data validation needs to be put in place.

In terms of practical considerations that might hinder data collection or hamper the ability to provide information consistently and precisely, fishers noted that weather condition would have a strong impact, as rough weather would mean that it was not possible or safe to undertake additional tasks. Some fishers stated that they would require additional crew, whereas others said that they would need to change their sorting practices to accommodate data collection (Fig. 1c). Limitations on deck and sorting space as well as accommodation for additional crew were constraints identified by fishers if they were to actively participate in data collection (Fig. 1d). Comparison of the themes shown in Fig. 1 with the original responses shows that the sense of the messages provided by respondents

Figure 1 Themes extracted from the responses to open-ended questions provided by fishers and PO managers on (a) advantages and (b) disadvantages of data collection, (c) additional effort required to collect data and (d) practical considerations for fishers to actively collect their own data. The size of each word is proportional to the number of times it was mentioned.

was same and therefore the words were not taken out of context.

Incentives for FDF

Fishers provided ideas for a variety of incentives that would encourage them to collect data during fishing operations (Fig. 2). The most frequently mentioned include direct payment, additional quota and the ability to receive more days at sea. Trust between government and the fishing industry and especially in terms of the uses of data was also mentioned strongly by respondents, with some stating that they would not want the data they collect to be used against them. Some respondents indicated that what would incentivize them is knowledge that they were collecting up-to-date data to improve fisheries management that hopefully would lead to better fishing opportunities.

Merits of technologies and approaches to FDF

Overall, respondents favoured the idea of using a reference fleet or self-sampling as a future method of implementing FDF in their fishery (Fig. 3a). This was evident for southwest netters (Fig. 3b), whereas southwest trawlers ranked self-sampling ahead of onshore grading machines and a reference fleet. Irish Sea Nephrops trawlers, on the other hand, ranked a reference fleet as their preferred approach, with self-sampling also scoring highly (Fig. 3d). None of the three case study fisheries ranked REM/CCTV as their preferred choice, which is surprising given the growing number of trials taking place in Europe using this technology. It is worth noting that some skippers who have firsthand experience of using REM have looked on the technology more favourably (e.g. Cefas 2010) and that none of the fishers that took part in the survey has participated in REM trials before. This may reflect the belief that REM systems require appropriate incentives in the right circumstances in order to gain acceptance by the fishing industry (Cefas 2010; Sustainable Seafood Coalition 2013).

When asked to highlight the strengths and weaknesses of the various approaches, respondents considered REM/CCTV to save time stating that it is tamper-free, consistent and accurate. However, fishers perceived that it had weaknesses including that it was considered an enforcement tool rather than a means of data collection. Most felt it to be an intrusion, with 'big-brother' being a term frequently used in relation to the use of REM/CCTV. There were also concerns about how the footage will be used, with the negative perception of discarding potentially damaging the image of the fishing industry. Concerns were also raised regarding equipment failure, blind spots and whether it was suitable in small vessels.

For self-sampling, respondents felt that it is simple to use, has the ability to provide more data cheaply and has buy-in from the fishing industry leading to trust in the data as fishers themselves are collecting them. Some of the weaknesses that were highlighted include self-sampling being time-consuming and there were doubts on accuracy of the data collected. Respondents also felt that it would depend on who was taking part and that there was a potential for bias, and even falsification of data. For reference fleet, respondents felt that it could provide accurate real-time data in a transparent and less-intrusive manner, and would provide fishing industry evidence to support fisher's beliefs on issues in the fisheries and accurately reflect changes in fisher behaviour. Weaknesses highlighted by respondents include how representative a reference fleet might be, given the diversity of fisheries (different areas, different methods) and the need to ensure funding for such a scheme.

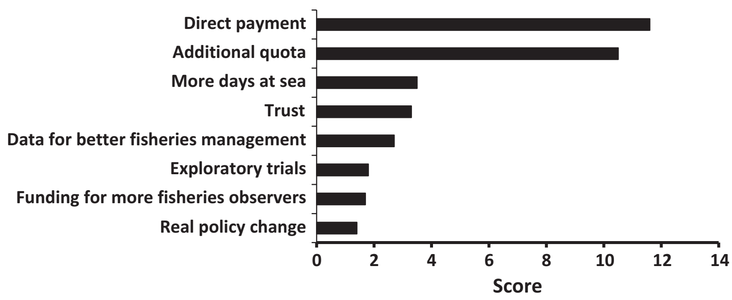

Figure 2 Scores for incentives provided by fishers and PO managers that could encourage active data collection during fishing operations based on responses from interviews.

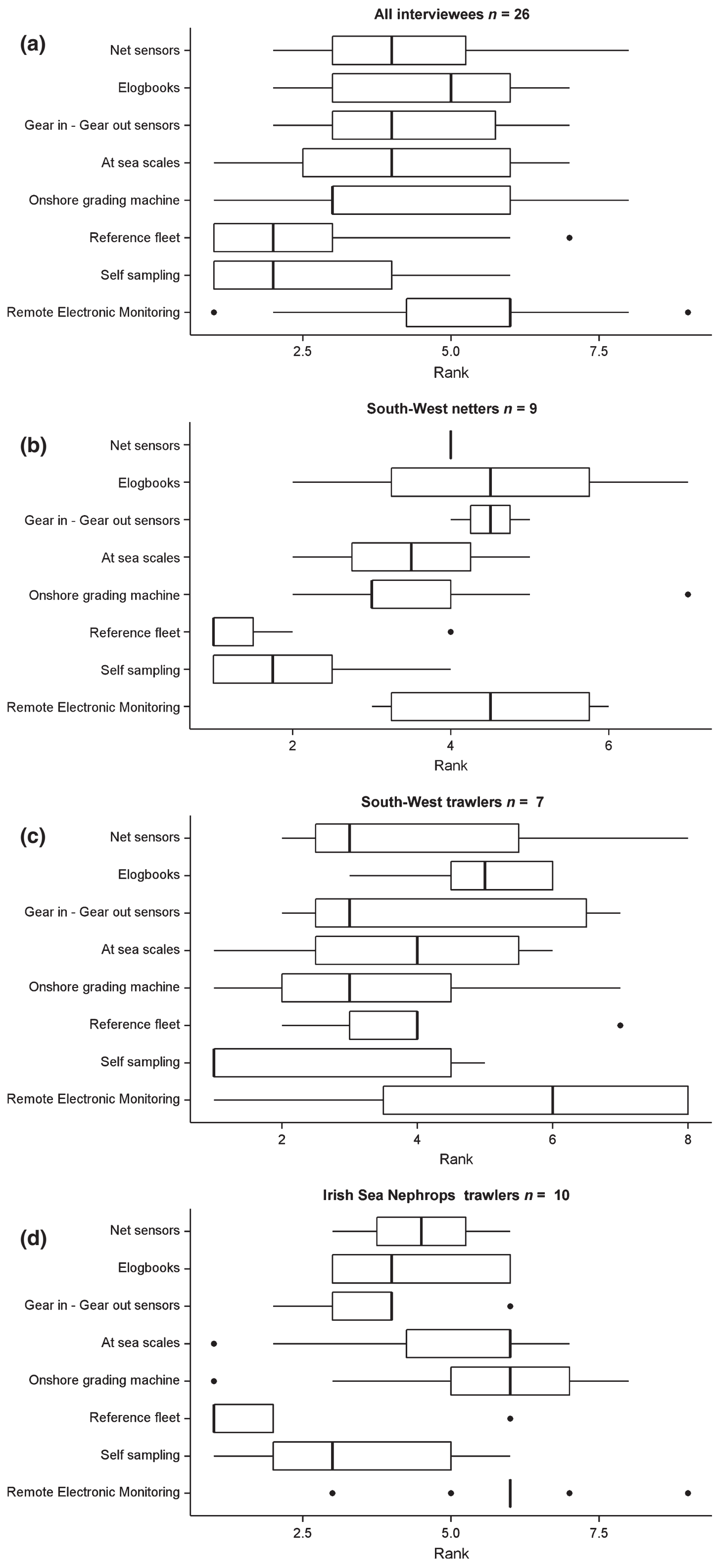

Figure 3 Box plots of ranks provided by fishers and PO managers on the suitability of each technology and approach to provide FDF, overall and by fishery.

Onshore grading machines were considered by respondents to provide accurate data on year classes; do not add time to fishing operations and would be lighter on workload. Respondents also mentioned that grading machines were already being used in some places (e.g. Lorient, France) and therefore could be rolled out widely. Weaknesses of grading machines include concerns about space on board for landing all the fish caught, and the additional mortality of discards when some fish might otherwise survive if discarded straightway. Concerns were also raised about the logistics of landing everything including non-marketable fish. These concerns are however, a result of the policy to retain all fish on-board rather than the technology. Some fishers were also unclear on how onshore grading machines could apply to *Nephrops* fishing. With regards to at-sea scales, respondents felt that at-sea scales could provide more accurate weights of fish, but they would only work in larger vessels (as there was not much space on smaller vessels), and such equipment was expensive. Concerns were also raised about the accuracy of at-sea scales.

Of the other approaches, fishers felt that gear-in gear-out sensors might provide accurate information on the location of fishing but the overall feeling was of a lack of trust in the information provided and that the technology might have limited overall use. Electronic-log books were considered useful in reducing paperwork, easy to submit and caused minimum disruption when functioning effectively, but concerns were raised about reliability and technical failure, as well as cost. Net sensors are already in use in some fisheries, but were not felt to add much to the full documentation process. Other approaches highlighted were the use of social networks, websites and the use of cameras to capture incidences where rare species are caught, providing an indication of presence/absence on fishing grounds.

Summary of stakeholder perceptions towards technologies and approaches to FDF

Fisheries stakeholders recognize that there are a number of technologies already available that could support full documentation and deliver the information required for FDF. Although groundbreaking work has been undertaken on REM/CCTV systems, many recognize that REM is not suitable for all fisheries. Other technologies and approaches such as fisheries observers, self-sampling and reference fleet are suitable and may be more practical to use in FDF, depending on the objective of the programme and the confidence required in the data. There was generally support from the fishing industry for data collection and enhancement, but there remained some mistrust concerning the use of the information and in some cases a lack of tangible benefits, i.e. nothing has changed as a result. Fishers stressed that FDF will be successful if its implementation will make practical and commercial sense at a vessel level. In the medium to longer term therefore, fishers see FDF as providing an opportunity for the industry to gain benefit from increased quota to land, a reduction in regulation and simplification of rules, and the ability to demonstrate sustainability of fisheries.

Practical issues and opportunities towards FDF

The regulatory context

Effective fisheries management requires many different types of information including data on fish resources, marine environment and fishing fleets (Graham *et al.* 2011; Lordan *et al.* 2011). Enforceable, effective and affordable methods of collecting such data are therefore needed to document catch in each fishery and to provide information for policy formulation and management plans for the long-term sustainability of the fishery. Further, if skippers and vessel owners want to have a greater degree of self-management and escape from a top-down system (Gray and Hatchard 2003; van Ginkel 2005), it is increasingly important they document their activities in order to demonstrate compliance with management measures. The literature review, case study interviews and stakeholder workshop conducted in this study indicate that a variety of technologies and approaches exist or are in development that can be used to deliver FDF. The most appropriate means and methods will depend on the circumstances and objectives for full documentation whether for enforcing a discard ban (control and compliance), documentation of total catch (catch auditing) or data enhancement (scientific data collection) (Table 5). In each case, there is need for clear objectives and an understanding of the desired outcomes as well as the right incentive structure for the successful

Table 5 Summary of main issues that need consideration in taking forward each of the technology and approach to deliver specific objectives for FDF. Each technology and approach is assessed in relation to the logistics required to implement the system, coverage that may be required to achieve full documentation, data that would be provided and its quality, precision and confidence (including issues around the data validation), how much support was evident from fishing industry, and the potential cost of implementing the approach.

		Objective		
Technology / approach	Main issue	Enforce discard ban	Document catch	Biological monitoring (L-W etc.)
REM / CCTV	Logistics	Setting up equipment on vessels Size of vessel (may not be suitable for small-sized vessels) Data storage, analysis and reporting	Setting up equipment on vessels Data storage, analysis and reporting Size of vessel	Data integration and reporting More training needed Recognition software – species, lengths
	Coverage	All vessels Quantity of data to be analysed will depend on level of enforcement required and the risk	Ideally full coverage of all the vessels in the fishery with the REM/CCTV equipment Given huge logistics with data storage and analysis, setting up a reference fleet would suffice	Full coverage of all the vessels in the fishery with the REM/CCTV equipment Data analyses on a percentage of the vessels (e.g. 30%)
	Data (quality, precision, confidence, validation)	Will depend on level of enforcement, risk Validation by observer	Recognition software Validation by observer	Validation by collection of samples for onshore laboratory measurements
	Support from industry	Scepticism, viewed in a similar way to speed cameras on public roads	Technology completes the reporting process that vessels now use Who owns data, trust Who pays?	Welcome, recognition that the technology will last for the duration of the research project
	Cost	It is possible to work out a full cost based on the cost of ongoing trials	No data	Will depend on quality of data and scientific rigour required
Observers	Logistics	Will need fisheries enforcement officers instead of fisheries observers Logistical nightmare to have the required number of officers for proper enforcement	Mixture of government- and industry-employed fisheries observers	
	Coverage	Difficult to get full coverage	Fishery level % coverage will depend on precision and confidence of the data required	% Coverage will depend on precision and confidence of the data required
	Data (quality, precision, confidence, validation)	Will depend on level of enforcement/risk	Generally good Automation of data collection	Generally very good Automation of data collection
	Support from Industry	Low	High	High
	Cost	Very high Will depend on risk-based approach adopted	High Set up costs similar to REM/CCTV	approximately $975 500/year for 215 trips

Table 5 Continued.

Technology / approach	Main issue	Objective: Enforce discard ban	Objective: Document catch	Objective: Biological monitoring (L-W etc.)
Self-sampling	Logistics	Time for skippers to collect own data Developing appropriate paperwork/suitable for offshore conditions Provision of training on data recording and collection Provision of appropriate equipment Appropriate incentives	Time for skippers to collect own data Developing appropriate paperwork/ suitable for offshore conditions Provision of training on data recording and collection Provision of appropriate equipment Appropriate incentives	Appropriate incentives
	Coverage	Full coverage	Full coverage	Partial coverage
	Data (quality, precision, confidence, validation)	Concerns with quality and reliability of data collected Data usually collected in very simplified form (lowest denominator used) Limit to analyses and uses of information collected Validation by observers	Concerns with quality and reliability of data collected Data usually collected in very simplified form (lowest denominator used) Limit to analyses and uses of information collected Validation by observers	Validation by observers
	Support from Industry	Depends on incentives	Good, easy to do but time-consuming Depends on incentives	Good, easy to do but time-consuming
	Cost	No data	No data	No data
Reference fleet	Logistics	Will depend on proportion of vessels used in the reference fleet Approach/technology used	Will depend on proportion of vessels used in the reference fleet Approach/technology used	
	Coverage	Partial, determined by quality/confidence and precision of data required	Partial, determined by quality / confidence and precision of data required	
	Data (quality, precision, confidence, validation)		Depends on size and representativeness of reference fleet Can be inferred assuming patterns in the fleet are representative of the fishery Validation by observers	Possible to calculate sampling levels
	Support from Industry		Good	Good
	Cost	No data	No data	No data

implementation of FDF. Given that the CFP reform includes regionalized management, each CFP region will need to discuss and decide how, when and by what method FDF are implemented at a fishery level. Such discussions should allow tailored solutions to be developed based on the unique circumstances and conditions of each fishery, but should also ensure that appropriate mechanisms are in place to provide a common standard across fisheries in EU waters.

The CFP reform will change the regulatory framework within which fisheries operate in Europe. For instance, the species-specific total allowable catch (TAC) will be based on a limit to the total caught, rather than the proportion landed as at present. This means that fishers will need to change their fishing operations and adopt more selective fishing gear in order to maximize their income by selling more of what they catch and avoid having to stop fishing when they exhaust the quota for any one species. A wide range of gear-based technical measures to reduce the capture of unwanted fish during fishing operations have been developed and trialled in several fishing grounds. Using coverless trawls (Revill *et al.* 2006; Eustace *et al.* 2007), benthos release panels (Anseeuw *et al.* 2008; Depestele *et al.* 2008), box trawl (Catchpole *et al.* 2011), selection grids (Catchpole *et al.* 2006; Valentinsson and Ulmestrand 2008; Drewery *et al.* 2010; Eigaard *et al.* 2012), separator trawls (Rihan and McDonnell 2003; Holst *et al.* 2009; Campbell *et al.* 2010) and diamond mesh cod-ends (Graham *et al.* 2004; Madsen *et al.* 2008; Enever *et al.* 2010) have been shown to reduce discards.

Drivers and incentives

The implementation of FDF not only helps deliver the CFP reforms but is also seen by fishers, managers and scientists as providing various benefits and opportunities. To scientists, having FDF will increase the quantity and quality of data thereby supporting traditional scientific data collection and scientific assessments of fish stocks and fishing activity. Fisheries managers, on the other hand, see FDF as providing an opportunity where fishers are being accountable for all catches and allowing authorities to review and verify the accuracy of that information to a high level of confidence. Implementing FDF will therefore put more responsibility on fishers to provide accurate fishing information thereby reversing the current burden of proof (Fitzpatrick *et al.* 2011; Österblom *et al.* 2011). Fishers, on the other hand, see FDF as a method for industry driven data collection which could support relaxation from some regulatory requirements (e.g. days at sea restrictions) and provide access to improved fishing opportunities. A move towards FDF therefore presents opportunities, e.g. marketing, where FDF would provide trust and confidence for retailers in an environment with increasing consumer awareness (Bush 2010). Full documentation of the fish supply chain (from net to plate) could bring strong market incentives through information on sustainability of the species, traceability and documentation on how the fish has been caught and treated onboard. FDF also presents an opportunity for fishing businesses to increase efficiency by reducing waste (discards) which would lead to increased profits. For example, REM/CCTV trials have shown that there is an incentive for fishers to change behaviour, improve selectivity and reduce the catch of juveniles / small fish in order to maximize catch revenue (McElderry 2008; MMO 2012).

A critical first step for the successful implementation of FDF therefore is the reconciliation of top-down and bottom-up objectives for FDF. As discussed above, top-down objectives stem from managers and regulators requiring confidence and assurance that total fishing mortality is accounted for in fishing operations through a verifiable method of recording. Bottom-up objectives, on the other hand, stem from vessel owners / skippers requiring appropriate incentives such as increased fishing opportunities through quota uplifts, relaxation of technical regulation, or relaxation of days-at-sea to be built in the management system. This was demonstrated in the case study interviews where fishers indicated that they were happy to deliver more and better data to scientists to encourage better fisheries management decisions, but they were not keen on using REM/CCTV as they perceived it a control mechanism and an intrusion in their fishing activities. Fisheries managers, on the other hand, see REM/CCTV as a highly effective technical tool for monitoring fishing activities. It is important therefore that expectations from managers and the fishing industry are realistic, and in line with the overall goal of fisheries management. In order to reconcile the objectives, technology and approaches for FDF need to include a combination of regulatory measures, changes to the technical operations of the fishery (e.g. more selective gear) and economic incentives. If such an approach is adopted, the two broad objectives (regulatory and business opportunity) would not be seen as opposing but rather as the starting point in a creative process to deliver the most effective and appropriate method for full documentation.

Method of delivery

Although there was support from the fishing industry for data collection and enhancement, findings from the interviews show that there remains some mistrust concerning the use of the information. Some fishers also indicated that despite providing all the data required in past projects, nothing has changed as a result. Further, it is not clear how FDF will be approached in mixed fisheries, where several species are caught simultaneously in the same fishing operation, as the method that will be used in calculating TACs remains a challenge especially where some fisheries or countries' fisheries may result in higher levels of discards. A level playing field is therefore needed across the fisheries to ensure FDF generate confidence that the system can account for total catch, while also providing the necessary incentive for it to work. This becomes more challenging where more species are included in FDF requirements, and where there is less flexibility.

The full documentation of fishing activities will result in considerable amounts of data being acquired and therefore mechanisms for data ownership, privacy and access need to be developed during the planning stage of implementing FDF. Further, any FDF scheme will be much more than the technology that delivers it, and therefore a monitoring plan needs to be put in place including the infrastructure to support it. Cost-benefit analyses for each technology or approach or a combination of technologies needs to be conducted to establish the applicability of the approach to the fishery. For example, under a REM system, the time to review video footage and the amount of footage that needs to be reviewed differs significantly depending on the objective (monitoring for presence of discarding, monitoring discarding of a particular species, or estimating weights of discards) and the fishery (large volume high species mix vs. small volume single species). Analysis should also be completed to establish how much footage is appropriate for review to ensure satisfactory confidence levels if data were to be used for enforcement or scientific purposes. For example, a report by the Scottish Government (2011) on the amount of footage required to accurately estimate the level of discarding found that at a 10% sampling rate, discarding levels for the majority of species were significantly underestimated. This led the Scottish Government (2011) to conclude that a 40% sampling rate is required to ensure accurate estimates. If only one commonly discarded species (e.g. haddock in this example) is used, a lower sampling level (20%) was required to ensure an accurate estimate. Similar conclusions were drawn on detecting discarding events, with a 50% chance of missing discarding events of non-commercial species if only a limited sample of footage was reviewed. Public resource limitation in delivering FDF will also need to be considered so is the level of coverage required to achieve the objectives for FDF and whether direct government financing or partnership type approaches are needed to support it.

Conclusion

The originally stated purpose of this review was to address three questions:

1. What are the relative merits of different approaches and technologies to collect catch data?
2. How is fully documentation of fisheries and the available tools and approaches perceived by stakeholders?
3. What are the practical issues and opportunities towards FDF?

The short answers to these questions are (i) each approach has its strengths and weaknesses and therefore to realize the range of possible data uses, it is likely that a combination of approaches would be required. (ii) Correctly applied, FDF could deliver a range of benefits to scientists (increased quantity and quality of data to support traditional scientific data), managers (improved confidence in monitoring and compliance of fishing activities with regulations) and fishing industry (support relaxation from some regulatory requirements and provide access to improved fishing opportunities). There are several tools and approaches that are available to deliver FDF and the one(s) appropriate for each fishery should be informed by consideration of the fishery characteristics, the logistics of implementing any approach fishery-wide, the cost of setting up, maintaining and running the programme, required vessel coverage (informed by risk tolerance and cost), data requirements (including quality, precision, confidence and validation techniques) and the level of underlying support from the fishing industry. (iii) A good understanding of the objectives of FDF is required for any approach or technology to be successful. Delivering FDF will require close collaboration between fishers, managers and scientists to identify risks, scientific rigour in data collection, manage expectations and build trust and confidence that the data gathered are accurate and are appropriately used. Such collaboration should identify the barriers, incentives and potential benefits for FDF for each stakeholder category, including how the benefits are to be realized. Once a collective understanding of the requirements, objectives and goals of FDF are established, the specific technology, approach or combination of approaches should be discussed and adopted.

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