Electronic Monitoring in Fisheries

A.T.M. van Helmond

Propositions

1. Electronic Monitoring (EM) is the only catch monitoring method in fisheries that is resilient to outbreaks of airborne diseases such as COVID-19.
   (this thesis)
2. The use of Electronic Monitoring (EM) leads to a paradigm shift where the fishing industry has ownership of data and becomes an actor in a result-based management system.
   (this thesis)
3. Scientific models should be used to make a process easy to understand or to visualise, not to reflect the true nature of reality.
4. Scientists are unconsciously biased and not consistent with scientific reproducibility, when including internet search engines, e.g. Google, in systematic literature reviews.
5. To overcome the human limitation to process large amounts of data we need to evolve to Artificial Intelligence driven workflows.
6. The widespread use of smart phone by teenagers in the Netherlands results in a deterioration of the motor skills required to win the FIFA World Cup.

Propositions belonging to the thesis, entitled

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Contents

CHAPTER 1

1

General introduction

The lack of sufficient catch information to support fisheries management

Sustainable fishery management relies on obtaining accurate estimates of fish abundance and the mortality imposed by fishing (Beverton and Holt, 1957; Hilborn and Walters, 2013). These accurate estimates could be derived from population models that are fit to reliable data, including catches (Punt et al., 2006; Rijnsdorp et al.,2007; Dickey-Collas et al. 2007; Aarts and Poos 2009). However, lack of sufficient catch data to support sufficient management of fisheries is a global problem (Uhlmann et al., 2014; FAO, 2020). From small-scale inland fisheries to advanced large-scale fisheries, not all fish caught are accurately documented (Punt et al., 2006; Zeller et al., 2017; FAO,2020). Fishery managers are confronted with insufficient or total absence of catch registration, which leads to mismanagement and failure of sustainable use of marine resources and conservation of biodiversity (Castello et al., 2012; Bradley et al., 2019; FAO, 2020). Biological overfishing leads to economical overfishing, which creates economical loses. A significant part of the world's major fish stocks are overfished, estimates on the number of stocks that are overexploited vary between 28% and 33% (Oceana, 2009; Froese et al., 2012; FAO, 2020). Even in countries with data registration systems in place, e.g. vessel monitoring systems (VMS) and obligatory electronic logbook registration systems, not all fish caught is registered. At sea, part of the catch may be thrown overboard, so called "discarding", with, for many species, low changes of survival (Kelleher, 2005; van der Reijden et al., 2017). Discarding is generally considered a waste of natural resources and goes often unrecorded (Uhlmann et al., 2014). Because discards may make up a large part of the total catch (Kelleher, 2005; Ulleweit et al., 2010; Uhlmann et al., 2014), knowing how much is discarded is important for providing advice on catch quotas.

The International Council for the Exploration of the Sea (ICES) provides catch quota advice for more than 250 individual fish (and shellfish) stocks, predominantly located in the North Western regions of Europe. For assessment purposes, ICES classifies the stocks into six main categories on the basis of available knowledge. Categories one and two represent stocks for which the available data and information allow an analytical assessment and provision of stock size information. But over 60 percent of the stocks fall into categories three to six and are graded as information-limited, due to lack of or insufficient data and knowledge to be able to carry out a full quantitative assessment. The lack of data varies from insufficient time series in catch information, due to lack of scientific monitoring, to no available catch information at all.

Including incomplete or biased catch estimates in stock assessment models results in a substantial loss of precision of predictions in stock abundance, making it difficult to detect trends (Dickey-Collas et al., 2007). Attempts to improve precision of catch estimates on population level have been partially successful (Aarts and Poos, 2009; Depestele et al. 2011; Cook, 2019; Suuronen and Gilman, 2020). Without intensive sampling, the high variation in catches in space and time is difficult to grasp in models (Amandè et al., 2012). An additional difficulty is the variation in catches caused by individual fishers. Tradition, culture, knowledge, experience, vessel constraints, regulation, enforcement, market and information sharing proved to be important drivers of the behaviour of fishers (Branch et al. 2006; Little et al. 2009; Paterson, 2014). The lack of recording of such detailed information on the individual level of fishers make it impossible to realistically model the behaviour of fishing fleets and, therefore, accurately estimate catch compositions on fishing fleet level.

Clearly, there is a need for more detailed high-quality fisheries data to get a better understanding of the condition of marine resources (Michelin and Zimring, 2020). There is a need for accurate and routine reporting and profiling of catch compositions per fishing operation. Every day, millions of fishing vessels go out at sea to catch fish, and only a fraction of these vessels provide detailed and complete information, e.g. detailed recordings of activity and catches, necessary to protect the productivity and biodiversity of the marine environment and eventually, the livelihoods of those depending on it.

Data collection in commercial fisheries

Collecting accurate catch information from fisheries is generally a logistically complex, expensive, and time consuming operation (Kindt-Larsen et al., 2011; Bradley et al., 2019; Suuronen and Gilman, 2020). Innovation to overcome these challenges are minimal or non-existent, as a consequence, the process of collecting catch information did not evolve during the last century. Most likely, initial data collection of fisheries started with early naturalists' descriptions of fish fauna, including information on presence, perceived abundance, size, etc. In case of Dutch fisheries, early recordings on collection of catch information originate from late 16th century in the handwritten 'Fish Book' by Adriaen Coenen, 1577 – 1581 (Bennema and Rijnsdorp, 2015). Another example is the historic record of landings from Northern Adriatic fish markets in Venice, Trieste and Rijeka (Fortibuoni et al., 2017). The start of data collection for fisheries research should however be defined at the end of the 19th century, when, in response to a rapidly increasing exploitation of fish stocks, a start was made in systematic collection of fisheries and catch statistics (Rijnsdorp and Millner, 1996; Barrett et al., 2004; Berghahn and Bennema, 2013). In 1902, the International Council of the Exploration of the Sea (ICES) was established, which embedded international cooperation in fisheries research, for most European countries, including data collection. Together with the development of fishery models by Beverton and Holt (1957) and the founding of the North East Atlantic Fisheries Commission in 1946 regional management of European fish stocks was initiated. Unfortunately, fish stocks and ecosystems were already heavily affected before systematic data collection and fisheries management was established (Bennema and Rijnsdorp, 2015; Kerby et al., 2012; Engelhard et al., 2016; Posthumus and Rijnsdorp, 2016). One could argue that the lack of reliable catch information on fisheries originated as early as mankind started to develop large-scale fishing industries. Perhaps, partly because information on how much where was caught could was basically a trade secret that should not be shared with competing fishers. But also the perception that the sea and oceans are immune from environmental degradation, that it provides a seemingly never-ending supply of seafood (Pauly et al., 2000).

A more coordinated approach in the collection and management of fisheries data was established much later. Since 2000, data collection was regulated within the European Union (EU) as the Data Collection Framework (DCF), enforced through a series of regulations accepted by the European Commission (EC 1543/2000 and EC 199/2008, from 2017 onwards: EU 2016/1701, EU 2016/1251, 2019/909, 2019/910 and EU 2017/1004). The DCF states which information should be collected, managed, and made available by EU Member States for scientific advice regarding the Common Fisheries Policy (CFP). For this purpose all European member states are obliged to submit a work plan for data collection in the fisheries and aquaculture sectors on a multiannual basis. Future plans on the data collection within EU fisheries are described in the Multi-Annual Programme (DCMAP). The aim of the new DCMAP is to have a stronger focus on regional cooperation of fisheries data collection. According to the EU, harmonized data collection efforts will improve the quality of the collected information. Institutes in other relevant fisheries regions have similar standardised scientific monitoring programmes in place, e.g. the National Oceanic and Atmospheric Administration (NOAA) Fisheries in the USA, or the Australian Fisheries Management Authority (AFMA).

Currently, dockside and at-sea observer monitoring programmes are still the common tools to collect essential catch information. Trained personnel collect high-quality information on the biomass, length, age, and species compositions of landed and discarded catch. Dockside estimates generally cover the majority of the landed part of the catch. The overall sampling coverage of the discarded part of the catch is just a miniscule fraction, < 1%, of the total fishing effort at sea (Borges et al., 2008; Ulleweit et al., 2010; Depestele et al., 2011; Uhlmann et al., 2014). On board, the ability of observers to take representative samples of the catch is limited, using small subsamples of large catch volumes, resulting in imprecise catch estimates. Fish are measured one by one on a measuring board and findings are recorded with pencil and paper. At a later stage these records are manually entered in digitalised systems, a labour intensive process that is prone to errors.

In the process of extrapolating discard quantities from a sample to a fleet-wide estimate it is generally assumed that data collected by observers on board can be exchanged for unobserved fishing trips. This is a risky assumption because the deployment of observers over fleets is seldomly fully random (Cotter and Pilling, 2007; Benoit and Allard, 2009; Faunce and Barbeaux, 2011). Often, getting observers on board depends on the willingness of fishers to participate in monitoring programmes. In addition, even when complete randomness could be achieved, changes in fishing practice or fishing locations may occur when observers are present on board or not; the so called 'observer-effect' (Benoit and Allard, 2009). The observer effect results in different catch compositions when observers are on board compared to usual fishing practices and behaviour. Both deployment and observer bias are inherent to observer sampling programs and difficult to quantify (Cotter and Piling, 2007; Uhlmann et al., 2014).

Despite these shortcomings, onboard-observer programmes often remain the only source of independent, verifiable information available for fisheries managers. Despite the known risks of unrepresentativeness and potential bias (ICES, 2014), this information is still used for decision making and management evaluation. One of the most striking examples is the use of imprecise discard estimates to evaluate a comprehensive policy like the landing obligation of the European Union (EU) (Holden, 1994; EU, 2013; Borges et al., 2016; Uhlmann et al., 2019). The landing obligation requires that the complete catch, landings and discards, of species under quota and/or minimum fish size regulations (MCRS) need to be reported and landed. This landing obligation was hailed as one of the key elements of the reformed Common Fisheries Policy of the European Union in 2013 (Salomon et al., 2014). So far, implementation and enforcement of this new regulation have proven to be a challenge (Alzorriz et al., 2016; Borges et al. 2016; Catchpole et al., 2018; Uhlmann et al., 2019). Exemptions to the obligation to register all catches still make it possible to discard part of the catch, making control at sea and evaluation of compliance complex. Within its objective to strive for a pan-European fisheries management the European Commission's Directorate-General for Maritime Affairs and Fisheries (DGMARE) requests the Scientific, Technical, Economic Committee for Fisheries (STECF) to provide discard estimates for all European fishing fleets (STECF, 2021). Being aware of the extremely small sample size (< 1% of total fishing activity, which results in low precision levels), and without considering the potential bias caused by deployment effects of non-random sampling in the different national sampling programmes, the scarce amount of available discard data are raised to European fleet level (ICES 2013;

Uhlmann et al. 2014). These extrapolated numbers are also used to fill data gaps for fleets that completely lack monitoring. Not surprisingly, this results in uncertain discard estimates for a large part of the European fishing fleet. Also, the choices made in using different segmentation schemes of fleets and areas to raise discard information can result in considerable differences of discard estimates between species and stocks: A comparison between estimates discard rates by STECF and ICES for the same species and stock revealed considerable differences, i.e. up to 45% for Plaice in the Irish Sea (STECF, 2013).

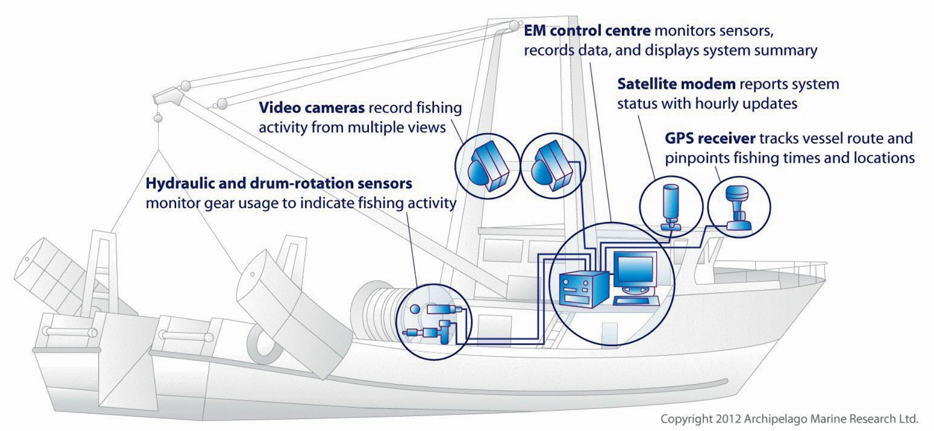
Previous studies pointed out that the European Common Fisheries Policy objectives, including the landing obligation, will be undermined without effective monitoring, control, and surveillance (Borges, 2015; Aranda et al., 2019). One could argue that the landing obligation is not in line with the availability of monitoring tools to collect fisheries information, e.g. logbooks, vessel monitoring systems (VMS), dockside monitoring, at-sea observers. Eventually, this results in disproportional raising of discard numbers and unjustifiable extrapolation of discard estimates to fill data gaps. The EU is not the only one struggling with a lack of information about discarding. The Food and Agricultural Organisation (FAO) of the United Nations assumes that the rate of discards is a function of fishery type (e.g. a fishery defined by country, area, gear and target species) (Perez Roda et al., 2019). This ignores the highly variable nature of discard information between fleets or even between vessels, which is repeatedly pointed out by scientists (Dickey-Collas et al., 2007; Uhlmann et al., 2014; Zeller et al., 2018). On the other hand, FAO recognises the general problem of limited or lack of routine monitoring. Some of the of the world’s largest inland fisheries come from basins or river systems that are facing severe threats from anthropogenic and natural environmental pressures. Lack of data constrains the ability to provide an indication of the status or health of inland fisheries and is a persistent problem in securing livelihoods in developing countries in Africa, Asia and South America (FAO, 2020).

Tackling the issue of low sampling coverage while at least matching or even improving the quality of data collection on board fishing vessels requires new technologies. Within the last two decades, Electronic Monitoring (EM) emerged as a new tool to monitor fisheries. EM, also often described as Remote Electronic Monitoring (REM), CCTV, as for the early EM-systems used closed circuit television systems (CCTV), or ‘Fully Documented Fisheries’, referring to the technology’s ability of constant surveillance, has the potential to significantly improve data collection in fisheries. The advantage over more traditional monitoring with at-sea observers is that EM is using autonomous computer-controlled camera systems to observe fishing activity on board vessels. Making use of computer systems possibly reduces the costs of monitoring and creates the opportunity to significantly increase the monitoring intensity, i.e. a computer enables non-stop monitoring in comparison with a human observer who needs to sleep, eat and go home from time to time. However, despite the foreseen advantages the adoption of EM is slow, fishing industry, managers and researchers are reluctant to its uptake. Almost twenty years after the start of the first pilot in British Columbia, there are, globally, only about one thousand vessels equipped with EM systems, an average growth of just over fifty vessels a year (Michelin et al., 2018).

Electronic Monitoring

EM systems generally consist of various activity sensors, GPS, computer hardware and cameras (Figure 1) which allow for video monitoring and documentation of catches and detailed fishing effort estimation. Pressure sensors measure force on the net tow cables in combination with net drum rotation sensors, signalling setting and hauling of the net(s). In a common EM system setup the sensors were used to trigger the control box to start video recording during fishing operations, such as hauling the net, releasing and sorting the catch on deck. After the fishing activity on deck is recorded the cameras stop, to limit storage of non-informative footage, e.g. idle times on deck without fish. The cameras record overhead views of the working deck and catch-handling areas, and register activities such as hauling the net, releasing the catch on deck and sorting of the fish by crew on conveyer belts. The recorded footage can be reviewed at a later stage to obtain catch information, for example species composition, numbers, volume and lengths. It is still common practice that EM data are stored on exchangeable hard drives. Once full, hard drives are replaced by empty drives to continue recording. Drives are usually replaced by authorized persons, for example fisheries inspectors or staff of research institutes. In some cases, i.e. compliance monitoring, data encryption is provided to ensure data protection in the chain of custody, and making it also possible to send drives by mail service. Recently, new EM systems allow wireless transmission of data via 3G, 4G, (5G) or Wi-Fi networks (in the harbour) and can be queried remotely to check if the system works properly. To avoid manual replacement of hard drives and increased convenience of accessing EM data, it is expected that wireless transmission will be progressively implemented in EM.

The initial development of EM systems was largely an industry-led process to cope with management reforms and gear theft in the Dungeness crab fishery of northern British Columbia (Ames, 2005). Archipelago Marine Research Ltd. developed the first monitoring programme using video surveillance to monitor vessel trap limits and record catch and gear theft. Each vessel marked their traps with radio frequency identification (RFID) buoys, and all vessels were equipped with camera systems. The buoys on the traps were scanned while hauling the catch on board, providing a simple and efficient means to identify the trap. In case a violation was observed, e.g. mismatch of trap ID and vessel-owner, a video clip and associated data was archived and reported (https://www.archipelago.ca/). The project was a success, number of traps hauled was accurately recorded and theft incident reduced. Currently, EM is fully integrated in the management system of the Dungeness crab fishery.



Copyright 2012 Archipelago Marine Research Ltd.

Figure 1: Overview of a standard remote electronic monitoring system setup. Courtesy of Archipelago

It was quickly recognized that video surveillance on board could also be used for monitoring and control in fisheries challenged by poor observer coverage at sea. Based on the success in the Dungeness crab fishery, the development of a more comprehensive monitoring programme was started for the British Colombia Groundfish Hook and Line Catch Monitoring Program. The EM system was tailored to the groundfish longline fishery monitoring needs, which included, besides effort, registration of catch information (McElderry et al., 2003). A first pilot started in 2001 and demonstrated that the concept of video monitoring to collect catch information for management could work. From that time on, EM developed from a system put together from 'off-the-shelf' components, to a comprehensive monitoring tool, including complete hardware and software packages to serve collecting, storing, analysing and reporting EM data. Since Archipelago Marine Research Ltd. started sharing their experiences, other small enterprises started developing and selling EM systems and services. Meanwhile, over 20 commercial companies provide services in EM around the world (https://em4.fish/). However, while EM is continuing to proof its effectivity for meeting a variety of monitoring functions, e.g. gear deployment, effort, catch, EM adoption on a larger scale remained relatively slow. So far there is no fully implemented EM programme in a single EU fishing fleet. Questions remain on the effectivity of EM in larger scaled fisheries characterised by a large catch volume, hauling in several tonnes of fish at the same time, or catch a mix of similar looking species, which could be misidentified on video image. Occlusions of fish on the sorting belts could potentially prevent a clear view of the complete catch, also the lay-out of the working deck and the positioning of cameras with respect to crew members blocking the camera view while sorting the catch (Needle et al., 2015). Fishing under constant camera surveillance and at the same time complying with the landing obligation, e.g. landing unmarketable undersized fish against quota, likely demands an increased level of flexibility in fishing operations to remain profitable. The possibility of fishers to adapt to these circumstances and the acceptance of cameras on board remains unclear. Still there is the need to improve the current situation of monitoring fishing vessels at sea. Besides better data for fisheries management and increased regulation, EM is also frequently put forward as the solution to improve traceability solutions and increased transparency of the fishing industry. There is the pressure of markets and consumers to improve accountability of fishers to be more transparent on their operations at sea. Engagement of NGO's could support the uptake EM to ensure data adequacy requirements needed for eco-labelling certification, e.g. EM could gain traction as a tool for demonstrating sustainable fishing practices (Michelin et al., 2018, Michelin and Zimring, 2020).

The introduction of EM into European fisheries started in Denmark. At the end of the 20th century EU management for cod, *Gadus Morhua*, was trapped in a vicious circle where low Total Allowable Catches (TACs) for cod led to over-quota catches, leading to discarding or illegal landings. As a result of these catches being poorly monitored and quantified, they undermined the quality and reliability of the stock assessment, leading in turn to even lower TAC advice the following year (Ulrich et al., 2011; Kraak et al., 2013). In 2008, the Danish Minister of Fisheries presented a comprehensive proposal to the EU Council of Ministers, stating that all catches and not only landings should be counted in the quota, a so called catch quota management (CQM) regime. The main objective is to create an incentive to maximize the available catch quota by avoiding unwanted catch, i.e. avoid catching and discarding juvenile cod, and break the vicious circle by restoring the basis for reliable assessments and management of the depleted cod stocks (Ulrich et al., 2015). The Danish proposal eventually led to specific regulation for cod in the North Sea. In 2010, the EU Council Regulation No 219/2010 describes, among other things, that Members States may allow vessels participating in initiatives regarding CQM regimes to make additional catches within an overall limit of an additional 5 % of the quota allocated to that Member State, participating vessels received additional quota under the following conditions: 1) the vessels make use of closed circuit television cameras (CCTV), associated to a system of sensors, that record all fishing and processing activities on board the vessel (e.g. Electronic Monitoring!), 2) all catches of cod with that vessel are counted against the quota, including those fish below the minimum landing size, 3) the additional catches are limited to 30% of the normal catch limit applicable to such a vessel or to an amount which is justified as being capable of ensuring that there will be no increase in the fishing mortality of the cod stock.

Such a CQM-trial on cod could also be interpreted as a test case for the landing obligation for a single species and the opportunity to investigate the possibility of EM to implement such a manage regime. The Dutch Ministry of Economics, Agriculture and Innovation at that time, decided that the additional cod quota of 5% should be more than adequate for a pilot study on the Dutch flatfish fleet (Miller et al., 2010). This marked the start of a series of EM studies on the Dutch demersal fisheries, which eventually resulted in this PhD study. The two main objectives of the study are: 1) determine the feasibility of EM to record catch, landings and discards, in the Dutch bottom trawl fishery, and 2) investigate the potential behavioural change of Dutch fishers in avoidance of catching juvenile cod under a CQM regime with EM.

In total, 12 bottom trawlers were equipped with EM systems. All these vessels participated in a cod CQM-scheme during a period, varying between vessels, from 2 to 5 years. This group of vessels was the basis for the different studies conducted within this thesis and formed the conceptual framework to investigate the potential of EM for the Dutch fisheries as a whole. Initial research focussed on the efficiency of EM to record the catch, and in particular discards, of a bottom trawl fisheries. So far, success of EM was reported in relatively "clean" fisheries, e.g. fisheries where catches are processed in such a manner that it was easy to detect individual fish on video footage. Hook-and-line fishing is a typical example of such a fishery because the catch is brought on deck one individual at a time (Ames et al., 2007). The exception, at that time, was the a Danish EM study on a cod directed fishery using bottom trawlers (Kindt-Larsen et al., 2011). However, the level efficiency of EM in Dutch bottom-trawl fisheries, a commercial important type of fishery in the Netherlands due to the catches of valuable flatfish species, remains questionable. The level of bycatch of undersized (flat)fish, debris and benthic organisms, such crabs, shells and sea stars, in this fishery is considerable. These large bycatch volumes could have a significant effect on the visibility of the catch on video footage. In this study, comparisons of catch recordings on board, landings and discards, and recordings based on EM are analysed to investigate the efficiency of EM for the mixed catches in the Dutch bottom-trawl fishery. The second study objective is to investigate behavioural change towards discard reduction through catch avoidance of juvenile fish. The group of fishers are granted additional cod quota and a more flexible effort cab, to be less restricted by the number of available sea-days per vessel, under the EU Council Regulation No

219/2010 (see above). Behavioural changes are analysed through a before-after-control-impact (BACI) analysis of catch and fishing activity data of peer vessels within the same fleet that are not part of the EM trials. Semi-instructed interviews are used to summarize experiences of fishers under the EM CQM regime, and provides essential background information the evaluate the outcomes of the BACI analysis. An additional EM experiment was conducted on two beam trawlers. The objective of extra experiment was to investigate the efficiency of EM in detecting discards of commercially important flat fish species sole, *Solea solea*. Sole is subject of the intended EU landing obligation and, because of the small size, potentially difficult to detect with EM. The ability of EM to detect discarding of sole and the possible implications for the implementation of the landing obligation for Dutch beam trawlers is investigated. Meanwhile the uptake of EM never reached the expected acceleration level in European fisheries. Despite its foreseen advantages the implementation progress is slow. Within this context, an additional review study is conducted on the state-of-play of EM around the world. Lessons from global experiences are used to evaluate the situation in European fisheries. Advantages and disadvantages, and potential bottlenecks for implementation are discussed.

Outline of the thesis

In **chapter 2** the efficiency of EM in the Dutch bottom-trawl fishery is evaluated. The Dutch bottom-trawl fishery differs from fisheries where EM was proven to be a successful method at that time. The combination of gear and the mesh size of the net used, 80 mm in the cod-end, generates large volumes of (by)-catch, including large quantities of debris and bottom dwelling organisms, e.g. crabs, shrimp, sea stars (benthos). This could have an effect on the effectivity on EM, since bulk of fish (occlusions), benthos and debris could block the view during video review. The hypothesis is tested that cod catches are difficult to detect with video monitoring, specifically in catches with large volume of by-catch. In 2011, a pilot study started in the North Sea which EM was used as an audit system to review the consistency of reported cod catches. Not being able to record catches of, in this case cod, would have implications for the further implementation of EM in the Dutch bottom trawl fisheries.

In addition, the effect of the transformation from a landings to a catch-quota regulated system, e.g. a test case for the landing obligation, was investigated. In **chapter 3**, the observed changes in fishing behaviour are described and analysed. Twelve participating vessels received a 30% increase in individual quota for cod and were compensated with extra effort in days at sea. In return, all cod catches were counted against their cod quota. EM provided the opportunity to observe actual changes in fishing behaviour of twelve vessels for multiple years. During this period EM systems recorded videos of all fishing and catch processing activities onboard.

EM is more and more presented as a solution to document all catches through video observations under the EU landing obligation. Based on the pilot studies of cod and the forthcoming landing obligation, knowledge on the ability of EM to detect smaller, and for Dutch bottom trawlers economically more important, flatfish species became more relevant. The study in **chapter 4** compared logbook records with video observations for catches to test efficacy of EM for different size classes of sole (*Solea solea*) on board Dutch commercial bottom trawlers. Not being able to accurately detect the smallest size class of sole (below 24 cm) on video footage, is a strong indication of the potential challenges the EU will run into after the implementation of the landing obligation at a larger scale.

So far, the uptake of EM in fisheries data collection programmes in Europe remains low. However, in other regions in the world, there are many cases EM has proven effective for meeting a variety of monitoring functions. Particularly when integrated in existing monitoring programmes EM could be a powerful tool in providing data for management, research and industry driven initiatives. To get a better understanding of the state of play of EM **chapter 5** presents the insights gained from a review of 100 pilots studies and 12 fully implemented EM programmes worldwide and, within this context, European experiences with EM are evaluated. EM could provide European fisheries the advantage in increased cost-efficiency and, as a result of that, provide an extensive monitoring coverage, which would significantly increase the quality of fisheries information. However, improved understanding of the fisher's concerns, for example intrusion of privacy, liability and running costs, is necessary. Also, explaining the fishing community the potential EM benefits on the long run, e.g. increased transparency, improved data quality and, as a consequence of that, opportunities in eco-labelling, sustainability claims and increased market access, may enhance implementation on a large scale.

In **chapter 6** an overview of the findings of the thesis is presented including a discussion on the main assumptions of studies. Furthermore, I discuss the bottlenecks of EM implementation and the outlook of EM in fisheries management, particularly in the context of the European landing obligation.

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CHAPTER 2

2

How effective is electronic monitoring in mixed bottom-trawl fisheries?

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Abstract

In the context of the landing obligation under the European Common Fisheries Policy, electronic monitoring (EM) is often presented as one of the solutions to fully document catches. EM includes video monitoring to record the catch handling process on board the vessels. This study evaluated the efficacy of EM for cod (*Gadus morhua*) catches on vessels in a mixed bottom-trawl fishery and tested the hypothesis that cod catches are difficult to detect with video monitoring, specifically in catches with large volumes of bycatch. In 2011, a catch quota pilot study started for cod in the Dutch bottom-trawl fishery in which EM was used as an audit system to review the consistency of reported cod catches. Eleven vessels joined the pilot study on a voluntary basis. Participants received a 30% increase in individual quota for cod and were compensated with extra effort in days at sea. In return, all cod catches were counted against their cod quota. This mixed bottom-trawl fishery differs from fisheries where EM was proven to be a successful method, e.g. hook and line or single-species fisheries with low bycatch volumes. And we conclude that distinguishing small numbers of cod in catches of mixed bottom-trawl fisheries is difficult because there is a low correlation between logbook and video data (Pearson r=0.17). We expect similar difficulty in other mixed demersal trawl fisheries with large bycatch volumes, when similar-looking species are targeted. Meanwhile, implementing a landing obligation will pose large challenges for fisheries with large volumes of bycatch. Limitations in the applicability of EM to control one of the most common types of fisheries in Europe will be a burden on the implementation of the European landing obligation. Improved protocols and technical adaptations may reduce some of the limitations encountered in this study.

Introduction

Fishery management often relies on obtaining accurate estimates of fish abundance and the mortality imposed by fishing. These estimates of fish abundance and fishing mortality are derived from population models that are fit to data, including catches (Beverton and Holt, 1957; Punt et al., 2006; Rijnsdorp et al., 2007). In many fisheries, not all fish caught are being landed and sold; part of the catch may be thrown overboard ("discarded"; Kelleher, 2005). Discarding fish may occur because of market conditions or because of fishery management regulations such as minimum landing sizes or quotas (Catchpole et al., 2005; Rochet and Trenkel, 2005; Poos et al., 2010). The traditional European quota system attempts to manage catches by setting quotas on landings (Holden, 1994). However, constraining landings may not reduce total catches because fishers optimize the use of their quota by discarding low-valued fish (highgrading), or fishing continues after quotas have been reached and all quota species are discarded (Gillis et al., 1995; Daan, 1997; Squires et al., 1998). The alternative to setting quotas on landings is to set quotas on total catches and, therefore, managing the total removal of a particular fish stock. In such a catch-quota regime, fishers are held accountable for the total amount of fish caught, including discards. Consequently, this could create the incentive for fishers to maximize their individual quota and avoid catching undersized fish (Condie et al., 2013, 2014).

Implementing a catch-quota system requires that the complete catch (landings and discards) is reported and deducted from the available quota. A phased implementation of the obligation to fully report all catches (EU, 2013) is planned in the context of the European Common Fisheries Policy (Holden, 1994). For several fisheries on pelagic species, the implementation starts January 2015, and the obligation to fully report all catches will be in place for all European fisheries by January 2019.

Remote electronic monitoring (EM) is often presented as one of the solutions to fully document catches (Mangi et al., 2013). EM systems consist of GPS, cameras, and sensors for measuring force on the tow cables and net drum rotation, all connected to a control box (McElderry et al., 2003). These systems allow full coverage of a vessel's fishing activity and the monitoring of all catches using video technology (McElderry et al., 2003; Ames et al., 2007; Stanley et al., 2009, 2011; Kindt-Larsen et al., 2011). Driven by the successful reduction of discards in catch-quota trials for cod (Gadus morhua) in Denmark (Kindt-Larsen et al., 2011) and the Scottish conservation credits scheme (Holmes et al., 2011; Needle et al., 2014), a catch-quota pilot study for cod in Dutch commercial fisheries was started in the Netherlands. This pilot study was initiated in 2012 as a collaboration between the Dutch Ministry of Economic Affairs and the Dutch National Federation of Fishermen's Organisations.

Previous studies on the efficacy of video monitoring concluded that EM is a reliable and accurate method to independently estimate catches on board vessels (McElderry et al., 2003; Ames et al. 2007; McElderry, 2008; Stanley et al., 2009, 2011). In all of these studies, catches were processed in such a manner that it was easy to detect individual fish on video footage. Hook and line fishing is a typical example of such a fishery because the catch is brought on deck one individual at a time. The exception is the Danish study on fully documented fisheries by Kindt-Larsen et al. (2011), where a seiner and several trawlers were included in the trials. However, the catch weight observations in that study were categorized in large intervals (see Kindt-Larsen et al., 2011), and the difference between video and logbook observations cannot be accurately quantified.

The Dutch pilot study included trawlers and (Scottish) seiners. There are several differences between the Danish and Dutch pilot projects. The Danish pilot was implemented in a fishery that targets cod year-round (Kindt-Larsen et al., 2011). In contrast, the Dutch pilot study is applied to a fishery that targets multiple species using various types of bottom trawl gear, e.g. otter trawl, seine (Scottish), or beam trawl, and frequently using small mesh sizes (80 mm) to target smaller demersal species. Cod is only targeted during a relatively short period of the year, typically <2 months, using a mesh size >120 mm. The Dutch fishery for cod is relatively small and economically less important than the Danish cod fishery, i.e. the Dutch national quota was <10% of the Danish quota in 2013.

The aim of this study is to evaluate the efficacy of remote EM for cod on vessels in a mixed fishery that does not target cod year-round. We use the Dutch demersal trawl fishery as a case study. We test the hypothesis that cod catches are difficult to detect with video monitoring in mixed fisheries. Specifically, we use periods of the year when fishers in the pilot study target flatfish, with large amounts of bycatch of fish and benthic species (Catchpole et al., 2005; Uhlmann et al., 2014). We do this by comparing logbook and video records for two aspects: (i) systematic differences between logbook records and video observations, and (ii) correlation between logbook records and video observations.

In the context of the Common Fisheries Policy and its landing obligation, this study gives important insight in the applicability of EM to fully report or verify reported catches, in this case for cod, in a mixed bottom-trawl fishery. A substantial number of European fisheries are identified as discard-intensive mixed bottom-trawl fisheries (Uhlmann et al., 2014). Considering the scale of the fleet and the level of discarding within these fisheries, reporting and controlling all catches will be a demanding task. Reliable methods to accurately monitor catches on board commercial fishing vessels are an important part of this process.

Methods

Data collection

Vessels in the pilot project participated on a voluntary basis. All vessels with cod quota were contacted by representatives of the national fisheries organization. To create an incentive for participation, participants received a 30% increase in individual quota for cod. In addition to the extra quota allowance, deploying EM on board was compensated with a derogation on national effort control regulations. The vessels using EM on board were allowed to continue fishing after the effort cap of this fleet was reached. All interested fishers were allowed to participate. The resulting study fleet consisted of two groups of vessels participating during 2012–2014. The first group consisted of five vessels, with 221 kW engine power. These vessels used otter trawls or beam trawls, depending on season and target species. The vessels used a wide range of mesh sizes from 20 to 130 mm. The second group consisted of six vessels, with engine powers between 677 and 1471 kW. These vessels used Scottish seines with a range of mesh sizes between 80 and 130 mm, depending on season and target species (Table 1).

Table 1. Overview of participating vessels and observed hauls.

Vessel group	Number of vessels	Engine power (kW)	Vessel length (m)	Observed hauls <120 mm	Observed hauls ≥120 mm
Bottom trawl	5	221	20 – 28	17	39
Scottish seine	6	677 – 1471	25 – 42	42	23

For vessels participating in the project, all cod catches, including discards of undersized fish, were counted against their cod quota. Also, vessels were fitted with EM systems consisting of GPS, up to four closed-circuit television (cctv) cameras, and sensors for measuring force on the tow cables and net drum rotation. All sensors and cameras were connected to a control box with exchangeable hard drives for data storage (McElderry et al., 2003; Kindt-Larsen et al., 2011). The sensors were used to trigger the control box to start video recording during fishing operations. The cameras recorded overhead views of the working deck and catch-handling areas, while fishing, hauling, and processing the catches (Figure 1). Sensor and GPS data were recorded continuously while at sea. The EM system and the video analysis software were developed by Archipelago Marine

Research Ltd. The installation costs per vessel were ca. 10 000 euro, and the annual running costs per vessel were ca. 4000 euro.

In addition to video observations on the catch obtained from the EM system, fishers filled in catchweights (kg) per haul in a logbook. Catch weights of legal sized (>35cm) and undersized cod (≤35 cm) were distinguished in the logbook. To estimate weight, the larger vessels generally have a scale on board, while the smaller vessels estimate catch by eye. A selection of the hauls was used for further analysis. This selection was made in a stepwise procedure. First, all trips with video recordings were matched to logbooks from those trips. Not all trips could be matched and analysed. Because of no EM data (due to technical failure or hard disks that were not replaced in time), 35% of the trips could not be used for further analysis, and missing logbooks for ca. 19% of the trips. As a result, only ca. 46% of the trips could be used for further analysis. Next, image quality was evaluated for each fishing day in those trips. For 75% of the fishing days, image quality was sufficient for video analysis, while 25% could not be used because of dirty lenses. From the days with sufficient image quality, ca. 10% of the hauls were randomly selected for analysis.

For the selected hauls, the logbook catch records were compared with catch estimates from video analysis. Based on analysis of video images, the number of cod per haul was counted. These estimates were done for the length categories of <35, 35–46, 46–55, 55–72, 72–88, and >88 cm. Length estimates were done visually by comparing each fish with a colour-coded tape with red and white markings that was used as a length reference in the image (Figure 1). Numbers per length category were converted to weights per category using a length–weight relationship of the form $W = aL^b$, where W is the weight in grammes and L the length in centimetres. Parameter values were taken from Coull et al. (1989), with a being 0.020475 and b being 2.8571. For individuals in each length category, the midpoint of the length interval was used, except the smallest and largest categories. For the length category, <35 cm, fish were assumed to be 35 cm; likewise for the category >88 cm.

Exploratory data analysis

First, we explored the data using simple statistics. Visual inspection of the statistical distribution of catches suggested that these are lognormal distributed. To correct for this in statistical tests that assume normality, a common logarithm transformation was done on all catch data. Because there were zero catches for both video and logbook observations, we added unity. For the sake of convenience, we used $\log_{10}$ in further explanations in this paper. In the exploratory data analysis, we also analysed the difference in weight between the logbook and video observations as a function of the weight estimated by the video observation. This was done for untransformed and for log-transformed data. Finally, we produced scatterplots of the estimated catches in weights for the logbooks and video observations by vessel and mesh-size category for visual inspection.

Figure 1. *Screenshot of the video images from four cameras on one of the vessels in the pilot study, including the vessels stern with net drums, the catch handling area, and an overview of the deck.*

Comparing logbook and video data

The relationship of catches between logbook and video can be explored from two aspects (Figure 2): systematic differences and correlation. With the analyses for systematic differences, we studied whether video overestimates or underestimates catches relative to the logbook. On the other hand, correlation investigates how the estimate from video changes according to the logbook, or whether they follow a linear relationship. In the ideal situation, we would expect no systematic difference and high correlations between logbooks and videos (white points in Figure 2a).

Systematic differences could derive from unintentional errors, possibly as a result of a specific setup flaw of the monitoring system, e.g. the inability to correctly estimate catch fromvideo. Systematic differences could also derive from participants under- (or over-) reporting catches compared with those observed on video. Since the two monitoring methods were tested in matched hauls, a straight forward way to quantitatively analyse the systematic difference is to apply a paired t-test on catch records between logbook and video. However, interactions of factors such as vessel or mesh-size category and monitoring method are not considered in a paired t-test.

To consider these interactions, we also fitted the log-transformed catch data per haul to the following original full model:

$$\mathrm{Log(catch)}_{ij} = V_i\gamma + \beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + V_i\delta m_j + \alpha_i + \varepsilon_{ij} \quad (1)$$

$$\alpha_i \sim N(0, \sigma_\alpha)$$

$$\varepsilon_{ij} \sim N(0, \sigma_s)$$

where $\log(\mathrm{catch})_{ij}$ refers to the observed catch in the ith haul and jth survey method [either video ($m = 0$ when $j = 1$) or logbook ($m = 1$ when $j = 2$)]. The mesh-size category is defined by s [either <120 mm ($s = 0$) or ≥120 mm ($s = 1$)]. Vessel is included as a factor variable, where V_i is a dummy vector with length equal to the number of vessels; its kth element is 1, if the observed catch belongs to the kth vessel, and 0 elsewhere. γ and δ are vectors of coefficients (in length equal to the number of vessels), specifying the effect of vessel, and their interaction with survey method, respectively. Coefficients $\beta 1$, $\beta 2$, and $\beta 3$ indicate monitoring method, mesh size category, and their interactions, while a_i indicates the random effect of the matched haul subscripted by i. We then used the Akaike information criterion (AIC) to further simplify the model. All statistical analyses are done using R software (R Core Team, 2014), using the "nlme" package (Pinheiro et al., 2013). In R, the model is implemented as "logCatch ~ vessel × method + mesh × method, random = ~1|haul" using the "lme" method.

The significance of the method effect (or whether $\beta 1$ is different from zero) indicates whether video yields, on average, a higher (or lower) catch record than logbook. If we are only interested in $\beta 1$ and the interaction effects are insignificant, a paired *t*-test of catch records between video and logbook would suffice.

The correlation between video and logbook catches was calculated by the Pearson correlation coefficient (Pearson's *r*). Pearson's *r* specifies the linear dependence between log-transformed video and logbook records, where 1 is a total positive correlation and 0 is no correlation.

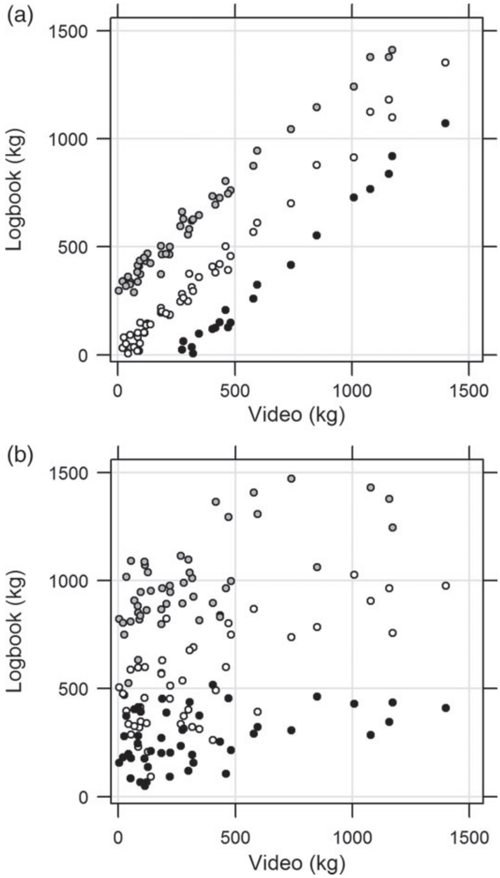

Figure 2. Illustrations of the systematic difference and correlation relationships between catches from video and logbooks. (a)Catches from video and logbooks have high correlation, while the average of logbook is higher (grey), equal (white), or lower (black) than video. (b)Catches from video and logbooks have low correlation, while the average of logbook is higher (grey), equal (white), or lower (black) than video.

Results

Data exploration

During the period 2012–2014, the 11 participating vessels completed 1610 fishing trips, from which 121 hauls were randomly selected for comparison with video data. The estimated catches of cod reported in the logbooks ranged between 0 and 1622 kg, with 25 hauls having cod catches of 0 kg. The estimates of cod catches derived from the videos ranged between 0 and 1484 kg, with 18 hauls having cod catches of 0 kg. The median cod catch estimates for the logbook and video observations were 33 and 31 kg, respectively.

The difference between catch estimates derived from logbook and video observations increased with an increase in the magnitude of catch records (Figure 3a). Isolines in Figure 3a indicate the absolute difference between video and logbook as a percentage of the video estimates. Ca. 65% of the compared observations differ by >30%. Application of a common logarithm transformation corrected for the increase in the difference with an increase in the magnitude of catch records, and results in the difference being expressed on a relative scale (Figure 3b). Because $\log_{10}$(logbook) 2 $\log_{10}$(video) = $\log_{10}$[(logbook)/(video)], the difference in the common log domain is equivalent to checking the ratio of catches between logbook and video.

Table 2. Model selection results.

No.	Formulation	Log likelihood	d.f.	AIC
1	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + V_i \delta m_j + \alpha_i + \varepsilon_{ij}$	-174.8	26	401.7
2	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + \alpha_i + \varepsilon_{ij}$	-180.3	16	392.7
3	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + V_i \delta m_j + \alpha_i + \varepsilon_{ij}$	-177.5	25	405.1
4	$V_i\gamma + \beta_1 m_j + V_i \delta m_j + \alpha_i + \varepsilon_{ij}$	-199.4	24	446.8
5	$\beta_1 m_j + \beta_2 s_i + \beta_3 s_i m_j + \alpha_i + \varepsilon_{ij}$	-186.9	6	**385.9**
6	$V_i\gamma + \beta_1 m_j + \beta_2 s_i + \alpha_i + \varepsilon_{ij}$	-182.9	15	395.8
7	$\beta_1 m_j + \beta_2 s_i + \alpha_i + \varepsilon_{ij}$	-189.5	5	389.0
8	$V_i\gamma + \beta_2 s_i + \alpha_i + \varepsilon_{ij}$	-183.0	14	394.0
9	$V_i\gamma + \beta_1 m_j + \alpha_i + \varepsilon_{ij}$	-204.8	14	437.5
10	$\beta_1 m_j + \alpha_i + \varepsilon_{ij}$	-222.1	4	452.3
11	$\beta_2 s_i + \alpha_i + \varepsilon_{ij}$	-189.6	4	387.3
12	$V_i\gamma + \alpha_i + \varepsilon_{ij}$	-204.9	13	435.8

Figure 4 gives the scatterplot between $\log_{10}$(logbook) and $\log_{10}$(video) by vessel. From the systematic difference perspective, if some vessels tend to overestimate the logbook, while others not (or the other way around), this would be an indication of an interaction of vessel and monitoring method. In other words, the effect of monitoring method on the catches differs among vessels. Logbooks from vessel 9, 12, 15, and 17 tend to overestimate the catches in the logbook, while other vessels do not show a difference between logbook and video. Although there seems to be no strong interactions between vessel and monitoring method, we decided to keep vessel monitoring method interaction in the model in analysing the systematic difference. From the correlation perspective, we see a different correlation of the two methods between small and large catches, defined by a solid diagonal line. Catches from both methods seem to be highly correlated in large catches (upper right corners of each panel) and much less correlated in small catches (lower left corners of each panel).

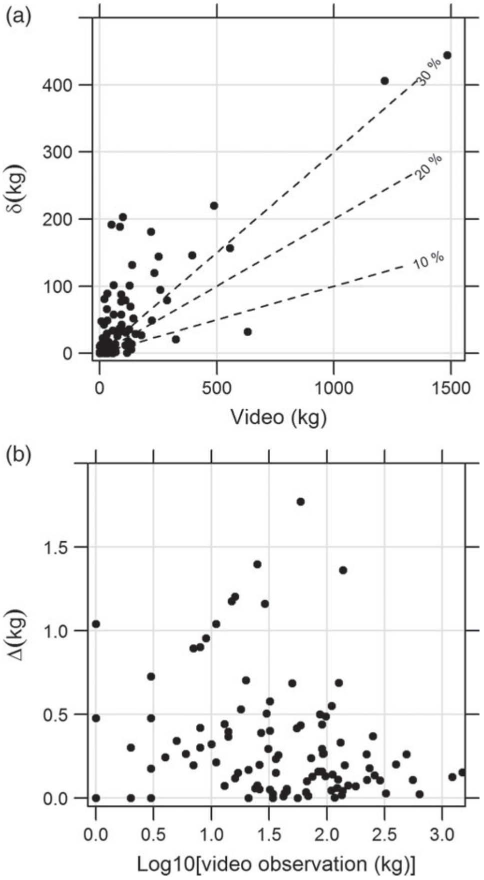

Figure 3. *(a) Absolute difference between catch estimation methods δ and catch in video observations before log-transformation. Dashed lines are isolines of δ as a percentage of the estimated catch from video. (b) Difference between* log_{10} *transformed catch estimation methods Δ and* log_{10} *transformed catch in video observations. Note that unity was added to all log-transformed estimates.*

Figure 5 gives the scatterplot between $\log_{10}$(logbook) and $\log_{10}$(video) by mesh size category (<120 vs. ≥120 mm). It seems that hauls made with the larger mesh size (≥120 mm) tend to obtain higher catches of cod than those with smaller mesh size (<120 mm) from both monitoring methods. From the systematic difference perspective, if one mesh-size category tends to overestimate the logbook (or the other way round), while others not, this would be an indication of a mesh-size monitoring-method interaction. In Figure 5, we observe a higher average catch in the videos compared with the logbooks for the small catches, and a lower average catch in the videos compared with the logbooks for the large catches. Therefore, we decided to keep mesh-size monitoring method interaction in the model in analysing the systematic difference. From the correlation perspective, similar to Figure 4, we observe a different correlation from large catches to small catches. Furthermore, the correlation seems to be different between mesh size categories. Therefore, we decided to analyse the correlation of the two methods by catch size as well as by mesh-size categories.

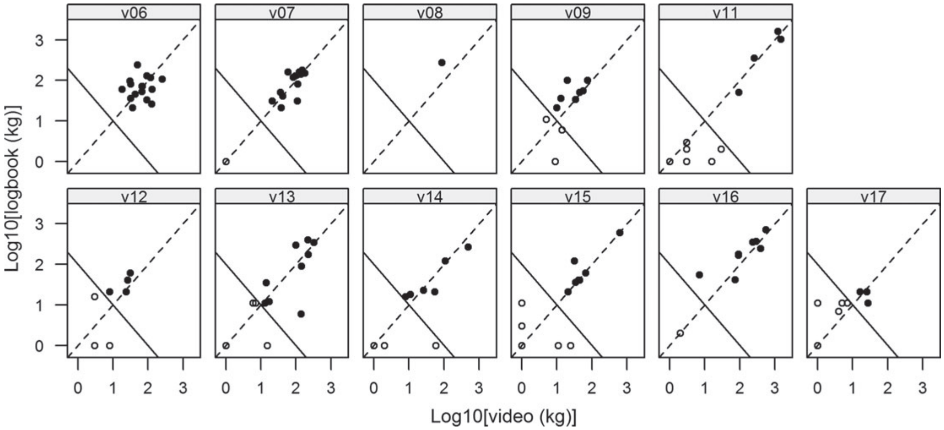

Figure 4. Scatterplot of $\log_{10}$(logbook) vs. $\log_{10}$(video) by vessel. Each panel represents a vessel. The diagonal dashed lines correspond to the ratio of 1. The solid diagonal lines distinguish small catches (in the lower left corners of each panel) from large catches (in the upper right corners). This diagonal line is defined by $\log_{10}$(logbook) + $\log_{10}$(video) = 2.

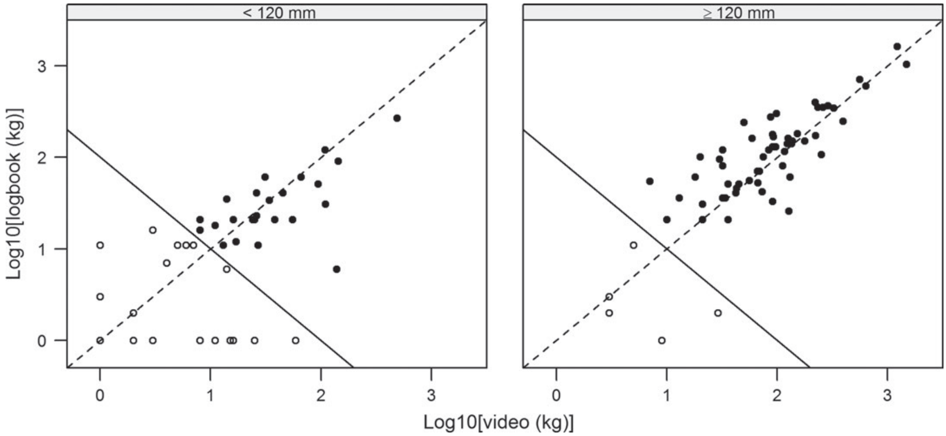

Figure 5. Scatterplot of $\log_{10}$(logbook) vs. $\log_{10}$(video) by mesh-size category. Each panel represents a mesh-size category. The diagonal dashed lines correspond to the ratio of 1. The solid diagonal lines distinguish small catches (in the lower left corners of each panel) from large catches (in the upper right corners). This diagonal line is defined by $\log_{10}$(logbook) + $\log_{10}$(video) = 2.

Systematic differences and correlation

Initially, model (1) was applied to test the systematic differences between the two monitoring methods, while testing for the effect of vessel and mesh-size category. The model results suggest that the interaction effect of vessel and method, and the interaction effect of mesh-size category and method do not significantly explain the variation in the observations. Model selection based on AIC suggests that 5 is the preferred model (Table 2). That model contains the effect of mesh-size category, the effect of method, and their interaction on the log-transformed catches (Table 3). The mesh-size category was significantly associated with the catch (ANOVA, $p < 0.01$). The monitoring method was not significantly associated with the catch (ANOVA, $p = 0.62$), indicating that there is no overall systematic difference between logbook and video. However, the interaction between mesh-size category and monitoring method was significant (ANOVA, $p = 0.02$) at the significance level of 0.05. The interaction suggests that for the smaller mesh-size category where cod catches are low, the video observations tend to be higher than the logbook records, while the reverse holds for the larger mesh-size category (Figure 6). For the mesh-size category <120 mm, the average cod catch as estimated by the logbooks is 4.8 kg [with 95% confidence intervals (CI) 2.9–7.6 kg], while for the videos, it is 6.6 kg (95% CI 4.1–10.3 kg). For the mesh-size category ≥120 mm, the average cod catch as estimated by the logbooks is 78.9 kg (with 95% CI 53.3–116.8 kg), while for the videos, it is 67.0 kg (95% CI 45.2–99.2 kg).

Table 3. ANOVA table for fixed effects of model 5.

Model term (intercept)	Numerator d.f.	Denominator d.f.	F-value	p-value
	1	119	574.0893	<0.0001
mj	1	119	0.2455	0.6212
si	1	119	85.1333	<0.0001
mj x si	1	119	5.1682	0.0248

Table 4. The Pearson r correlation coefficient for catches by catch size and mesh-size category.

Mesh-size category	Small catches (95% confidence intervals)	Large catches (95% confidence intervals)
<120 mm	0.17 (-0.18 to 0.47)	0.60 (0.25 to 0.81)
≥120 mm	-0.29 (-0.93 to 0.79)	0.80 (0.69 to 0.88)

Small catches are defined as $\log_{10}$(logbook) + $\log_{10}$(video) <2, while large catches are defined as $\log_{10}$(logbook) + $\log_{10}$(video) ≥2 (small catch vs. large catch).

The correlations by mesh size are presented in Table 4. For small catches and small mesh sizes, the Pearson correlation coefficient between logbook and video was low and not significantly different from zero (Pearson's $r = 0.17$ with 95% CI of 20.18 to 0.47). Likewise, the correlation coefficient for small catches with large mesh sizes did not significantly differ from zero. Conversely, the Pearson correlation coefficient for large catches was high and significantly different from zero for both small mesh sizes (Pearson's $r = 0.60$ with 95% CI of 0.25–0.81) and large mesh sizes (Pearson's $r = 0.80$ with 95% CI of 0.69–0.88).

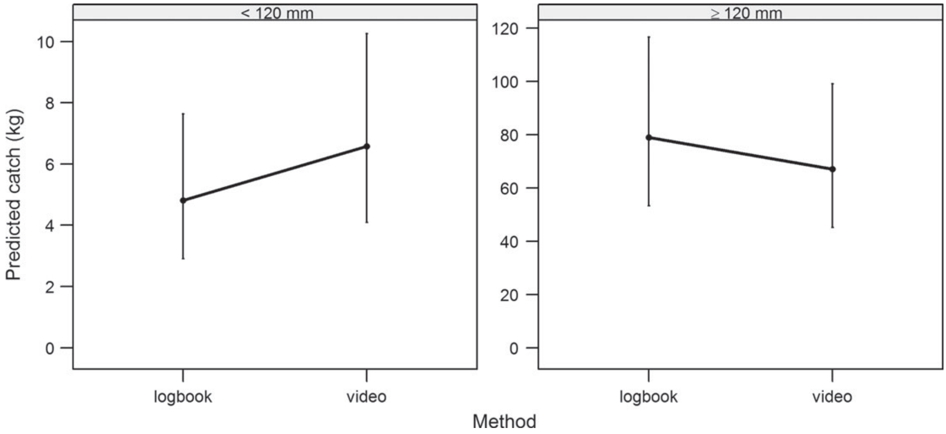

Figure 6. *Back-transformed predictions of catch as a function of observation method for the two mesh-size categories, resulting from model 5. Black dots indicate means; arrows indicate 95% CI.*

Discussion

This study estimates the systematic difference and correlation between logbook and EM video-estimated cod catches. Importantly, the EM system was installed on a heterogeneous group of vessels that fish not only for cod, but also for other demersal species. The mesh size used by the fishing vessels depends on the season and target species. A substantial fraction of the direct comparisons of cod catch weights estimated by logbook and video observations differed by >30%. According to Stanley et al. (2011), there is general agreement among managers and industry advisors in a groundfish hook and line fishery in British Columbia, Canada, that such a 30% error does not meet the operational objectives for EM monitoring.

We find that the amount of cod in the catches depends on the mesh size used. In this respect, the mesh size is a proxy for the type of fishery that the vessel is participating in, with mesh sizes ≥120 mm typically being used to target cod. The results from the analyses of systematic differences between the observation methods suggest an effect of the interaction between mesh-size category and the observation method on the estimate of the cod catches. That is to say, for the smaller mesh-size category where cod catches are low, the video observations tend to be higher than the logbook records. The reverse holds for the larger mesh-size category where the video observations tend to be lower than the logbook records. This is in contrast to Stanley et al. (2011) who found that logbooks showed a modest tendency to overestimate small catches. The analyses of the correlation between video observations and logbook records suggest that the larger catches are more strongly correlated than the smaller catches. On the log scale used in the analyses, clearly there is more variability for small catches in the observations for both methods.

It must be emphasized to point out that both video and logbook records are estimates. The video estimates require a conversion from the number of fish per species per length category to the total weight of cod in the catch. Three sources of error may be introduced in this procedure. First, species identificationmay be wrong. In mixed fisheries such as those used in this pilot study, cod is caught together with similar-looking gadoids such as whiting (Merlangius merlangus), pollack (Pollachius pollachius), and bib (Trisopterus luscus). All video reviews were done by the same reviewers with many years of experience as on-board observers in similar fisheries. Nevertheless, species identificationwas difficult when large concentrations of fish are processed on the conveyer belt. Second, the length estimates are made by visual observation, and individuals may be wrongly classified for length. Third, a length–weight relationship is used with parameters obtained from the literature (Coull et al., 1989) that does not account for seasonal or spatial differences. Logbook records did not require any conversions, but the accuracy of the logbook records relies on the skippers. Our analysis did not find a significant effect of vessel on the difference between logbook and video records. Hence, the "skipper effect" (see Squires and Kirkley, 1999) is probably low.

The limitations of using video estimates in mixed bottom-trawl fisheries could be reduced in several ways. During this study, not all hauls could be analysed. Poor image quality due to murky camera lenses was an important factor; scales, slime, mud, and water drops frequently blurred the view, specifically for the cameras used for species identification close to the conveyor belt, where crew members sort the catch. Stringent protocols to manage and maintain the equipment on board, particularly the camera lenses, would improve image quality and eventually species identification. Possibly an automated warning system, triggered when image quality is insufficient or a substance sticks to the camera lens, would help fishers maintain a clear camera view. Meanwhile, advances in resolution and light sensitivity of digital cameras can improve image quality soon. However, external factors such as lighting (day and night), distance from target, and weather conditions will still affect image quality (Ruiz et al., 2013).

Commonly on European bottom trawlers, the catch is hauled on board and large volumes of catch are immediately placed on the conveyor belt. A method or protocol for managing the volume of catch on the conveyer belt to allow recording of all individual fish would improve the documentation of the catch by video-based monitoring (Hamid et al., 2012; Ruiz et al., 2013). Images of individual fish would ensure that all fish are counted and would facilitate species recognition by video reviewers. Ultimately, the species identification could be made using computer vision (Strachan et al., 1990; Storbeck and Daan, 2001; White et al., 2006). When fish could be recorded individually and move alongside a scale of reference, e.g. measuring board or tape with banded pattern, accuracy of length estimates made by video reviewers can be improved. Alternatively, computer vision would allow fast and accurate length or weight estimations of individual fish (Storbeck and Daan, 2001; White et al., 2006). However, ensuring that individual fish can be recorded by camera would require either changing the conveyor belt system such that high belt velocities can be obtained or that the catch is brought onto the belt at a low pace. While the first option would likely require substantial investments and possible increase in costs, the latter option increases the handling time of the catch. Computer vision generally requires high light intensity and high contrast images, and would probably also require changes to the camera system or conveyor belt.

Based on the results of this study, we conclude that distinguishing small numbers of cod in catches of small-meshed gears is difficult. We expect similar difficulty in other mixed demersal trawl fisheries with large bycatch volumes where similar looking species are targeted. Still, the results appear encouraging for using EM for control purposes: the system is only inaccurate when the number of cod in the catch is low. Nevertheless, mixed bottom trawling is a common type of fishery in Europe (Uhlmann et al., 2014). In those fisheries, small numbers of cod, or any other target species, will be difficult to distinguish in large volumes of discards for these fisheries. Meanwhile, implementing a landing obligation will pose large challenges for fisheries with large volumes of bycatch. Limitations in the applicability of EM to control one of the most common types of fisheries in Europe will be a burden on the implementation of the European landing obligation.

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CHAPTER 3

3

Changes in fishing behaviour of two fleets under fully documented catch quota management: Same rules, different outcomes

Published as

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Abstract

A Dutch pilot study of fully documented fisheries provided the opportunity to observe actual changes in fishing behaviour under catch quota management (CQM). Interviews with fishers in the pilot study aided in interpreting the results and giving insight in the decision making process and reasoning of fishers. The CQM pilot study entailed a fleet of small and large demersal vessels. For these vessels, all cod catches were counted against quota, including catches of individuals below minimum landings size. To obtain reliable catch data all vessels were equipped with electronic monitoring (EM) systems. These systems recorded videos of all fishing and processing activities on board. In return, fishers received a 30% quota bonus for cod and were compensated with more flexibility on effort regulations. It was hypothesized that vessels in the CQM will (i) increase their landings by 30% according to their quota bonus, (ii) increase the use of gear with large mesh size, and (iii) change effort towards fishing locations with high catch rates of large cod and avoid areas with high catch rates of undersized cod. The results showed that CQM had no effect on fishing behaviour of the small vessels. In contrast, large vessels significantly increased their cod landings (216%) and avoided undersized cod. This difference in response of different fleets suggested that implementation of CQM, for instance in the context of the European common fisheries policy, should consider fleet characteristics. It seemed that the larger vessels in this study more easily adapted their behaviour to new management regimes and that the quota bonus opened up new fishing strategies, that were not envisaged during the implementation.

Introduction

European fishery management traditionally attempts to control fishing mortality in commercial fisheries by setting annual quotas on landings (Holden, 1994; Msomphora and Aanesen, 2015). However, constraining landings may not reduce total catches, and thus fishing mortality, because fishers may optimize the use of their quota by discarding low-valued fish (high-grading), or continue fishing and discard species after quotas have been reached (Gillis *et al.*, 1995; Daan, 1997; Squires *et al.*, 1998; Poos *et. al.*, 2010). Apart from the discarding of fish because of quota restrictions on landings, fishers also discard fish as a result of technical regulations and the economics of the fishery, e.g. fish that is caught but that is under the allowed minimum landing size, and fish that has no market value (Catchpole *et al.*, 2005). These aspects are particularly challenging in a mixed fishery context (Batsleer *et al.*, 2016; Murawski, 1996).

In general, discarding is considered to be a waste of natural resources. Indeed, the fish that does not survive after being discarded does not contribute to the future catch, as it would have if it had remained alive. Additionally, the discarded and unreported catch leads to unaccounted mortality and makes it difficult to appropriately monitor and manage the effects of fishing activities (Crowder and Murawski, 1998; Punt *et al.*, 2006; Uhlmann *et al.*, 2014). Recognizing these problems, the European Union (EU) has agreed to reform the Common Fisheries Policy (CFP) (Fernandes and Cook, 2013). The reformed CFP includes a phased implementation of the obligation to land all catches (EU, 2013).

If properly enforced, the obligation to land all catches prohibits discarding of commercial species and should serve as a driver for improved selectivity, and provides more reliable catch data (Salomon *et al.*, 2014; Condie *et al.*, 2014a; Sarda *et al.*, 2015). Implementing a landing obligation requires that the complete catch is reported and deducted from the available quota. In such a catch quota management (CQM) regime fishers are held accountable for the total amount of fish caught, including the unwanted and unmarketable (previously discarded) part of the catch. Consequently, an incentive is created to change fishing behaviour, because every fish caught is deduced from the quota, including small and low-valued fish (Msomphora and Aanesen, 2015).

In order to gain insight in the potential effects of the landings obligation prior to its full implementation, the EU established provisions in the quota regulations to conduct pilot studies on fully documented catch-quota management schemes, or “fully documented fisheries”. These provisions are established for cod in the North Sea, Skagerrak and Eastern Channel, under the condition that participating vessels use closed circuit television (CCTV) associated to a system of sensors, that record all fishing and processing activities on board. All cod catches are counted against the quota, including catches of individuals below minimum landings size. In order to create incentives for fishers to participate in the pilot studies, member states are permitted to allow additional catches of participating vessels within an overall limit of 5% above the national cod quota. However, per vessel, additional quota is limited to 30% of the normal quota applicable to the vessel (EU, 2010). Within this context, a fully documented catch-quota pilot study for cod in Dutch demersal fisheries is initiated in 2012. The pilot study is a collaboration between the Dutch Ministry of Economic Affairs and the Dutch Federation of Fishermen's Organisations. In addition to the increase of individual cod quota, the Dutch government provides a derogation on national effort control regulations: vessels deploying a CCTV on board are not limited by the available number of days at sea for fisheries with mesh size ≥ 120 mm. The idea behind this derogation is to create extra flexibility for participants to be able to operate in a catch-quota system.

So far, publications on fully documented fisheries (FDF) concentrate on the efficacy of catch documentation technology (Stanley *et al.*, 2009; Kindt-Larsen *et al.*, 2011; Needle *et al.*, 2015; Ruiz *et al.*, 2015; van Helmond *et al.* 2015; Ulrich *et al.*, 2015). The efficacy of catch documentation by video gives promising results, particularly when fish are processed in such a manner that it is easy to detect individual fish in video footage, e.g hook-and-line fisheries (Ames *et al.*, 2007; van Helmond *et al.*, 2015). However, few studies investigate changes in fishing behaviour under a fully documented catch-quota management regime and little is known about the effectiveness of the landings obligation in changing fishing behaviour. Kindt-Larsen *et al.* (2011) and Ulrich *et al.* (2015) observe that fishers participating in catch-quota trials reduced discarding of legal sized cod of low value. When asked, the participating fishers confirm that they are more aware of catch compositions than before the start of FDF, and more often change fishing grounds to avoid small cod (Kindt-Larsen *et al.*, 2011). Avoiding discarding of small cod can be achieved by fishing with larger mesh sizes and fishing effort reallocation towards fishing grounds with high densities of larger cod (van Helmond et al., 2015).

Changes in fishing behaviour in two mixed bottom trawl fleets that participate in a pilot study on catch quota management are studied. The results are used to indicate whether the changes of behaviour comply with the purpose of the regulation, i.e. avoiding undersized cod. A before-after control-impact (BACI) study of catch and effort data is used, contrasting vessels within the two fleets with their peers who are not under CQM. In addition, interviews with participating fishers about changes in behaviour under CQM are conducted. It is hypothesized that vessels in the CQM will (i) increase their landings by 30% according to their quota bonus, (ii) increase the use of gear with large mesh size, and (iii) change effort towards fishing locations with high catch rates of large cod and avoid areas with high catch rates of undersized cod.

Improved understanding of fishers behaviour, eventually, allows for a better understanding of fisheries dynamics, which in turn is essential for effective fisheries management (Salas and Gaertner, 2004; Branch *et al.*, 2006; Paterson, 2014). In the context of the Common Fisheries Policy, with the implementation of catch quotas and the obligation to land all catches, this study gives an important insight in what the significant factors are in the decision making process of individual fishers in a mixed bottom trawl fisheries under such management systems.

Methods

Implementation of CQM in the pilot study

The full documentation of cod catches was done by the participating fishers in the study. Catch weights (kg) per haul were recorded in a logbook for each fishing trip. All catches were landed and subtracted from the quota. Undersized individuals that were landed are not allowed to be sold, and were therefore collected by the control authorities.

In order to attract vessels, 30% extra individual cod quota was handed out to participants of the pilot study. This 30% quota increase was based on the total quota (owned and leased) in the previous year. In addition to the increase of individual cod quota, the Dutch government provided a derogation on national effort control regulations: vessels deploying a CCTV on board were not limited by the available number of days at sea for fisheries with mesh size ≥ 120 mm. The idea behind this derogation was to create extra flexibility for participants to be able to operate in a catch-quota system.

To verify if logbooks were filled out correctly, video observations on the catch were obtained with electronic monitoring (EM) systems. A random selection of hauls (ca. 10% of the total number of hauls) was used to compare catch recordings in the logbooks with catch estimates from video analysis, see van Helmond *et al.* (2015).

The EM system consisted of a GPS unit, up to four closed circuit television (cctv) cameras, and sensors for measuring force on the tow cables and net drum rotation. All sensors and cameras were connected to a control box with exchangeable hard drives for data storage (McElderry *et al.*, 2003; Kindt-Larsen *et al.*, 2011). The sensors were used to trigger the control box to start video recording during fishing operations. The cameras recorded overhead views of the working deck and catch-handling areas, while fishing, hauling, and processing the catches. Sensor and GPS data were recorded continuously whilst at sea. See also van Helmond *et al.* (2015) for a detailed description of the EM system set up on board of the vessels.

Study fleet

The pilot study was applied to a bottom-trawl fishery that targets multiple species using various bottom trawl gears (e.g. otter trawl, Scottish seine , or beam trawl), and mesh sizes depending on target species. Within this fishery cod is targeted during short periods of the year, typically < 2 months, using a mesh size ≥ 120 mm, or as valuable by-catch in fisheries with mesh size ≤ 100 mm, by a small part of the fleet. Vessels within this fleet were identified based on their possession of individual cod quotas and fishing effort track records. The identification of vessels in the fleet was done by the Dutch Federation of Fishermen's Organisations. In total, 40 vessels were identified as cod fishers and all were contacted by the Dutch Federation of Fishermen's Organisations.

Vessels were divided in two groups based on their engine power because in the Dutch demersal fleet vessels with different engine power exhibit different spatial fishing patterns due to (amongst others) regulations (Poos and Rijnsdorp, 2007; Rijnsdorp *et al.*, 2008). Vessels with engine power ≤ 221 kW have access to fishing grounds within the 12 nautical mile zone and within a protected nursery area; the "plaice box" (Beare *et al.,* 2013). Vessels with engine power exceeding 221 kW are forbidden in this zone. In the ≤ 221 kW engine power group, 24 vessels were contacted, of which 6 vessels participated in the study (Table 1). These vessels used otter trawls and beams trawls with a wide range of different mesh sizes, from 20 to 130 mm, depending on season and target species. Of the group in the second category (with engine powers between 677 and 1471 kW), 16 vessels were contacted, and 6 vessels decided to join (Table 1). These vessels used Scottish seines with a range of mesh sizes between 80 and 130 mm, depending on season and target species.

Catch and effort data

The CQM pilot study resulted in high-resolution catch and effort data for the participating vessels through haul-by-haul catch registration in logbooks and the EM system. However, because comparisons between vessels within and outside of the pilot study are required, only data that is available for the entire Dutch fleet can be used. Hence, catch and fishing effort data is collected from two different sources for the vessels: EU logbook data and vessel monitoring system (VMS) data. The EU logbook data contains catch and fishing effort information. Each fishing vessel must provide a logbook to the authorities at the end of each fishing trip in which more than 50 kg of fish is caught. The data comprise: vessel code; engine power; type of fishing gear and mesh size; date and time of departure; harbour of departure; date and time of arrival; harbour of arrival; landings (in weight) by species per geographic area ("ICES rectangle"). The data were obtained as the annual landing and effort for each vessel and year, where year ranges from 2010 to 2013. A "programme" variable was added to the data, indicating whether the vessel participated or not.

Table 1. Overview of participating vessels per group, including fishing effort per year. Effort is in bold for the years the vessels participated in the pilot study. Underlined vessels code names indicate that the skipper of the vessel is interviewed.

Group	Vessel	Engine power (kW)	Effort (days at sea)				
			2009	**2010**	**2011**	**2012**	**2013**
Small vessels	V08	221	120	147	**166**	**186**	**185**
	V06	221	78	139	113	**166**	**176**
	V07	221	46	47	41	**63**	**53**
	V09	221	166	179	153	**162**	**180**
	V17	221	-	-	-	**215**	**224**
	V19	221	103	147	89	173	**164**
Large vessels	V16	1052	208	231	**242**	**271**	**221**
	V14	735	220	219	**214**	**187**	**202**
	V15	677	212	214	**185**	**219**	**195**
	V13	1471	-	59	205	**243**	**235**
	V11	734	194	200	193	**192**	**216**
	V18	762	192	202	191	222	**223**

The VMS data contains information on the location of fishing vessels at a high temporal (~ 2hr) and spatial (~ 200 m) resolution. This information is available all vessels in the study. The VMS sends GPS information on board of the vessel to land-based stations using satellites. This GPS information includes the position and ground speed of the vessel. High resolution fishing effort (in hours) maps are created from the pings. First, each ping is converted to an estimate of fishing effort in terms of time by calculating the time span between all pairs of subsequent pings, and assigning it to the first ping in each pair. Then, pings that are located in fishing harbours are removed. Finally, all pings with speeds > 8 knots are removed as those pings likely indicate steaming activity of the vessels. The final maps of fishing effort are raster representations of the sum of the time associated to the remaining pings (Hintzen *et al.*, 2012).

As a first step in the data analysis, differences in cod landings between participating and non-participating vessels in the years prior to the study (2009 and 2010) were analysed using a t-test with equal variance on log-transformed landings.

BACI analyses on landings and gear use

A before-after-control-impact (BACI) analysis was used to investigate the impact of the pilot study. It was hypothesized that after joining the study, the participating vessels changed their annual landing and effort, and their behaviour is different as compared to the non-participating or "control" vessels. To adjust the annual variation in landings and effort, the vessel-year-programme data were re-structured for the pooled BACI analysis: Since CQM was employed from an increasing number of vessels in the years 2011-2013, three BACI (year-before vs. year-after) data structure can be extracted: 2010 vs. 2011, 2011 vs. 2012, and 2012 vs. 2013. Each record of the vessel-year-programme was assigned to one of the three BACI structures, or else excluded. In the BACI analysis, the change in fishing behaviour caused by the entrance in the CQM pilot study was investigated (one year before, and one year after). Therefore, a participating vessel was selected either as a control vessel in a BACI structure when it did not enter the CQM pilot study, or as a test vessel in the BACI structure when it entered the study. Afterwards, it was excluded in the analysis in the following BACI year structure. As a result, a participating vessel can be selected either as a control vessel or a test vessel in the three BACI structures, depending on whether the vessel joined the programme in the year-after (Table 2). Not all vessels could be used in the BACI structure because of missing data (Table 2). After re-categorizing the records into the three BACI structures, they were pooled as an entire BACI structure. Analysis on such pooled structure assumes that the difference in change of the fishing behaviour from the participating vessels (as compared to the control vessels) is only caused by the programme, rather than year.

The BACI method was used for testing whether (i) there was a change of the log-transformed cod annual landing from participating vessels compared to non-participating vessels, and (ii) there was a change of the proportion of annual fishing effort using large (≥120mm) mesh size from participating vessels compared to non-participating vessels. Both were tested by comparing the average change of landing or effort (year-before vs. year-after) between control and test vessels, using a two sample t-test with equal variance.

patial distribution of fishing effort

To analyse shifts in spatial fishing effort distribution, the spatial effort distribution for the study fleet was plotted in gridded maps of the North Sea. In the plots, a distinction was made between (i) vessels that were asked to participate, but never joined the CQM pilot, (ii) participating vessels prior to entering CQM, and (iii) the same vessels under catch quota management.

Table 2. Selection of vessels and their treatment types for the three BACI structures. "Test" = vessel entering CQM, "control" = vessel not entering in CQM, "NS" = not selected because already in CQM or because of missing data.

Group	**Vessels**	**Number of vessels**	**BACI**		
			2010 versus-2011	**2011 versus-2012**	**2012 versus -2013**
Small vessels	v08	1	test	NS	NS
	v06, v07, v09	3	control	test	NS
	v19	1	control	control	test
	group of non participants	13	control	control	control
	v25[*]	1	control	control	NS
	v17, v23, v24, v28, v31[**]	5	NS	NS	NS
Large vessels	v14, v15, v16	3	test	NS	NS
	v11, v13	2	control	test	NS
	v18	1	control	control	test
	group of non participants	9	control	control	control
	v12	1	NS	NS	NS
Total number of vessels		40			

[*] Vessel v25 was taken out of service in 2013, and hence could not be selected in BACI 2012-2013.

[**] Data for vessels v12, v17, v23, v24, v28, v31 were not available in the period 2010-2013.

The plots of spatial effort allocation are compared to the spatial distribution of cod Catch Per Unit Effort (CPUE) from the International Bottom Trawl Survey in quarter 3 (IBTS Q3). The survey in the third quarter was chosen because it co-occurs with the commercial fishing season for cod in the Dutch fishery. The IBTS Q3 survey uses a standardized GOV net with 20 mm mesh size in the codend. Several nations around the North Sea take part in the survey that covers the North Sea and Skagerrak area. Annual survey CPUE per length and ICES rectangle were available through ICES. Spatial distribution of abundance is calculated for the period 2001-2015 for fish sizes under and over 55 cm. The sum of CPUEs over all observed lengths within the size classes are calculated over the period 2005-2015.

Interviews

In addition to the collection and analysis of catch and effort data, semi-structured interviews were conducted with eight participants; four skippers from small vessels and four skippers of large vessels (Table 1). The interviews were conducted in order to help interpret the results and to provide insight in the decision making process and reasoning of fishers in the study. Each interview lasted for approximately one hour. Interviews were conducted in the period from February 2014 to February 2015. Fishers were visited at their docks, their ships, their homes or their local bar. Sometimes family and co-owners of vessels or companies joined the interview.

Each interview started with questions about the incentives for participating in the study. Then, data was presented on participant's annual landings of cod, effort data per mesh size category and maps of annual cod landings per statistical rectangle. Fishers were asked to comment and elaborate on this information. Annual landing information of cod was presented in the years before and after entering the pilot study. This landings information indicated whether the participant made use of the extra quota and increased cod catches. Effort data was presented as the average number of trips per year per mesh size categories of ≤ 24 (shrimp gear), 79-99, 100 -119, and ≥ 120 mm. Participants were asked to elaborate on the number of trips per mesh size category and fishing locations before and after entering the study.

Interviews were audio-recorded and converted in transcripts afterwards. Interview transcripts were analysed for common themes using text mining. Responses were analysed with the software package Atlas.ti (Friese, 2004).

Results

Study fleet

From the 24 small vessels that were contacted prior to the pilot study, the annual cod landings of the 6 small vessels that eventually participated were on average 31 tons higher in the years before the pilot study (2009 and 2010) than those that did decide not participate (Figure 1). A t-test on the log transformed weights revealed that for the small vessels, this difference was statistically significant (t = -3.70, df = 40, p-value < 0.001). For the 16 large vessels that were contacted prior to the pilot study, there was no statistically significant difference between the 6 vessels that eventually participate and those that decided not to participate (t = -0.75, df = 27, p-value = 0.46).

BACI

Landings

For small vessels, there was no statistical difference in the average change of annual cod landing between participating and non-participating vessels (*p*-value=0.53, Figure 2,Table 3). For large vessels, the cod landings decreased by = 20.6% for the control vessels. For the large vessels, the cod landings increased by = 216%. The t-test indicated that for large vessels, the average change of annual landing from the participating large

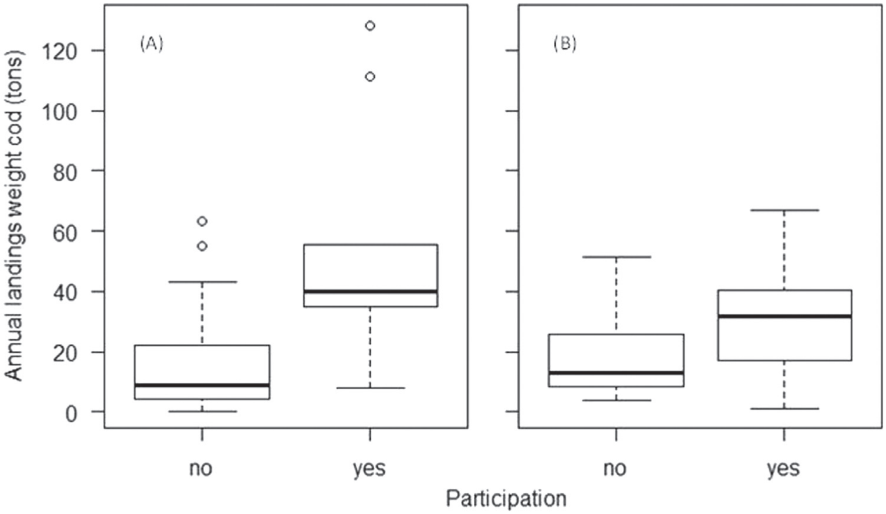

Figure 1. Box and whiskers plots of annual cod landing (t) in the period before the CQM pilot study (2009 and 2010) for (A) small vessels and (B) large vessels, that eventually decided to join the programme ("yes") or decided not to participate ("no"). Boxes represent Q1 and Q3. Thick drawn lines represent the median. The whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box.

vessels was statistically significantly different than those from the non-participating vessels (*p*-value < 0.01, Figure 2, Table 3).

Mesh size

For small vessels, there was no difference in the average change of fishing effort ≥ 120 mm between participating and non-participating vessels (p-value=0.48, Figure 3, Table 3). For large vessels in the control group, there was a decrease in the use of mesh sizes ≥ 120 mm: the percentage of fishing effort with mesh sizes ≥ 120 mm decreases by 2.7% per year. For large vessels entering the CQM pilot study, there was an increase in the use of mesh sizes ≥ 120 mm: the percentage of fishing effort with mesh sizes ≥ 120 mm increases by 8.7% per year. The t-test indicates that for large vessels, the average change of effort using ≥120 mm mesh size from the participating large vessels was statistically significantly different than that from the non-participating vessels (*p*-value=0.05, Figure 3, Table 3).

Spatial distribution of fishing effort

The spatial distribution of cod CPUE from the IBTS Q3 survey showed clear spatial variation, with higher CPUEs in the north and north-eastern areas off the Danish coast (Figure 4). Also, the contribution of large fish (≥ 55 cm) to the CPUE of the survey was higher in those areas compared to the central and southern areas of the North Sea.

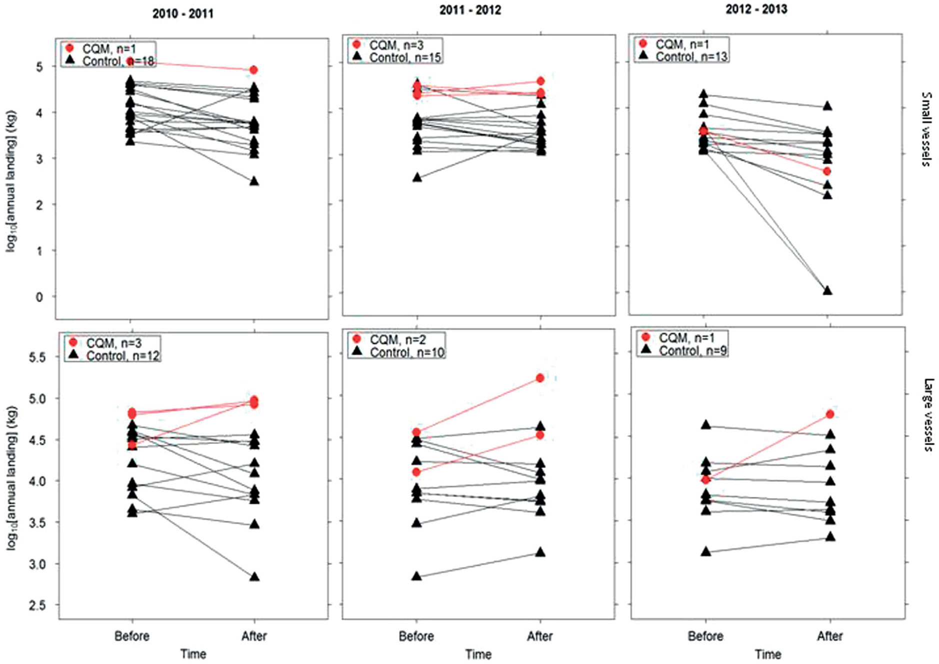

Figure 2. BACI plots of $\log_{10}$ transformed annual landing (kg) from year 2010-2011, 2011-2012, and 2012-2013, respectively. Top panels represent the small vessels, bottom panels represent large vessels. In each panel, the CQM vessels refer to vessels that switched to CQM in that period. The control vessels refer to vessels that did not participate until that year, being vessels who were offered to join but never participated and vessels starting CQM in later years. A participating vessel is plotted either as a control vessel in panel year when it did not use CQM yet, or in the panel year when it was the first year of CQM. It is excluded in the plots of the subsequent years. For instance, in 2011, three vessels (V14, V15, and V16) started CQM and they are excluded in the plots of 2012 and 2013. This procedure is repeated for vessels V11 and V13, and for vessel V18 who started CQM in 2012 and 2013, respectively.

Table 3. Comparing the change in landing and percentage of effort (in days at sea) with mesh size larger than 120 mm (year before vs. year after) between control and test vessels, using a Welch two sample t-test (equal variance).

Variable	Group	Mean change CQM vessels	Mean change control	t-value	df	p-value
Landings ($\log_{10}$[kg])	Small vessels	-0.2	-0.4	0.6	49	0.53
	Large vessels	0.5	-0.1	4.2	35	<0.01
Percentage effort > 120 mm	Small vessels	-3.7	-1.2	-0.7	49	0.48
	Large vessels	8.7	-2.7	2.0	35	0.05

For small vessels, the spatial distribution of fishing effort in the North Sea was concentrated in the Dutch coastal zone, and a number of fishing grounds scattered around the southern North Sea Figure 5a-c). There were no marked differences between the vessels that were asked but never joined, and those vessels that joined in the years before par-

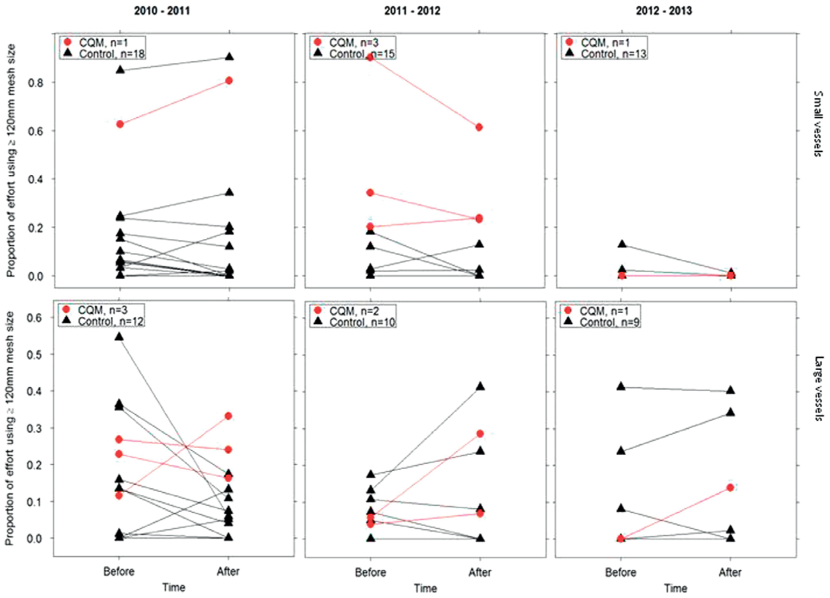

Figure 3. BACI plots of proportions of annual fishing efforts (days at sea) using ≥ 120 mm mesh size for large vessels from year 2010 versus 2011, 2011 versus 2012, and 2012 versus 2013, respectively. Top panels represent the small vessels, bottom panels represent large vessels.

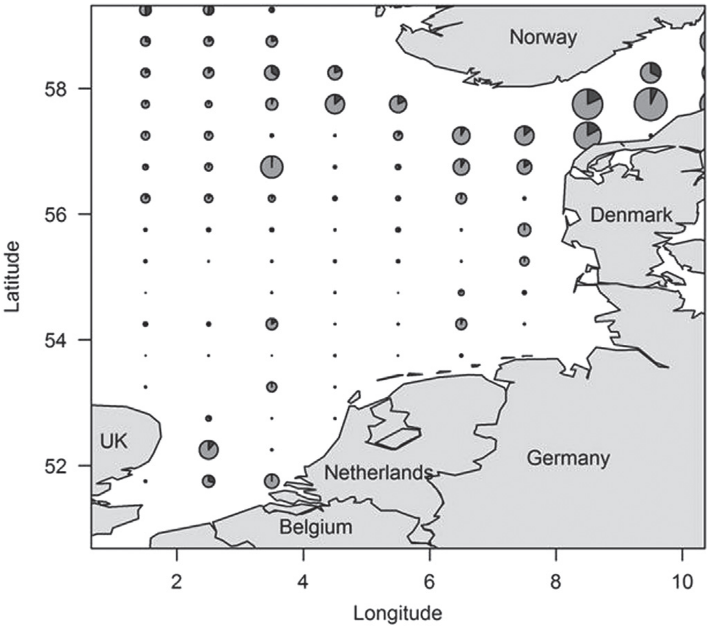

Figure 4. Spatial distribution of cod CPUE calculated from the annual International Bottom Trawl Survey in quarter 3, in the period 2005-2015. Larger surfaces of the pie charts indicate increasing CPUE. Light grey within the pie charts indicates proportion of CPUE of fish < 55 cm and dark grey indicates proportion of CPUE of fish ≥ 55 cm.

ticipating (Figure 5a vs. 5b). For those vessels in the CQM pilot study, the fishing effort was largely similar to the vessels and years for which there was no participation, with the exception of the absence of fishing effort of CQM vessels in the Sylt fishing grounds off the south-western coast of Denmark (Figure 5a&b vs. 5c), one of the brown shrimp (*Crangon crangon*) fishing grounds. However, there was no marked change in the other brown shrimp fishing grounds off the Dutch and Belgian coasts.

For the large vessels, there were marked differences between the vessels that were asked but never joined, and those vessels that joined in the years before participating (Figure 5d vs. 5e). Clearly, the vessels that eventually joined the program have a more Easterly fishing effort distribution than the vessels that never participated. The fishing effort for those vessels participating in the study showed a clear difference in the years for which the vessels participate (Figure 5e vs. 5f): there was a move of fishing effort towards the north and north west coast of Denmark, in an area that the fishers call "The Holmen Grounds". This area was associated with high CPUE of large cod in the IBTS.

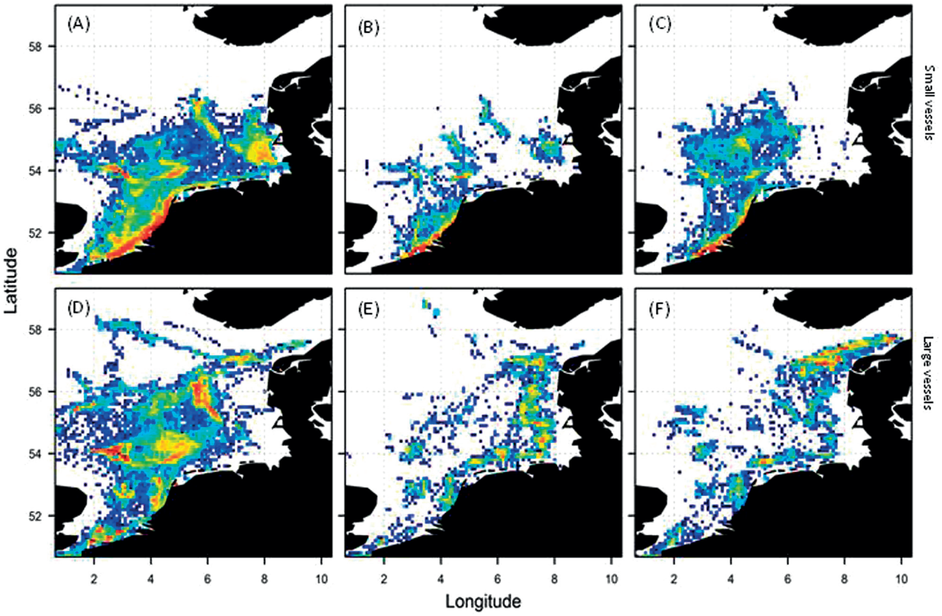

Figure 5. Spatial effort distribution for the study fleet. Warmer colours indicate increasing fishing effort. Top panels indicate small vessels, bottom panels indicate large vessels. Distribution for vessels that were asked to participate, but never joined the CQM pilot (A & D). Distribution for participating vessels in the years prior to entering the pilot (B & E). Distribution for vessels in CQM during the pilot (C & F).

Interviews

Incentives

For the skippers of the small vessels the flexibility on the effort regulation was an important incentive to join the pilot study (Table 4). Three out of four interviewed skippers mentioned this during the interviews. The flexibility on effort regulations was a sufficient incentive to participate and outweighed the presence of the cameras: two skippers of the small vessels mention that they "*have nothing to hide*". Finally, one skipper mentioned that his main motivation was the interaction with scientists that participation would bring.

For the skippers of large vessels the interviews made clear that the quota bonus was an important incentive to participate in the pilot study. For example the skipper of v14 mentions: *"The reason is the extra 30% cod that we get. It is as easy as that. To have a camera in your neck the whole day is not something you do for fun".* One skipper mentioned the increase in transparency of what is happening on board was also an important motivation to join: "*There is always sort of a haze around the fisherman*". In addition, he hoped that the cameras would show that "*...there is really enough cod to be caught...*". In contrast with the motivations given by the skippers of the small vessels, none of the skippers of large vessels mentioned the additional flexibility on the effort regulation as an important motivation to join.

Landings

No significant increase in landings of cod was observed for the small vessels after entering CQM. Three out of four skippers indicated that they observed too little cod on their fishing grounds. The skipper of vessel v07 answers: *"We tried to catch cod, but cod fishery in front of the coast seems to be finished, at least for the last two years",* while the skipper of v09 mentions *"...no cod in the area this year...",* and *"...I think cod moved towards northern areas...".*

Two skippers said that they fished on shrimps the whole year because it was a good shrimp year. Going to the fishing grounds off the Danish coast, was not an option for these fishermen, because it was either not profitable given the cod prices, or the risk for bad weather and resulting low catches was too high.

For the large vessels, interviews for two owners suggested that they had started specifically targeting cod after the start of the project on fishing grounds off the Danish coast. The skipper of V16 stated his change in targeting behaviour: *"Back then [before participation] it was not interesting to target cod. We caught cod as bycatch, but we did not* *have enough quota to specifically target cod".* One of the fishers (v14) noted however, that his change in fishing grounds was unrelated to project but that it resulted from the need to find new target species when the price of the tub gurnard had decreased (Table 4).

The large variation in the increase in cod landings among the different large vessels could be explained by the difference in attitude towards cod as target species: One of the skippers (v11) that had a small increase explains that they see cod as a bycatch: *"But we really don't go to the north with the intention, let's catch some cod, we do not have enough quota for that. But they are in the bycatch. Last year and this year were good cod years. I see it getting better".* On the other side of the spectrum there were vessels for which landings have increased by more than the quota bonus of 30%. The skipper of v16 explained that the 30% quota bonus created an incentive to rent additional quota, because the bonus was calculated on the total of owned and rented quota in the previous year (Table 4).

Mesh size

The analysis of catch and effort data did not find an increase in the use of large mesh sizes for small vessels. Effort control regulations of the common fisheries policy (EU, 2009), permits only one gear of one mesh category per fishing trip. Skippers of the small vessels did not use large mesh sizes as they did not target cod. Species that they were targeting instead required smaller mesh. Two of the four interviewed skipper of small vessels indicated that they target shrimp which are caught using small mesh sizes.

The large vessels traditionally fished with 80 mm in winter and with at least 100 mm in summer. The two skippers specifically targeting cod both do as expected: They fish with larger mesh sizes, 130 mm and 135 mm, to avoid catching undersized cod. One of these skippers (of v16) explains: *"We have started fishing with larger mesh sizes in order to let the small ones swim".* The other two large vessels fish with 110 mm and 120 mainly to target larger, more expensive plaice, red gurnard and dab. One of the skippers explains he changed to larger mesh sizes when he catches a lot of cod in order to comply with the regulations about catch composition (see EU, 2001; Kraak et al. 2013). With a lower mesh size a lower percentage of cod could be held on board.

Spatial distribution

For the small vessel skippers going north towards fishing grounds with high densities of larger cod was not profitable or too risky as the vessels were too small to cope with possible bad weather (e.g. V07, V09 in Table 4). Another skipper mentioned that even with the quota bonus he did not have enough quota for cod to make fishing in the these distant areas profitable (V19 in Table 4).

The two large vessels targeting cod confirmed that they fish off the Danish coast for large cod. They both mentioned the possibility to catch small cod at the Cleaver bank. One of the skippers said that it is not attractive to fish for cod at the Cleaver bank as he had to report catches of undersized cod, and hence they shifted their practice to the coast in front of Denmark. As a result of the change in fishing grounds both vessels regularly landed their cod in Denmark (V14 & V16 in Table 4).

The two large vessels with less cod quota did also go more north. One said that he went looking for large gurnards, dab and plaice as the price for regular gurnard was low. The skipper of the other vessel (V11) said that the project did make a difference for him as it created the flexibility to go further north*: '[Historically] we caught 2-3-4-5 thousand kilos of gurnard a week, for which we got on average 3-4 euro. So we made a good landings value with the bycatch. But then more Scottish seiners came – first we were only four – and we are now with approximately 25 of those ships that target gurnard. So the gurnards have no value anymore, and it is no longer worth it. [...] So then we went North and then you have cod as bycatch, which is really good. There is a lot of cod here. Right now you often catch 1000 kg of cod, and big ones, not small ones.'*

Table 4. Summary of interviews.

Group	Vessel	Interview	Motivation	Feedback from interview		
				Landings	**Mesh size**	**Fishing grounds**
Small vessels	V06	Skipper	More flexibility on the effort regulation. Also quota bonus and more transparency. Skipper: "*I have nothing to hide.*"	Constant cod landings overall, no difference before and after participation. Targeted other species. Skipper: " *But 2012 was of course a fantastic shrimp year. Look, if the shrimps are 4 or 5 euros, then yes, I would be crazy to go for cod if I can earn more if I go for shrimps*". Also, "*..there was no cod, due to high water temperatures..*".	Did not change mesh size. Skipper targeted Brown shrimp *Crangon crangon*, with mesh 20 -24 mm in 2012.	Skipper: "...we always fish on the same grounds, just under the coast line...". He avoids places with smaller cod. Based on experience he knows which places to avoid.
	V07	Skippers (father and son).	Quota bonus and more flexibility on the effort regulation.	Did not increase landings. Skipper 1: "*We tried to catch cod, but cod fishery in front of the coast seems to be finished, at least for the last two years*".	Skippers explained, they used 80 mm mesh to target other species then cod. Skippers feel limited in their gear/ mesh choice due to technical measures cod recovery plan. Difficult to estimate what they will catch before leaving harbour.	No shift in fishing grounds. Skippers explain it is to problematic to fish that far north, due to the weather conditions. Skipper 2: "*We can't go that far, it is out of our range*".
	V09	Skipper	Quota bonus and more flexibility on the effort regulation. Skipper: "*we have nothing to hide*"	Did not increase landings. Skipper: "*... no cod in the area this year...*", "*...I think cod moved towards northern areas...*", "*Not profitable to target cod with 120 mm last year*". "*Fifteen years ago, we caught lots of cod just in front of the Dutch coast*".	Skipper explained, he used 80 mm mesh to target other species then cod. Skipper: "*Not profitable to target cod with 120 mm...*". Skipper feels limited in his gear/mesh choice due to catch composition regulations (technical measures cod recovery plan).	No shift in fishing grounds. Skipper: "*Not profitable for us to fish that far north*". "*...we are too dependent on good weather conditions to travel to distant fishing grounds..* "

Table 4. Summary of interviews. (continued)

Group	Vessel	Interview	Motivation	Feedback from interview		
				Landings	**Mesh size**	**Fishing grounds**
	V19	Skipper	Interaction with scientists in order to be part of what is going on.	Did not increase landings. The quota bonus was not a motivation. Cod was a bycatch, skipper did not target cod specifically. Skipper: ”*There is no cod near the coast last few years. If the cod is in the area, I go for it. It need to be close to shore to make enough profit*”.	Skipper explained they fished for shrimp after he joined the pilot study. Fishers use 20 to 24 mm in cod end to catch Brown shrimp, *Crangon crangon*. Skipper: “*Made enough profit with shrimp fishery. Rather stay near the coast to target shrimp, then going off shore to catch something else*”.	No shift in fishing grounds. Did not move north to richer cod grounds. Skipper: “*Not enough quota available to make it profitable to travel that far*”.
Large vessels	V16	Skipper, his brother (deckhand), and his father (previous skipper of this vessel).	Quota bonus.	Increased landings. Start targeting cod, after participating in the pilot study. Before cod was valuable bycatch. Start to rent more quota. Fisher: “*We see more cod*”. “ *The rent for cod quota is very high. If you get 30% extra quota over your rented cod quota, the rent prices goes down in total. If we would not have gotten those 30% extra it would not have been profitable to rent*”.	Increased mesh size to target cod in North sea. Skipper: “*We started fishing with larger mesh sizes in order to let the small ones swim*”. Brother:” *It is purely to let the small ones escape*”.	Changed fishing grounds. Start targeting more cod and moved to richer cod ground based on experience. Father: *“In the north in front of the Danish coast are richer cod grounds”*. Father explains that, based on his experience they moved to that area. Start avoiding smaller cod. Father: “*Cod at the Cleaver bank. is really small*”. Skipper: ”*....we have to record the undersized, which is not attractive. That is why we shift from the Cleaver bank to Denmark*”.
	V14	Skipper	Quota bonus. Skipper: “*When the opportunity was there, we immediately joined the pilot study*”.	Increased landings. Start targeting cod. Did rent extra quota. Previous target species was Tub gurnard, *Chelidonichthys lucerna*, the price dropped at the time the pilot study was initiated.	Increased mesh size, from 100 mm to 120 mm or more (up to 135 mm) to target cod in North sea. Before, 100 mm was used regularly to target Tub gurnard.	Changed fishing activity to more Northern grounds (Denmark). Skipper avoided the “Cleaver bank”, since cod is smaller in this area.

Table 4. Summary of interviews. (continued)

Group	Vessel	Interview	Motivation	Feedback from interview		
				Landings	**Mesh size**	**Fishing grounds**
	V11	Skipper	Quota bonus.	Did not increase landings in general. Cod is bycatch.	Did not change mesh size, targets mainly gurnards and plaice with 110. Skipper: "*If we catch more cod we have to increase mesh to 120 mm* [technical measures cod recovery plan]".	Did not specifically change area to target cod. However, when prices of main target species drop, e.g. gurnards, they move northwards, but not specifically for cod. Skipper: "..*we not only move north for cod, we don't have enough quota for that...*".
	V18	Skipper (cousin of V11 skipper).	Increase the transparency of what is happening on board. In addition, the quota bonus provides extra flexibility to land the cod.	Did not increase landings in general. Cod is bycatch. Although, the extra quota did trigger additional cod landings in 2013. However, this was not the case in 2014.	Did not change mesh size, targets mainly gurnards and plaice with 110 and 120 mm.	Did not specifically change area to target cod. However, explains, that they caught more and larger cod together with commercially interesting species North in front of Danish coast. Skipper also explains that cod on the "Cleaver bank" area is smaller.

Discussion

Several studies hypothesize that catch-quotas and discard bans potentially create strong incentives to change fishing behaviour for more selective fishing practices (Batsleer et al., 2013; Condie et al., 2014b; Simons et al. 2015). Those studies use models to forecast vessel fishing behaviour based on the premise that fishers optimize a utility function. Simplifying assumptions have to be made when defining a utility function and net revenues are often used as proxies for the actual utility function of the fisher. Another simplifying assumption is that fishers with similar gears and vessels respond similarly to changes in management systems. Indeed, economic performance variables provide useful information about fisher preferences in resource use (Dorn, 1998; Sarda and Maynou, 1998; Wilen et al., 2002; Vermard et al., 2008). However, tradition, culture, knowledge, experience, vessel constraints, regulation, enforcement, and information sharing are also important elements in the rationale of fisher behaviour (Wilen *et al.*, 2002; Branch *et al.*, 2006; Little *et al.*, 2009; Paterson, 2014). Rather than relying on model predictions on the potential outcome of catch quota management, the pilot study allows observing actual fishing behaviour under CQM. Additionally, the interviews help to interpret the results and give insight in the decision making process and reasoning of fishers in the study.

It was hypothesized that all participating fishers would attempt to increase their annual cod landings, given their 30% increase in cod quotas. However, for the small vessels no significant increase in annual cod landings was observed in the BACI analysis: catches were either equal or lower after joining the study in comparison with previous year. In interviews, fishers explained that there was no cod on their fishing grounds (Dutch and Belgian coast). Two fishers described the year, in which they switched to CQM, as a good year for catching brown shrimp and that targeting shrimp close to shore is more profitable than fishing for cod. Possibly, all fishers would have switched to shrimping. However, not all vessels are fitted with the specialized equipment and gear that is necessary for the fishery on brown shrimp (Berghahn et al. 1992). The large vessels, on the other hand, did increase their annual cod landings, on average by 216%. The reason that landings have increased considerably more than 30% was that the large vessels rented additional quota. A substantial increase in quota renting is an unforeseen side effect of the pilot study. Participants receive the 30% bonus on their total quota share of the previous year, including additional rented quota. Hence, there is an indirect discount on renting cod quota, when you consider the 30% bonus for next year. Fishers confirmed this concept in the interviews. This unintended consequence of the pilot study might have triggered participating fishers to focus more on cod as they would have normally done and possibly overstated the effect of the catch quota regime in this study. Two fishers of the 'large vessel group' did not increase their cod landings under the CQM regimes. They consider cod as a valuable by-catch product when targeting other species.

It was hypothesized that vessels participating in the pilot study would increase their use of large mesh sized gear and change fishing grounds. For the fleet of small vessels, there was no significant increase in effort with mesh size ≥ 120 mm compared to the control group. Also, small vessels did not change their fishing effort towards areas with large cod. For the fleet of large vessels, there was a significant increase in fishing effort with mesh size ≥ 120 mm, and changes in fishing grounds to avoid undersized cod. These are indications that the participants change their fishing behaviour in compliance with the purpose of CQM, i.e. maximize individual quota and change fishing behaviour to avoid catching undersized cod. Part of the change in mesh size may also be explained by technical measures in the cod recovery plan (Kraak et al. 2013). This plan dictates catch limits for cod in the total catch: max. 20% cod bycatch with 80mm mesh and max. 5% cod bycatch with 100-119 mm mesh. Catches taken by demersal towed gears of mesh size equal to or greater than 120 mm are exempt from conditions relating to percentages of target and non-target species (EU, 2001). Fishers targeting plaice and gurnard with 110 mm mesh have to increase mesh size to 120 mm to comply with the regulations, when the catch consist of more than 5% of cod. Because all cod catches are registered, discarding cod to get the desired catch compositions, i.e. high grading, is not an option. Similar behaviour is observed in the study of fully documented fishery in Denmark (Kindt-Larsen *et al.,* 2011). Meanwhile, fishers that specifically targeted cod adjusted their mesh size in order to avoid undersized cod and more frequently fished on Northern fishing grounds (Danish coast). Those fishers confirmed that they avoided areas with smaller cod, such as the Cleaver bank. Other large vessels, that did not increase their cod landings, did not increase their mesh size nor changed fishing locations.

Compared to the larger vessels in the pilot study, the small vessels are more constrained by physical vessel characteristics (e.g. size, engine power) and with the existing regulations. Effort control regulations of the common fisheries policy (EU, 2009) permits only one gear of one mesh category per fishing trip. When cod is not abundant, it is not profitable to go out with 120 mm mesh. As a result, fishers of small vessels prefer to use 80 mm mesh size gears, instead of exploring cod fishing grounds with large mesh. The latter holds the risk of not finding cod and having to return home empty handed. However, when they unexpectedly start catching cod with small mesh, the cod recovery plan dictates catch limits for cod in the total catch (max. 20% cod bycatch with 80mm mesh and max. 5% cod bycatch with 100-119 mm mesh). Fishers of small vessels find it difficult to foresee cod catches before leaving the harbour. The complexity of regulations and technical measures has an effect on their fishing behaviour, as the skipper of v07 explains: "*Actually you are occupied with this* [the right catch composition] *every week, having the right percentages*". CQM possibly complicates their situation, since discarding of cod is not an option with video monitoring on board.

The derogation on the effort regulation is emphasized as an important motivator for the small vessels to participate in the pilot study. Not being limited by a lack of available sea-days provides them with the opportunity to fish with large mesh, ≥ 120 mm, and target cod at the end of the year. This would otherwise be impossible, since the scarcely available sea-days in this fleet segment (bottom trawlers with mesh size ≥ 120 mm) are normally finished before the end of the year, as a result of the fishery on cod by large vessels earlier in the year on more distant fishing grounds in the North. Skipper v09: "*We had to participate... Because there is no other way... Last year* [2011] *we still had cod quota available, but couldn't go for it, because there were no sea-days available. But, colleagues with camera's on board were allowed to go out and fish cod*". The pilot study created an opportunity for the traditional cod fishery of the smaller vessels in the coastal areas at the end of the year. This fishery now struggles with effort control that has been developed with a focus on larger scale fishing operations; an example of unfit fisheries management for small scale fisheries (De Vos & Kraan, 2015).

The methodology of the study relies on a BACI (Green 1979) approach. Ideally, the control and impacted part of the population are exactly the same. In this case, the population is created through the network of industry representatives, who are of the opinion that all contacted vessels are eligible and likely to participate. The fishers in the pilot study are offered a bonus of 30% cod quota and increased flexibility in effort regulations under the conditions that all cod catches, including discards, is counted against their quota. Rational choice theory (e.g. Scott, 2000; Segre, 2014) predicts that fishers with cod discard rates above 30%, and no options to reduce cod discards, will most likely not participate under the proposed conditions. Meanwhile, fishers with low cod discards rates, large cod quotas, and the possibility to reduce the catches of small cod, most likely, will participate in the 'burdensome' CQM project with camera's on board, because they gain most from adopting the CQM rules (Msomphora and Aanesen, 2015). Indeed, small vessels joining the program had larger cod catches on average prior to the pilot study than those vessels not joining (Fig. 1). For large vessels no statistically significant difference in cod catches was found prior to the program. However, differences in the spatial distribution of fishing effort were found between participating and non-participating large vessels in the period prior to the study (Figure 5D and E). Hence, although the populations of control and impacted vessels are very similar, there are always individual differences among the skippers of the vessels that are considered potential candidates by the fisheries organisations. Those differences most likely play a role in accepting to join the CQM pilot study. It is expected that almost all fisheries pilot studies, where participation is voluntary, suffer from selection bias. Hence, control and impacted populations may differ.

Conclusion

To summarize, changes in fishing behaviour are observed. For the large vessels, participants in the CQM increased their landings to use their quota bonus, increased the use of large mesh-sized gear, and changed effort towards fishing locations with high catch rates of large cod and avoid areas with juvenile cod. These observations are in line with the hypotheses. However, the increase in landings was on average much larger than 30%, because fishers found ways to use the quota bonus to their advantage and increase their landings beyond the envisaged 30%, e.g. by borrowing quota on the market. The observations for population of small vessels are not in line with the hypotheses. First of all, the incentives for joining the pilot study were generally related to having increased flexibility in effort regulations rather than the quota bonus. Also, no increase in cod catches was observed in the year that vessels entered the pilot. Likewise, no change in mesh size was observed, nor a clear change in fishing grounds. Interviews with fishers suggest that the small vessels do not change mesh size nor explore richer cod fishing grounds because they are hindered by technical regulations and constrained by the limitations of their vessels, e.g. size, engine power. Within their options, the small vessels changed to alternative options such as shrimp fishing.

To conclude, the results show that (i) the incentives created in the CQM pilot study have very different effects on two different fleets. The fleet of large vessels changed fishing behaviour while under CQM, while the fleet of small vessels did not. Within fleets different effects for different individuals are observed. The different effects of CQM, for fleets and individual fishers, should be taken into account by fisheries managers when implementing CQM regimes. It seems that the larger vessels have more flexibility in adapting their behaviour to new management regimes. Meanwhile, these large vessels managed to use the pilot rules to their maximum advantage, with the quota bonus opening up new fishing strategies, that were not envisaged during the implementation.

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CHAPTER 4

4

Using electronic monitoring to record catches of Sole (Solea solea) in a bottom trawl fishery.

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Abstract

Electronic monitoring (EM) is often presented as a solution to document all catches through video observations under the EU landing obligation. However, identifying small fish on video in large volumes of catch is challenging. In this study, logbook records were compared with video observations for catches to test efficacy of EM for different size classes of sole (Solea solea) on board bottom trawlers. Comparisons were based on: (i) systematic differences (paired t-test), (ii) linear correlation (Pearson's r), and (iii) absolute agreement (ICC). Results suggest that EM of small individuals in mixed fisheries is not as effective as it is for large individuals. To improve efficiency for estimating quantities of small fish, additional methods are required to enhance video review. One possible method for enhancing video review is using a protocol where crew arranged the individual fish in front of the cameras. Indeed, this study suggests that such a protocol substantially improves EM of the complete catch. However, the protocol requires an additional three minutes of processing time per haul for a single species. Given the large number of quota species under the landing obligation for this fishery, implementing the protocol thus comes with a cost for the fishing industry; the extra time needed to conduct a simple protocol probably would exceed 12 h per fishing trip.

Introduction

A phased implementation of the policy to fully report and land all catches is part of the reform of the European Common Fisheries Policy (Holden, 1994; EU, 2013). The obligation to land all catches will be in place for all European fisheries by January 2019. For several species in demersal fisheries, including sole (Solea solea) in the North Sea, the implementation started in January 2016. Implementing the landing obligation requires that the complete catch (landings and discards) of species under quota regulations needs to be reported and deducted from the available quota. Reliable methods to accurately monitor catches on board commercial fishing vessels are a crucial element of the implementation of the landing obligation. Without accurate methods for monitoring all catches, sustainability of fisheries may be hampered as unobserved catches cause fishing mortality to exceed limits set by quotas (Daan, 1997; Crowder and Murawski, 1998; Batsleer et al., 2015).

Electronic monitoring (EM) is often presented as one of the solutions to fully document catches in the context of the implementation of the landing obligation (Kindt-Larsen et al., 2011; Mangi et al., 2013; Msomphora and Aanesen, 2015; Needle et al., 2015; Ulrich et al., 2015). EM systems typically consist of GPS, cameras, and sensors for measuring force on the tow cables and net drum rotation, all connected to a control box (McElderry et al., 2003). These systems allow 100% coverage of a vessel's fishing activity and the monitoring of all catches using video technology (Ames et al., 2007; Stanley et al., 2009; Kindt-Larsen et al., 2011; Stanley et al., 2011).

However, when catch volumes are large and specimens of fish are small and similar in appearance, estimating species-specific catches on video can be challenging (Ruiz et al., 2013; van Helmond et al., 2015). This is the case in the bottom-trawl fishery (Catchpole et al., 2008; Ulleweit et al., 2010), where it will be difficult to observe relatively small specimens, like undersized sole, through video review. A substantial part of the flatfish stocks in northern European waters are fished with bottom trawlers or gears with comparable volumes of bycatch (Catchpole et al., 2008; Uhlmann et al., 2014).

At the end of 2014, a study was initiated as a collaboration between the Dutch Ministry of Economic Affairs and the Dutch National Federation of Fishermen's Organisations (van Helmond et al., 2016). In the context of the landing obligation, the aim of the study was to evaluate the efficacy of EM to record sole catches in the Dutch bottom-trawl fishery. Sole was chosen because it is a good representative of a bottom-trawl species and represents a substantial part of the commercial catch (Gillis et al., 2008). Two commercial fishing vessels were equipped with EM systems for a period of 10 months. Using

EM for catch monitoring is based on the premise that video monitoring accurately detects complete catches of sole. To test this, we compared direct observations registered in logbooks by crew members with video observations of sole catches in weight and numbers. In addition, the improvement in accuracy of video observations by having a simple protocol to display the catch is explored. Protocols of displaying the catch in front of EM cameras potentially improve accuracy of video observations, but impose an extra burden on fishers (Ulrich et al., 2015). In this study, we analyse three aspects of video observations: (i) systematic differences, (ii) linear correlation, and (iii) absolute agreement between video observations and logbooks of crew members. In addition, the time needed to display the catch in front of EM cameras was estimated. As such, this study gives an insight into the possibilities of using EM on board bottom trawlers in the context of monitoring the landing obligation.

Methods

Data collection

To find participants, all vessels with sole quota were contacted by representatives of the national fisheries organization. In response, two vessels offered voluntary participation in the study. These vessels received a 2% increase in their individual sole quotas to compensate for potential revenue losses for vessels that participate in research projects.

The two participating trawlers had identical engine powers (ca. 1471 kW) and similar vessel lengths (ca. 40 m). The average trip duration of these trawlers is 4–5 d, during which there is continuous fishing. The vessels operated pulse trawl gear. Pulse trawling is a variant of bottom trawling that makes use of an electrical pulsating field as an alternative to tickler chains attached to a beam. The electrical field stimulates flatfish out of the sea bed (De Haan et al., 2016). Pulse trawling is used, to a growing extent, in the Dutch flatfish beam-trawl fleet and is considered to be a promising alternative to conventional chain beam trawling (van Marlen et al., 2014; Batsleer et al., 2016).

Monitoring started in January 2015. One vessel participated for 35 weeks, while the other vessel participated for 42 weeks. The vessels were fitted with EM systems consisting of GPS, six digital cameras (closed-circuit television), and sensors for measuring force on the tow cables and net-drum rotation. The EM system and the video analysis software were developed by Archipelago Marine Research Ltd. All sensors and cameras were connected to a control box with exchangeable hard drives for data storage (McElderry et al., 2003; Kindt-Larsen et al., 2011). Sensor and GPS data were recorded continuously while at sea. Video recording was done only during fishing operations, triggered by hauling activity (pressure and rotation sensors). The cameras recorded overhead views of the working deck and catch-handling areas while fishing, hauling, and processing the catches (van Helmond et al., 2015).

For each haul, the total catch was unloaded over two parallel conveyor belts, from which the crew sorted the different species and size classes. The catch of sole, above and below the minimum landings size (MLS) of 24 cm, was registered per haul in both weight and numbers in a computer spreadsheet by the crew. Electronic scales were used to estimate catch weights on board the vessels. Crew members were asked to count the individuals below MLS and to keep them separate during the sorting process.

Figure 1. Video still from fish according to protocol

Comparing logbooks with video registrations

A selection of hauls was used for further analysis. This selection was made in a stepwise procedure (van Helmond et al., 2015). In a first step, all hauls with video recordings were matched with onboard observations from those hauls. In a second step, image quality was evaluated for each fishing day in those trips. Reviewing the video footage from both conveyor belts was time consuming. Hence, in a third and final step, ca. 5% of the hauls were randomly selected for comparison from days with sufficient image quality. The main reason for poor image quality was dirt and water droplets on the lenses of the cameras. The crew did not always follow the instruction to clean the lenses before each haul. In addition, moisture entered the camera during a few trips, which caused technical failure.

During video review, footage was observed during the usual catch-sorting process, when fishers did not change their routines on board. Counts of sole, under and above minimum landing size, were made from footage of unsorted catch from cameras above the sorting conveyer belt. Video reviews were done by a reviewer with several years of experience as an on-board observer in research vessel surveys. In addition, the video reviewer had experience with the EM software from previous projects. The video was watched at normal speed and paused when necessary to verify species identification. Length estimates (above or below MLS) were done visually by comparing fish with a colour-coded tape that was used as a reference in the video image.

An additional video review was done when crew members executed the additional protocol of displaying the catch in front of EM cameras. All individuals below MLS had to be clearly displayed on the sorting belt in front of the cameras after the catch was processed (Figure 1). Counts were recorded from footage taken during this protocol.

Statistical analyses

Visual inspection of the statistical distribution of catches suggested that these are log-normally distributed (Figure 2). To correct for this in statistical tests that assume normality, a common logarithmic transformation was applied to all catch data. The agreement between the paired logbook vs. video estimates was explored for three aspects: systematic differences, linear correlation, and absolute agreement. A paired t-test was applied to compare the average difference between the two sources, with the hypothesis that the average difference is zero. A p-value smaller than the 0.05 significance level implied a systematic difference. The linear correlation was calculated by the Pearson correlation coefficient (Pearson's r). Additionally, an intraclass correlation coefficient (ICC) was computed (Shrout and Fleiss, 1979). In our case, the absolute agreement ICC (2,1) was selected, computed as the ratio of variability between catches (subjects) to the total variability including catches, video reviewer, and error variability, thus ranging from 0 to 1 (Shrout and Fleiss, 1979). A higher value of ICC (2,1) indicates a higher agreement between the two sources; in other words, how close the observations are to the diagonal of a scatterplot. In ICC, the data are centred and scaled using a pooled mean and standard deviation, whereas in the Pearson's r, each variable is centred and scaled by its own mean and standard deviation. Therefore, ICC provides a more advanced way of quantifying agreement between two or more resources (Shrout and Fleiss, 1979).

The agreement of catch estimates from video observations was tested in three different comparisons: (1) logbook records vs. video observations, 24 cm in weight, (2) logbook records vs. video observations, <24 cm in weight and number, and (3) logbook records vs. protocol video observations, <24 cm, in number. The first comparison was only done in weights, because catch above 24 cm was only recorded in weights on board. Agreement in the second comparison was tested for both numbers and weights. Agreement in the third comparison was tested for numbers only. Differences in agreement between comparison 1 and 2 indicate that individual fish size affects accuracy of video monitoring. Differences in agreement between comparison 2 and 3 indicate that using a protocol to display catch in front of the cameras affects accuracy of video monitoring.

To be able to compare catch weights on board with video observations, the catch estimates in numbers of the video reviewer were converted to weights using a length–weight relationship. Fixed lengths were assumed for sole below and above MLS, because identifying more detailed length categories was not possible from the videos. Individuals below MLS (<24 cm) were assumed to be 21.1 cm, and individuals above MLS (24 cm) were assumed to be 28.5 cm. These are the average lengths of discarded and landed sole on beam trawlers in the North Sea (Ulleweit et al., 2010; van Helmond and van Overzee, 2010). The length–weight relationship was W = aLb, where W is the weight in grams and L is the length in cm. Parameter values a and b were taken from Coull et al. (1989), with a being 0.0036 and b being 3.3133. The accuracy of this conversion from numbers to weights with fixed lengths was tested in a crosscheck with logbook records; numbers in logbooks were converted to weights and compared to the weights recorded. The agreement between recorded weight and converted weight was explored for systematic differences, linear correlation, and absolute agreement.

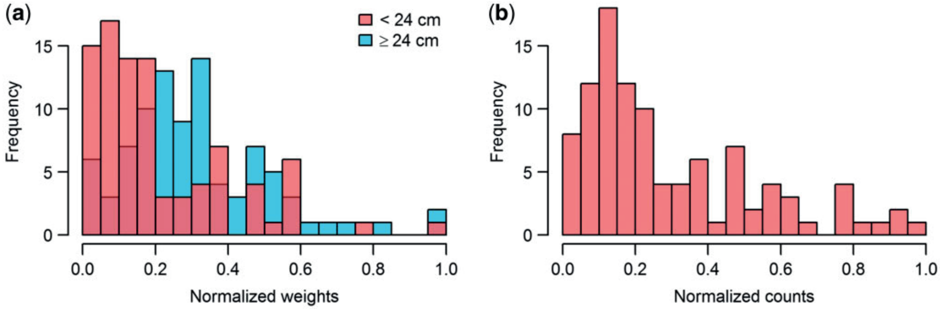

Figure 2. Histograms of normalized catch distributions in weight (a) and in counts (b).

All analyses were performed in R version 3.2.0, using packages "base", "lattice", "stats", and "psych", respectively (R Core Team, 2015).

19. Conducting the protocol

To review the extra costs of conducting the protocol, the duration of different phases of catch processing were analysed using video data. The phases that were distinguished were sorting, gutting, and conducting the protocol. For this analysis, all hauls from a single fishing trip were selected. This selection resulted in 31 hauls, and the protocol was followed for 10 of these hauls. The time measurements were done by visual inspection of the video footage of the EM system, which included a timer. Time was recorded at the beginning and end of each phase.

The mean and standard deviation of the duration (in minutes) of the different phases were estimated from these hauls. In addition, the relationship between the number of fish displayed in the protocol and the duration of the protocol was estimated using a simple linear regression model. The explanatory variable was the number of fish divided by the number of crew members taking part in conducting the protocol. Because expected duration of the protocol is zero when there are no fish, the intercept was removed from the model.

Results

Data collection

During the study, the two vessels together completed 73 trips. The average catch of sole ≥24 cm was substantially higher than the catch of sole <24 cm for both vessels (Figure 3). No seasonal trends in catch rates were found.

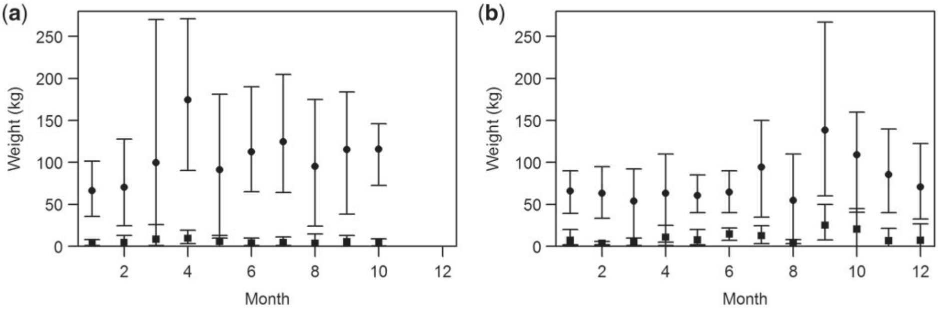

Figure 3. Average monthly catch of sole <24 cm (squares) and sole ≥24 cm (dots) recorded by haul in the logbooks for vessel A (a) and vessel B (b). Bars indicate 5 and 95% quantiles.

Due to technical failure, poor image quality or missing video data, 15 trips (21% of the total) could not be used for further analysis. For three trips (4% of total), there were no logbook data available on the haul level. From the remaining trips, 45 hauls were randomly selected for comparison of logbook records and video data. From these 45 hauls, the crew counted the fish<24 cm 39 times. In addition, they used the protocol 17 times to display catches in front of the cameras.

Systematic differences, correlation, and agreement

In total, there were 45 samples available for the comparisons of logbook records vs. video observations of sole ≥24 cm based on weights. The paired t-test for this comparison suggested no systematic difference in the means of the samples (comparison 1, Table 1). Moreover, this comparison had a Pearson's r value of 0.65 (with 95% CI 0.45–0.80) and ICC (2,1) of 0.64. This suggests a moderate agreement between the logbook records and the video observations for sole ≥24 cm (Figure 4).

The results of comparison for logbook records and video observations of sole <24 cm was done in terms of weight and numbers (comparison 2A and 2B, Table 1). For both comparisons, there was a significant difference in the means of the two methods. When comparing weights, the average weight is ($10^{0.38}$) 2.4-fold higher in the logbooks records than in the video observations. When comparing numbers, the average number is ($10^{0.34}$) 2.2-fold higher in the logbooks records than in the video observations. The comparisons for fish <24 cm had lower Pearson's r values (0.35 and 0.54 for the comparison based on weight and numbers, respectively) than the comparison for fish ≥24 cm. The ICC (2,1) agreements were also low, being 0.20 for the comparison based on weights and 0.34 for the comparison based on numbers. The data thus suggest a weak-to-moderate linear trend that is, however, not on the diagonal, as can be seen from Figure 5. When using the protocol to improve the video review, the comparison between logbook records and video observations of sole<24 cm improved substantially (Figure 6 and Table 1). There was no significant difference between the means of logbook records and video observations. Meanwhile, there is high agreement in the observations, with Pearson's r = 0.98 and the ICC (2,1) = 0.98.

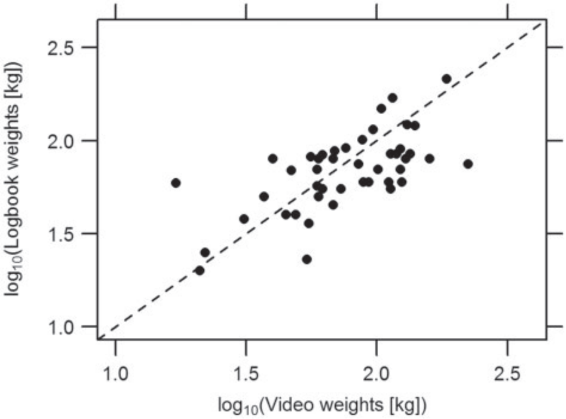

Figure 4. Scatter plot of video weights (kg) vs. logbook weights (kg) for sole ≥24 cm. The dotted line represents the identity line, y=x.

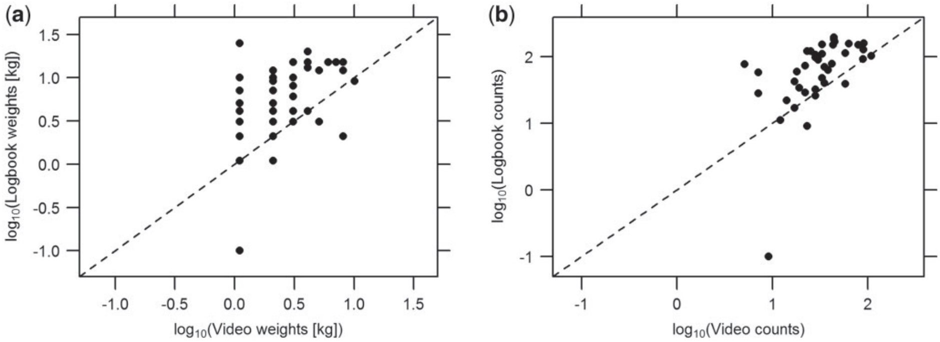

Figure 5. Scatterplot of video observations vs. logbook records for sole <24 cm based on (a) weights (kg) and (b) counts. The dotted line represents the identity line, y=x.

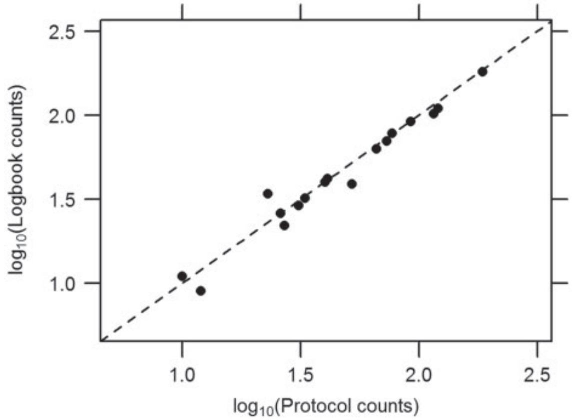

Figure 6. Comparison between logbook counts and video counts using a protocol to display the catch of sole <24 cm. The dotted line represents the identity line, y=x.

Table 1. Results of paired t-test, Pearson's r, and ICC (2,1) –agreement for the logbook-video comparisons.

Comparison	**1** (n=45)	**2A** (n=45)	**2B** (n=39)	**3** (n=17)
	logbook vs. video (≥24cm, weight (kg))	logbook vs. video (<24cm, weight (kg))	logbook vs. video(<24cm, number)	logbook vs. protocol (number <24cm)
Paired t-test mean difference	0.05^{ns}	$0.38^{**\ 1}$	$0.34^{**\ 1}$	0.02^{ns}
Pearson's r (95% CI)	0.65 (0.45, 0.80)	0.35 (0.06, 0.59)	0.54 (0.26, 0.73)	0.98 (0.95, 0.99)
Agreement ICC(2,1) (95% CI)	0.64 (0.43, 0.78)	0.20 (0.00, 0.47)	0.34 (0.00, 0.64)	0.98 (0.95, 0.99)

ns=not significant; *=significant at p≤0.05; **=significant at p≤0.01.

Accuracy of number–weight conversion

A cross-check with logbook weight records and weights converted from logbook number records indicates that the conversion from number to weight in a length–weight relationship using fixed lengths, 21.1 cm for sole <24 cm and 28.5 cm for sole ≥24 cm, provided reliable weight estimates. The difference in mean weight was not significant ($p = 0.42$). The estimated weights exhibit high agreement with the actual recorded weights in the logbooks for sole below MLS, Pearson $r = 0.96$ and ICC (2,1) = 0.96 (Figure 7).

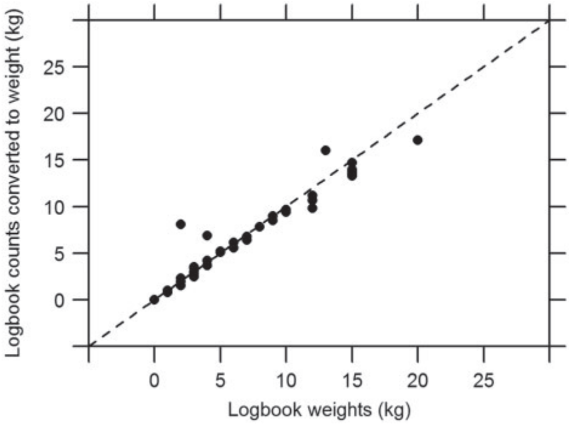

Figure 7. *Scatterplot of logbook records in weight (kg) and estimated weights converted from recorded numbers in logbooks using a length–weight relationship with a fixed length for sole <24 cm. The dotted line represents the identity line, y=x.*

Implementation of the protocol

For 31 hauls, the duration of the different phases of the catch-processing routines on board a vessel were estimated. The catch-processing routine without the protocol was divided into two phases: the sorting phase and the gutting phase. During the sorting phase, the catch was transported onto a running conveyer belt, and crew members sorted out the marketable fish from the unmarketable fish, putting marketable fish aside. The average time needed to complete this phase was 20.4±5.5min. During the gutting phase, the intestines and other internal parts were removed to prevent disintegrating when the fish was stored on ice for the remaining part of the fishing trip. On average, four crew members needed 10.8±4.8min for this processing phase.

For 13 hauls, the crew conducted the protocol to improve video review (Figure 1). The average time needed for the protocol was 2.7±0.9 min. The simple linear regression model of duration as a function of the number of fish divided by the number of crew members taking part in the protocol suggested that the protocol took ca. 3.5±0.20 s per crew member per fish.

Discussion

Video review of the standard catch-processing routines on board bottom trawlers significantly underestimates the number of sole <24 cm present in the catch. The average estimated weight based on video review is 2.4-fold lower than recorded in logbooks by crew. When comparing numbers, the average difference is smaller but still significant at 2.2-fold lower for video review than records in logbooks (Table 1). This suggests that EM is unfit to detect small fish species in mixed catches of bottom trawlers. However, the implementation of a simple protocol substantially improves the efficacy of video monitoring. Using the protocol, there is no difference between the means of logbook records and video observations, and a high agreement between logbooks and video for sole <24 cm (Table 1 and Figure 6).

For sole ≥24 cm, no significant systematic difference was found between logbook records and video observations (Table 1). Also, the agreement between video review and on-board observations was considerably higher for sole ≥24cm than for sole <24 cm (Table 1, Figures 4 and 5). This result is consistent with findings by Ruiz et al. (2013) who concluded that it is difficult to identify small fish as bycatch in purse-seiners using EM. The consistent underestimation of sole<24 cm in weight and number (Figure 5) indicates that part of the catch is not identified during video review. Larger individuals are easier to spot on video during the sorting process on board.

Eventually, 21% of the collected footage could not be used due to technical failure or poor image quality. Since there was sufficient footage remaining for further analysis, this did not impact the overall effectiveness of the project. In the future, more emphasis should be put on the importance of maintenance, e.g. clean the camera lenses, regular checks of EM systems, etc. Technical failure and poor image quality is a potential risk to the effectiveness of EM in controlling the landing obligation on a commercial fishing fleet.

Lengths of sole in the catch of North Sea beam trawlers vary between 13 and 42 cm (Ulleweit et al., 2010). Under the landing obligation, a sole of 23 cm should be classified as below minimum reference size, whereas a sole of 24 cm can be sold for human consumption. It was not possible from the video footage to see the difference between a sole of 23 and 24 cm. To overcome the issue in this study, the fish were correctly categorized in length classes by the crew on board. For video review, fixed lengths were used for fish above and below the minimum reference size. Fish weights for the two categories were subsequently calculated using a length–weight relationship. The comparison between converted weights from numbers in logbooks and actual logbook recorded weights

(Figure 7) suggested that the lenght–weight conversion used did not bias the results in this study. Nevertheless, the inability to accurately estimate fish lengths may be a limitation of EM in the context of monitoring the landing obligation. Developments on automated measurement of fish by computer vision may resolve this issue in the future (White et al., 2006; French et al., 2015).

EM is seen as a promising option in monitoring catches under the forthcoming landing obligation in the European Union (Kindt-Larsen et al., 2011; Mangi et al., 2013). However, this is mostly the case for fisheries where it is easy to detect individual fish, e.g. hook and line (McElderry et al., 2003; Ames et al., 2007; Stanley et al., 2009, 2011) or where EM focusses on a single species that is easy to detect with video review, like cod (Gadus morhua) (Kindt-Larsen et al., 2011; Ulrich et al., 2015). However, the efficiency of EM may be limited for fisheries catching small individuals with large volumes of bycatch (Ruiz et al., 2013; van Helmond et al., 2015). Nevertheless, this study suggests that when EM is used in combination with protocols that allow for better recording of individual fish, there can be considerable improvement in the efficiency of video review. Hence, this combination could be a successful formula for controlling the landing obligation for fisheries with less favourable conditions for video inspection, e.g. fisheries for small species with large volumes of mixed catches, like bottom trawling. However, the extra time needed to conduct the protocol imposes a burden for the crew. It is, therefore, important to clarify the purpose of the protocol with skippers to reach the desired balance of data quality and feasibility of operations on board (Hold et al., 2015; Ulrich et al., 2015). This process of discussing the balance between data quality and feasibility of protocols on board is especially important in the context of the landings obligation (Salomon et al., 2014; Borges, 2015) that may drastically change fishing practices.

The average time needed to conduct the protocol was almost 3 min. During an average trip, a beam trawler sets its net 40–50 times (Poos et al., 2013). Hence, the total estimated time to conduct the protocol is 2–21/2 h for a single species. In the context of the EU landing obligation, multiple species will fall under the obligation to record and land all catches. These trawlers catch a number of quota species, including plaice (Pleuronectes platessa), sole, turbot (Scophthalmus maximus), brill (Scophthalmus rhombus), dab (Limanda limanda), and European flounder (Platichthys flesus) (Gillis et al., 2008). The catches for some of these species exceed the sole catches, and the time to conduct the protocol would likely exceed (6 species x 2h=) 12 h per fishing trip. Installing automated devices on board to display individual fish in front of cameras, e.g. by changing the conveyer belt system, is an option, but probably requires substantial investments. Meanwhile, automated image recognition and computer vision are promising solutions to improve video monitoring and may replace the need for protocols (Zion et al., 2000;

White et al., 2006; Needle et al., 2015; Griffin et al., 2016). However, these technologies are still under development, and the conditions for monitoring catches on board commercial fishing vessels are challenging.

Conclusion

The implementation of the landing obligation is currently ongoing in the EU, and finding a way to ensure that all cathes are documented is of great importance. EM is often presented as one of the solutions, and possibly the only cost-effective solution, to fully document catches. However, EM systems, as implemented in our study, underestimated catches of small sole during the current catch-processing routines on board bottom trawlers. In addition, video data were lost due to technical failure and poor image quality. Given the urgency to identify robust monitoring systems to support the landings obligation, technical failure and insufficient image quality are potential risks in regard to the effectiveness of EM.

The implementation of a simple protocol in which the crew place individual fish in front of the cameras improves video observations and substantially increases the ability to record all catches of small sole. However, displaying individual fish in front of cameras on board is time-consuming manual labour. The success of monitoring the landing obligation with EM likely depends on the burden that it imposes on skippers and crews. To reduce this burden, there is a need for technologies to improve the implementation of EM.

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CHAPTER 5

5

Electronic monitoring in fisheries: Lessons from global experiences and future opportunities

Published as

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Abstract

Since the beginning of the 21st century, electronic monitoring (EM) has emerged as a cost-efficient supplement to existing catch monitoring programmes in fisheries. An EM system consists of various activity sensors and cameras positioned on vessels to remotely record fishing activity and catches. The first objective of this review was to describe the state of play of EM in fisheries worldwide and to present the insights gained on this technology based on 100 EM trials and 12 fully implemented programmes. Despite its advantages, and its global use for monitoring, progresses in implementation in some important fishing regions are slow. Within this context, the second objective was to discuss more specifically the European experiences gained through 16 trials. Findings show that the three major benefits of EM were as follows: (a) cost-efficiency, (b) the potential to provide more representative coverage of the fleet than any observer programme and (c) the enhanced registration of fishing activity and location. Electronic monitoring can incentivize better compliance and discard reduction, but the fishing managers and industry are often reluctant to its uptake. Improved understanding of the fisher's concerns, for example intrusion of privacy, liability and costs, and better exploration of EM benefits, for example increased traceability, sustainability claims and market access, may enhance implementation on a larger scale. In conclusion, EM as a monitoring tool embodies various solid strengths that are not diminished by its weaknesses. Electronic monitoring has the opportunity to be a powerful tool in the future monitoring of fisheries, particularly when integrated within existing monitoring programmes.

Introduction

Historically, fishing has largely been an unregulated industry, with fishers operating as independent explorers of the sea (Johnsen, Holm, Sinclair, & Bavington, 2009; Stevenson & Oxman, 1974). It was primarily governed by affective relations, often in local fishing communities (Johnsen et al., 2009). However, over the course of the 20th century, awareness of the impact of fishing on marine resources has grown, resulting in an increase in rules and regulations (Botsford, Castilla, & Peterson, 1997; Johnsen et al., 2009). Fisheries-dependent data collection has also increased, as more data are needed to assess fish stocks, and to monitor and regulate the environmental impact of fishing.

The value of fishery-dependent information in estimating the status of fish populations has regularly been called into question (Cotter & Pilling, 2007). Information may be biased because fisheries do not randomly sample fish populations and because fishing methods vary from place to place and time to time. Furthermore, landings do not provide information about all fish that are caught, since catch that is discarded at sea can represent a large proportion of the total catch (Borges, Zuur, Rogan, & Officer, 2004; Fernandes et al., 2011; Poos et al., 2013; Uhlmann et al., 2014; Ulleweit, Stransky, & Panten, 2010). Finally, misreporting may occur when fishers under-report problematic interactions with by-catch and quota-limited or "choke" species (Borges, 2015).

Despite the rapid increase in availability of new technology, such as GPS, network communication, digital cameras and image analysis software, the implementation of these innovations to monitor fisheries catches at sea has not evolved much. For instance, the vast majority of discard estimates are based on expensive fisheries observer programmes, and are associated with low coverage, often less than 1% of the fishing activities (Benoît & Allard, 2009; Depestele et al., 2011; Poos et al., 2013; Rochet, Péronnet, & Trenkel, 2002), often using subsamples of catches where fish are measured one by one on a measuring board and recorded with pencil and paper. Only within the last two decades, electronic monitoring (EM) has emerged as an additional approach for documenting catches in fisheries (Ames, Leaman, & Ames, 2007; Kindt-Larsen, Kirkegaard, & Dalskov, 2011; McElderry, Beck, & Anderson, 2011; Stanley, McElderry, Mawani, & Koolman, 2011). While the initial development of EM systems was largely an industry-led process to cope with management reforms and gear theft in the British Columbia crab fishery (Ames, 2005), it was quickly recognized that EM could also be used for monitoring and control in fisheries challenged by poor coverage by at-sea observations (McElderry, Schrader, & Illingworth, 2003). Electronic monitoring systems generally consist of various activity sensors, GPS, computer hardware and cameras (Figure 1) which allow for video monitoring and documentation of catches and detailed fishing effort estimation without requiring additional on-board personnel, unless additional biological data, for example otoliths, are needed (e.g. Needle et al., 2015; Ulrich et al., 2015). The data recorded can be reviewed at a later stage to obtain catch information, for example species composition, numbers, volume and lengths.

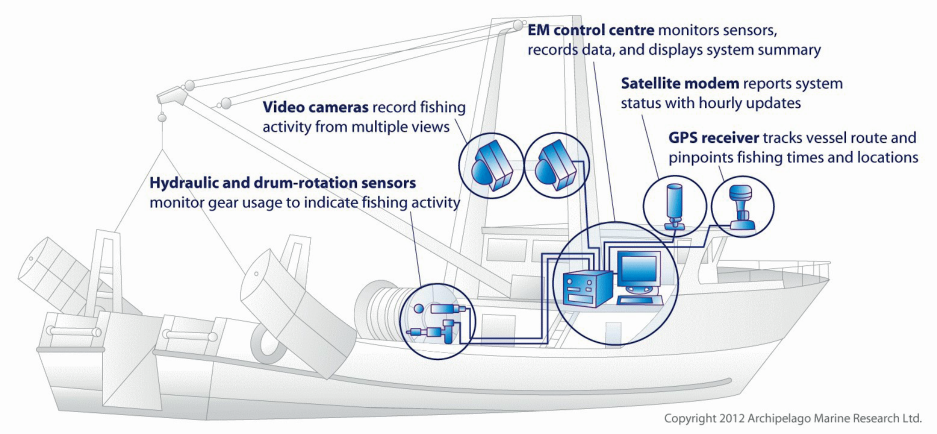

Figure 1. Overview of a standard remote electronic monitoring system set-up. Courtesy of Archipelago Marine Research Ltd

In North America, the first EM trial was implemented in the Area "A" crab fishery in 1999 in British Columbia, Canada, to monitor vessel trap limits and to control catch and gear theft. As a result, the fisheries authorities implemented a full EM programme involving 50 vessels with a 36,000 fleet-wide trap limit. Subsequently, in 2002 EM was tested in the Alaskan longline fisheries to register catch and effort in the Pacific halibut (Hippoglossus stenolepis, Pleuronectidae) fishery and to test for compliance with regulations on seabird catch mitigation devices (Ames, Williams, & Fitzgerald, 2005; McElderry et al., 2004). In 2006, one of the largest EM programmes was introduced in the groundfish hook and line and trap fishery in British Colombia, Canada, to monitor compliance with self-reporting responsibilities on about 200 vessels.

In New Zealand, an EM programme was started to monitor marine mammals' and seabirds' interactions in gill net and trawl fisheries in 2003 (McElderry, McCullough, Schrader, & Illingworth, 2007). In 2005, EM trials started in Australian waters, monitoring fish handling and by-catch mitigation measures in several fisheries. Since 2012, EM has been tested in tropical tuna fisheries in the Atlantic and Indian Ocean, and during the same period, EM technology was introduced in trials on similar fisheries in the Western and Central Pacific Ocean with the aim to enhance sampling coverage of observer programmes for these vast fishing grounds.

European EM trials started in 2008, with the rising awareness of the vicious circle in which North Sea demersal fisheries were trapped (Rijnsdorp, Daan, Dekker, Poos, & Densen, 2007). A recovery plan for Atlantic cod (Gadus morhua, Gadidae) in the region had evolved into a complex and micromanaged regulation with multiple gear categories and exemptions (Kraak et al., 2013; Ulrich et al., 2012). Eventually, this resulted in the establishment of a new cod plan that included severe effort reductions. Several EU member states tried to incentivize cod discard reductions by making volunteer fishers accountable for their total catches rather than for their landings, in exchange for increased quota shares and, in some cases, exemptions from the effort reductions (Ulrich et al., 2015). Consequently, several EM trials were funded in order to verify declared catches, also known as "Fully Documented Fisheries" (FDF).

Electronic monitoring seems to be a good candidate for full catch documentation. However, in spite of the obvious advantages of EM, European managers have so far remained reluctant to use it because of its unpopularity among fishers. The fishers consider EM an intrusion in their private workspace (Baker, Harten, Batty, & McElderry, 2013; Plet-Hansen et al., 2017) and argue that camera surveillance reflects a governmental mistrust against them (Mangi, Dolder, Catchpole, Rodmell, & Rozarieux, 2013). This paper aimed to review the current status of EM worldwide and to discuss whether EM is a viable monitoring tool for fisheries. In addition, we summarize experiences with EM trials in northern Europe, where uptake of EM in monitoring programmes is slow, and compare them with experiences worldwide.

Methods

A global review was conducted on published EM trials and fully implemented EM programmes. Published literature was searched through SCOPUS using the search query TITLE-ABS-KEY (("electronic monitoring" OR "video capture") AND fish*). Given that many trials and EM programmes are not documented in peer-reviewed journals, the literature search was augmented with the latest unpublished knowledge from principal scientists involved in trials worldwide. Studies using video monitoring techniques to capture images of catch or by-catch, but not necessarily described and referred to as EM, were included in the review. The global literature review summarized EM trials and programmes by region, describing the first year of implementation, number of vessels and objectives of the trials and programmes. The results of the global review were summarized for different regions and fisheries: North America, Tropical Tuna Fisheries, Australia and New Zealand, South and Central America and Europe. The global review was followed by a detailed review of EM performance in the European trials. All contributing authors of reports and publications were asked to provide summaries of their research. In addition to the aspects of EM covered in the global review, a more detailed review covered EM set-up and data flow, EM analyses, EM performance and EM costs in European trials.

Results

The comprehensive review collected information on 100 EM trials and 12 fully implemented EM programmes worldwide (Tables 1 and 2). Electronic monitoring is predominantly implemented in Canada and the United States of America (USA) (including Alaska, West Coast and East Coast), as well as Oceania, Europe and West Pacific. Full programmes are in operation for fisheries in the United States, Canada, Australia and tropical tuna fisheries in the Atlantic and Indian Ocean (Figure 2). Since 1999, there has been a steady increase in the number of EM systems deployed on vessels worldwide, with strong increases in 2006 and 2015 (Figure 3). These strong increases were caused by the implementation of the British Columbia Groundfish Hook and Line Catch Monitoring programme in 2006 (~200 vessels) and the Atlantic Highly Migratory Species programme for pelagic longlines in 2015 (112 vessels), and four Alaska trawl fisheries between 2007 and 2014 (~60 vessels). The United States and Canada are the two dominant countries in terms of numbers of vessels involved in EM (Figure 4). Longline and demersal trawl, for example bottom trawl, are the two main fishery types for which EM trials are conducted (Table 1). The number of trials on demersal trawls is worth noting, since EM is, intuitively, expected to be more efficient for gears that bring catch on deck one individual at a time, such as hook and line, rather than a mixed catch brought on deck at once, as is the case for demersal trawls (van Helmond, Chen, & Poos, 2015).

The main objective for the use of EM was the need for detailed effort and catch monitoring. Out of 100 trials, 82 used EM for effort monitoring and 75 tested EM for catch monitoring purposes (Table 1). In contrast, there were clear differences between regions for other EM objectives: there was more focus on the by-catch of megafauna such as dolphins, sharks, turtles and birds in the trials of Australia, New Zealand and the West Pacific compared with Canada and Europe. For example, 6 out of 10 (60%) EM trials and programmes in Australia had by-catch monitoring as key objective, whereas only 2 out of 6 (33%) trials and programmes in Canada monitored by-catch. Five programmes in the United States were designed to monitor bycatch of several species, including bluefin tuna, Pacific halibut and Chinook salmon. Likewise, the possibility to use EM to monitor compliance with technical regulations on gear mitigation measures was explored in

Table 1. Overview of EM trials worldwide.

Country, region	**Source**	**No. trials**	**Years**	**Gears**	**No. vessels**	**Monitoring objectives (no. trials)**†					
						EM‡	**CM**‡	**CH**‡	**PS**‡	**GM**‡	**VA**‡
Canada	McElderry 2002, 2006; McElderry *et al.* 2003, 2011; Riley and Stebbins 2003; Stanley *et al.* 2015	6	2001-2007	bottom trawl, longline, seine, traps	1 - 19	5	4	1	2	1	
USA, Alaska	Ames 2005, Ames *et al.* 2007; McElderry *et al.* 2004a, 2005a, 2008a,b; Cahalan *et al.* 2010; Haist 2008; McElderry 2008; Bonney *et al.* 2009; NOAA 2017a; Wallace *et al.* 2015; Henry *et al.* 2016; Buckelew *et al.* 2015; Saltwater Inc 2017	16	2002 - 2017	bottom trawl, longline, traps	1 - 90	12	12		5	2	3
USA, West coast	Pria *et al.* 2008; Bryan *et al.* 2011; Carretta & Enriquez 2012; NOAA 2017d; Al-Humaidhi and Colpo 2014; Damrosch 2017	7	2006 - 2015	bottom trawl, gillnet, longline, midwater trawl, traps	5 - 10	7	6		1	1	
USA, North east	Pria *et al.* 2014; Kennelly & Hager 2018; NOAA 2017c; Baker 2012	7	2004 - 2018	bottom trawl, gill net, longline, midwater trawl, bandit	3 - 17	7	7		2		
USA, South east	Stebbins *et al.* 2009; NOAA 2017^{e}	3	2008 - 2014	longline, shrimp trawl	1 - 8	2	2		3		
USA, Hawaii, American Samoa	McElderry *et al.* 2010; NOAA 2017b	5	2008 - 2018	longline, gillnet, purse seine	1 - 17	4	5		1	1	
Australia	McElderry *et al.* 2005b, 2005c; Piasente *et al.* 2011, 2012; Larcome *et al.* 2016; Lara-Lopez *et al.* 2012; Evans and Molony, 2011; Wakefield *et al.* 2017; Jaiteh *et al.* 2014; ARM 2005	10	2005 - 2012	Bottom trawl, gillnet, longline, midwater trawl, shrimp trawl	1 - 10	8	3		6	1	

Table 1. Overview of EM trials worldwide. (continued)

Country, region	Source	No. trials	Years	Gears	No. vessels	Monitoring objectives (no. trials)[†]					
						EM[‡]	CM[‡]	CH[‡]	PS[‡]	GM[‡]	VA[‡]
New Zealand	McElderry *et al.* 2004b, 2007, 2008c, 2011; Geytenbeek *et al.* 2014; Middleton *et al.* 2016a, 2016b; Austin & Walker 2017	9	2003 - 2016	bottom trawl, gill net, longline, midwater trawl	1 - 12	6	5		8	4	
Fiji Islands	Million *et al.* 2016; Hosken *et al.* 2017	1	2015	Longlines	31	1	1	1	1		
Cook Islands	Hosken *et al.* 2017	1	2017	Purse seine	2	1	1	1	1	1	
FSM	Hosken *et al.* 2017	1	2016	Longlines	5	1	1	1	1	1	
RMI	Hosken *et al.* 2017	1	2017	Longlines	6	1	1	1	1	1	
Palau	Hosken *et al.* 2017	1	2016	Longlines	7	1	1	1	1	1	
Solomon Islands	Hosken *et al.* 2017	1	2014	Longlines	2 (2014) 7 (2017)	1	1		1		
New Caledonia	Hosken *et al.* 2016	1	2014	Longlines	1	1	1		1		1[§]
China (tuna fishery, Pacific)	Hosken *et al.* 2016	1	2015	Longline	33	1	1				
Denmark	Dalskov and Kindt-Larsen 2009; Kindt-Larsen et al. 2011; Ulrich *et al.* 2015; Plet-Hansen et al. 2019; Mortensen *et al.* 2017a,b;	3	2008-2016	Bottom trawl, gillnet, purse seine	6-27	2	2		1	1	
Germany	Götz *et al.* 2015; Oesterwind and Zimmermann 2013	2	2011	Bottom trawl	2-3	2	1		1		
The Netherlands	van Helmond *et al.* 2015, 2017; Bryan 2015; Scheidat *et al.* (2018)	4	2011-2017	Bottom trawl, gill net, purse seine, midwater trawl	2-12	33	2		1		
Sweden	Tilander and Lunneryd 2009	1	2008	Gill net	2	1			1		

Table 1. Overview of EM trials worldwide. (continued)

Country, region	Source	No. trials	Years	Gears	No. vessels	Monitoring objectives (no. trials)[†]					
						EM[‡]	CM[‡]	CH[‡]	PS[‡]	GM[‡]	VA[‡]
UK	Needle *et al.* 2015; French *et al.* 2015 ; Course *et al.* 2011 ; Marine Management Organisation 2013a, b, 2014a, b, 2015a, b, c, 2016 ; Hold *et al.* 2015	6	2008-2015	Bottom trawl, gill net, longline, trap	1-27	6	6				1
Spain (tuna fishery, Atlantic)	Chavance *et al.* 2013; Ruiz *et al.* 2014, 2015, 2016; Monteagudo *et al.* 2015; Briand *et al.* 2017;	5	2012-2016	Purse seine	1-2	5	5		2		
Ghana (tuna fishery, Atlantic)	Million *et al.* 2016	1	2016	Purse seine	11	1	1		1		
Spain (tuna fishery, Indian Ocean)	Legorburu *et al.* 2018	1	2015	Supply vessel	5	1					
France (tuna fishery, Indian Ocean)	Ruiz et al. 2015; Briand *et al.* 2017	2	2012-2015	Purse seine	1	1	1				
Peru	Bartholomew *et al.* 2018	1	2015-2016	Gillnet	5	1	1		1		
Mexico	NOAA 2016, 2017b	1	2016	Gillnet	87 net sets		1				
South Georgia	www.archipelago.ca	1	2014	Longline	2					1	
Indonesia	Kennelly & Borges 2018	1	2016	Hand line	5		1		1		

†) A single trial can have multiple monitoring objectives.

‡) EM=effort monitoring; CM=catch monitoring; CH=catch handling; PS=protected species; GM=gear modification (mitigation devices); VA=automated video analysis (computer vison technology).

§) Some of the EM records collected from the NC EM trial vessel were used in an automated video analysis competition. At this stage, none of the EM trials in the WCPO include automated video analysis, although EM service providers are focusing their R&D in this area.

almost half of the EM trials undertaken in New Zealand, but less often in Europe (Table 1). Below, we summarize the findings of the review for different areas and fisheries.

Table 2 Overview of EM fully implemented programs worldwide.

Country	Programme	Year	Gears	No. vessels
Canada	British Columbia, "Area A" crab fishery (Dungeness crab)	1999	Trap	50
	British Columbia, Groundfish Hook and Line / Trap Catch Monitoring Program (GHLCMP)	2006	Hook and Line/ Trap	200
	British Columbia, Hake fishery	2006	Midwater trawl	35
USA	Alaska EM programme Bering Sea & G. o. Alaska: Pollock, Non-Pollock, Rockfish, Cod	2014	Bottom trawl; longline	66
	Atlantic Tuna Longline Highly Migratory Species (HMS) Fishery, monitoring bluefin tuna bycatch.	2015	Longline	112
	Alaskan Small Boat fixed gear fishery	2018	Longline; trap	141
	West Coast, Pacific Total-Catch Accounting on fixed gear	2018		
	West Coast whiting fishery	2018	Midwater trawl	25
	West Coast Groundfish bottom trawl	2018	Bottom trawl	11
Australia	Australian Fisheries Management Authority (AFMA) Electronic Monitoring Programme	2015	Longline; hand line; gill net; trap	75
Spain	ANABAC-OPAGAC Tropical tuna purse seine programme, Indian Ocean	2018	Purse seine	27
	ANABAC-OPAGAC Tropical tuna purse seine programme, Atlantic Ocean	2018	Purse seine	22

Figure 2. EM trials and fully implemented programmes on world map

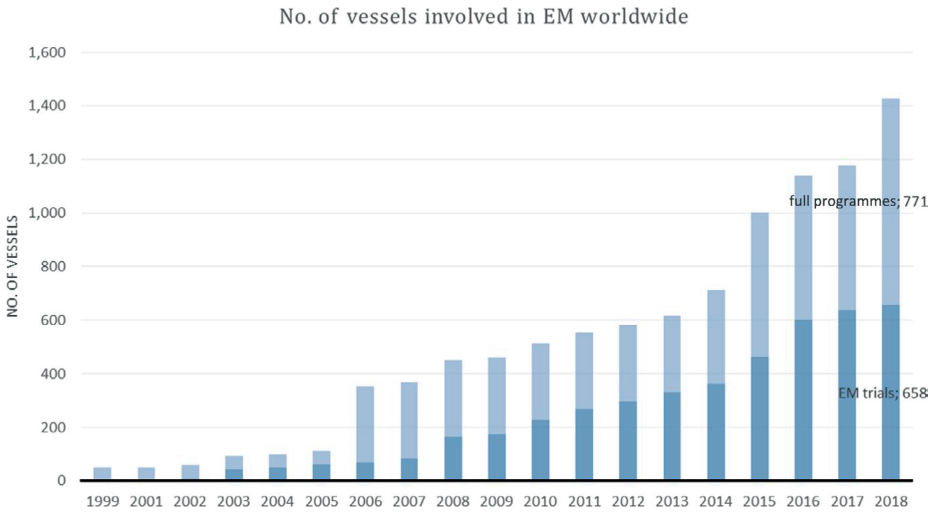

Figure 3. Number of fishing vessels involved in EM worldwide

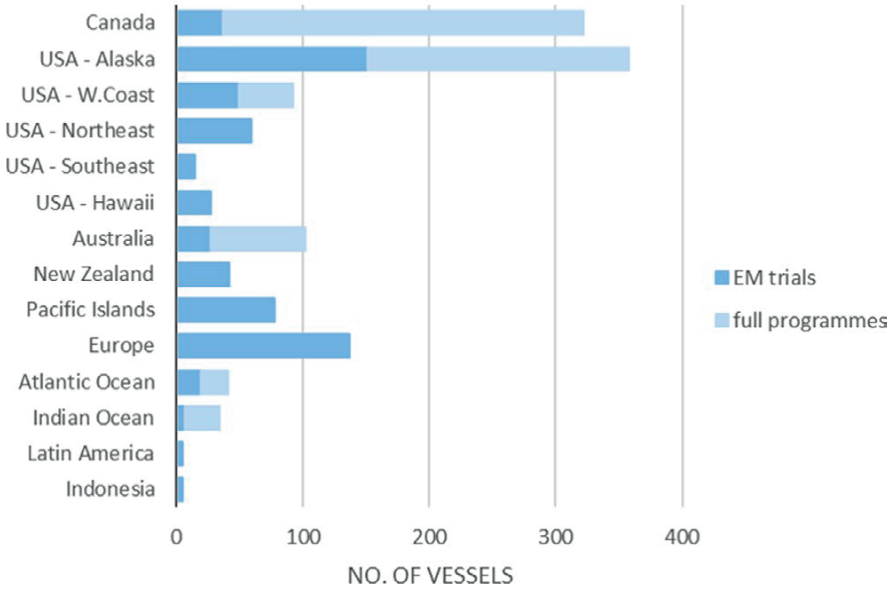

Figure 4. Number of EM trials and fully implemented programmes by region

North America

The majority of fully implemented comprehensive EM programmes, 9 out of 12 (75%) worldwide, run in both Canada and the United States (Table 2). All these programmes are management-driven monitoring schemes, where EM is officially used for compliance monitoring purposes. Vessels under these regulations are required to have some form of monitoring and may choose to use EM. The number of vessels involved in a fully implemented programme varied widely, between 7 and 200 vessels. In most cases, EM proved to be a cost-effective reliable alternative for human observation: The costs of human observation were high, and mismatches between the availability of observers and vessel departures sometimes caused delays or additional costs. The latter was caused by, for example, bad weather conditions when fishing trips were on hold and observers had many down days waiting for good weather. The levels of monitoring coverage varied among the different programmes: some have 100% EM coverage of all trips on all vessels, for example in the British Columbia Groundfish Hook and Line Catch Monitoring programme and the Atlantic Tuna Longline Highly Migratory Species (HMS) fishery (Stanley et al., 2011). Others use EM as an alternative to onboard observers, for example in the whiting midwater and fixed gear programme on IFQ Fleets on the US West Coast (McElderry, Beck, & Schrader, 2014; NOAA, 2017d). Some use partial coverage with the possibility to opt into an EM selection pool for a period of time where they are only required to turn on the EM systems on randomly selected trips. This method is used to integrate EM into the existing observer programme for the Alaskan small boat fixed gear fishery. The funding of monitoring programmes varies as well. The Canadian programmes started under co-funding arrangements, but eventually moved to 100% industry funding. The programmes on the US West Coast are co-funded by government and fishing industry. Initially, the National Marine Fisheries Service (NMFS) covered a substantial part of the costs, but is transitioning to only cover specific costs. In Alaska, a combination of federal and industry funds is used for EM deployment (NOAA, 2017a), but this too will transition to industry funding.

The vast majority of the 43 American and Canadian EM trials tested the feasibility of EM to complement or (partially) replace on-board observers in recording fishing activity, catch and discard composition. The results of almost all these Canadian and US studies demonstrated that EM is a promising tool for at-sea monitoring applications. It was repeatedly reported that EM differs from the more traditional observer programmes in terms of data collection capabilities and programme design issues (Kindt-Larsen et al., 2011; McElderry et al., 2014; Needle et al., 2015; Pierre, 2018; Plet-Hansen, Bergsson, & Ulrich, 2019). In comparison with observer programmes, EM has a number of advantages including its suitability across a broad range of vessels, the ability to review video for data verification, its presumed lower cost and higher scalability, and its ability to engage the industry in self-reporting processes. On the other hand, observer programmes are more suited as a tool for industry outreach, complex catch sampling perations and the collection of biological samples. In 14 trials, EM was successfully used to register interactions with or by-catches of marine megafauna and seabirds. In one trial, this included the registration of by-catch handling and release procedures. In 5 trials, the ability to monitor the use of gear mitigation devices to avoid by-catch was successfully tested. In 2014 and 2015, a series of American projects was initiated to develop automated image analysis for EM systems (Huang, Hwang, Romain, & Wallace, 2016, 2018; Wallace, Williams, Towler, & McGauley, 2015; Wang, Hwang, Rose, & Wallace, 2017, 2019; Wang, Hwang, Williams, Wallace, & Rose, 2016). It was concluded that achieving automated species recognition and fish counts potentially reduces the workload on video review, which is currently a manual, time-consuming and therefore expensive procedure.

Tropical tuna fisheries

France and Spain conducted EM trials in tropical tuna purse seine fisheries in the Atlantic and Indian Oceans. Management organizations in both regions have management programmes that require a 5% observer coverage. While the International Seafood Sustainability Foundation requires participating companies to solely conduct transactions with large-scale purse seiners that have 100% observer coverage. Besides logistical constraints and high costs, there are serious security issues, as piracy makes it dangerous to place human observers on-board (James et al., 2019; Ruiz et al., 2015). The trials showed that EM was a promising tool to replace or to supplement current observer programmes (Briand et al., 2017; Ruiz et al., 2016). As a result, two Spanish tuna purse seiner associations started a 100% EM coverage of fishing activities in 2018. So far, these are the only fully implemented EM programmes worldwide that are not directly managed by national or subnational bodies, but are initiated by the fishing industry and where all fishers participate on a voluntary basis.

Electronic monitoring trials have also taken place in the tuna purse seine and longline fisheries in the Western and Central Pacific Ocean (Hosken et al., 2016). Trials are currently taking place in the Fiji Islands, Cook Islands, Solomon Islands, Palau, Federated States of Micronesia (FSM) and the Republic of the Marshall Islands (RMI). The objectives of these trials were to evaluate the efficiency of EM in monitoring effort, catch, catch handling and by-catch of protected species. One of the most recent EM trials on a topical tuna purse seiner was implemented in Ghana by the World Wildlife Fund for Nature (WWF) in cooperation with the Ghana Fisheries Commission and the International Seafood Sustainability Foundation (Million, Tavaga, & Kebe, 2016). There the objective was also to monitor effort, catch and by-catch.

Australia and New Zealand

In 2015, the Australian Fisheries Management Authority (AFMA) implemented an EM programme covering the Eastern Tuna and Billfish Fishery, Western Tuna and Billfish

Fishery, and the Gillnet Hook and Trap fishery for scalefish and shark. Electronic monitoring is used as a compliance tool and to assist fisheries management with accurate near real-time data on discards and by-catch and/or interactions with protected species (Table 2). AFMA requires that a minimum of 90% of fishing effort is covered by EM. In situations with an increased risk of by-catch of protected species, monitoring coverage is increased to 100%. The baseline audit rate for all fisheries is a minimum of 10% of hauls for each vessel. This includes analysis of full catch composition for each shot selected for review. Catch composition, discards and interaction with protected species on audited shots are compared to logbook records, and discrepancies are flagged and reported to the authorities. Initially, AFMA funded the equipment costs, installation and initial standard service events for EM. From a later stage, the costs of getting EM systems up and running were met by industry through annual quota levies collected by AFMA.

In total, 19 EM trials, 10 Australian and 9 New Zealand, were reviewed in this study. The earliest EM trials in New Zealand were documented in 2003. These were mainly to monitor the by-catch of protected species in an inshore groundfish set net fishery. In Australia, the first EM trials were conducted in 2005. In total, 14 trials with the objective to test the efficiency of monitoring the interaction with protected species were undertaken in a wide range of different fisheries, making this the most common objective in this region. Based on a review of trials in New Zealand, Pierre (2018) pointed out the capabilities of EM to successfully monitor the capture of protected species in commercial fisheries and recommended developing standardized approaches around the review of EM imagery. The trials demonstrated that implementing data standards, review protocols and training materials will promote efficiency and harmonization of EM in monitoring by-catch. Remarkably, one trial successfully used an "in-trawl" video system to monitor by-catch: underwater video footage was recorded with high definition video cameras mounted inside trawl nets (Jaiteh, Allen, Meeuwig, & Loneragan, 2014).

South and Central America

In total, three EM studies were conducted in South and Central America (Table 1). The results of the Peruvian trial indicate that EM was an effective alternative to human observers in monitoring catches of Peru's small-scale elasmobranch gill net fishery (Bartholomew et al., 2018). The Mexican trial, comparing the efficacy of video monitoring systems versus on-board observers, used the "Flywire Camera System," a low budget EM system developed for small-scale and artisanal fisheries using high-quality video linked to a GPS. The same system was used in a Hawaiian EM project for catch and by-catch monitoring (NOAA, 2017d). To enhance data collection on small-scale fisheries in developing countries, the World Wildlife Fund for Nature (WWF) supports the development of "affordable" EM systems for this region (www.world wildl ife.org). Such low-cost EM systems will help address the more challenging but globally significant fishing regions, for example Asia and Southern Europe (Michelin, Elliott, Bucher, Zimring, & Sweeney, 2018). For example, a very basic low-cost EM application, just using a camera mounted on a small fishing vessel and video recording the complete fishing trip, also proved to be successful in other regions, for example monitoring protected species interactions in the Indonesian hand-line fishery (Kennelly & Borges, 2018). Along the development of low budget, the Chilean government is in the process of implementing EM in a fleet-wide programme to monitor compliance as part of the "by-catch law and mitigation plans" (Cocas, 2019).

Europe

In total, 23 published studies describing 16 different trials from 6 different nations (Scotland, England, Denmark, the Netherlands, Germany and Sweden) were reviewed (Table 3). Trials were mainly conducted in demersal fisheries using active gears (trawls and seines), although some passive gears (gill net and longline) have also been monitored. Different types of vessels have been involved, from larger beam trawlers and seiners to small-scale fisheries with vessels less than 10 m in length. The trials often lasted several years and generated large amounts of data. The first trials started in Sweden, Denmark and Scotland in 2008, and a spin-off of the Scottish trial was still ongoing at the time of writing. The number of vessels participating in each trial varied between 1 and 27 vessels. Evaluating the usefulness of EM as a monitoring tool was the most common research objective among the studies and countries, with 17 out of 23 (74%) studies sharing this objective (Table 3). In 7 (30%) cases, this objective was combined with an evaluation and feasibility study of a catch quota management (CQM) regime or landing obligation. Other studies' objectives focused on EM as an alternative method for, for example, scientific data collection, testing increased flexibility in technical fisheries measures, monitoring by-catches, analyses of high grading or estimation of discards. One study investigated the possibilities to use computer vision technology to automate the process of data collection in EM (French, Fisher, Mackiewicz, & Needle, 2015). Even though several studies briefly described the acceptance of EM in the fishing industry and among fisheries inspectors, there was only one comprehensive study on this aspect, Plet-Hansen et al. (2017).

Review of European EM operations

In the period 2008–2016, results of European EM trials were reported in a manner that allowed a detailed review of EM on an operational level. The trials were summarized and compared for efficiency for EM set-up and data flow, EM analyses, EM performance and EM costs. In addition, levels of acceptance and objective for the trials were described.

EM set-ups and data flow

In all trials, the EM system set-up consisted of (a) a GPS recorder supplying information on vessel location, (b) cameras supplying visual information on fishing activities and catches, and (c) hydraulic and drum-rotation sensors to mark deployment and retraction of gears. All data are conveyed into a computer, which saves the information (Figure 1). Vessels in all trials were initially equipped with the technology developed by the Canadian company Archipelago Marine Research (www.archi pelago.ca). This system uses hard discs to store sensor data, geographical location and video recording. These hard discs were replaced manually before reaching data storage limits. The Danish and German trials switched to another provider that allowed the transmission of data using 4G cellular networks (www.anchorlab.dk).

In all trials, the cameras were usually installed in a way that crew workflow was minimally affected. The number of cameras deployed depended on the size and the specific characteristics of the vessels. The layout and selection of camera models and settings was the result of an optimization between quality and data storage requirement. The number of cameras, their field of view, the resolution (pixel density) and the frame rates were considered against the specific monitoring objectives. It was always necessary to dedicate time to optimize camera locations on each vessel. Locations were chosen in order to maximize the vision given the vessel layout, the workflow and the position of the crew, while avoiding moisture, dirt and blind spots. Meanwhile, electrical wiring locations sometimes limited the possible locations for cameras. Typically, there were 4 cameras used (Figure 5). The general systems among the reviewed trials had at least one camera pointed directly at the discard chute and sorting belt, one camera to cover the processing area or the deck on smaller vessels, one camera to observe net hauling and one camera to cover the catch in the hoppers. Meanwhile, recent EM systems have been able to store data from up to eight cameras. These additional cameras have been used for larger vessels in Scotland and Denmark to get a better coverage of the vessel and to limit blind spots (Mortensen, Ulrich, Eliasen, & Olesen, 2017; Needle et al., 2015; Ulrich et al., 2015). On smaller vessels, the sorting areas may be small or absent and positioning the cameras was often challenging. Installing custom mounting infrastructure to improve camera positions was useful in trials on small vessels with open decks (Marine Management Organisation, 2013b; Mortensen et al., 2017; Needle et al., 2015). Also, the availability of electrical power on small vessels may be limited by battery capacity when the engine is not running, thereby limiting the scope for implementation on some smaller inshore vessels. Meanwhile, autonomous systems have been developed that are powered by solar panels and batteries (Bartholomew et al., 2018).

Figure 5. Example of camera views from EM trials. Camera views show different angles of the sorting process and the hauling area

Cameras can be set to record at different resolutions. For many applications, low resolution may be adequate. In current systems, low-resolution camera feeds are able to record at higher frame rates, which offers a smoother view and allows for the detection of abnormal behaviour in the handling process or when counting fish. However, using low-resolution images hampers species recognition and measuring fish lengths. High-resolution camera feeds have lower frame rates and use considerably more hard disc space than low-resolution camera feeds. In several studies, for example #10 and #18 in Table 3, the cameras directed at the discard chute or processing area were set to record at maximum resolution. This resulted in high-quality images, but frame rates were limited to 5 frames per second (Bergsson, Plet-Hansen, Jessen, & Bahlke, 2017; Course, Pasco, Revill, & Catchpole, 2011). With the declining cost of highresolution cameras and high-capacity data storage, recent studies have used higher resolution and higher frame rates compared with earlier studies. Also, the introduction of digital cameras had significant implications for data storage. Digital cameras process and store all imagery in compressed data files. Higher resolution and increased frame rates are, therefore, less of a problem. In earlier EM systems, imagery of analog cameras was processed by the central computer, limiting resolution and frame rate by the processing capacity of the computer.

Table 3. Overview of European EM trials, including references and study objectives for the studies describing the trials.

Study	Trial	Years	Vessels	Fisheries	Reference	Study objectives
1	German North Sea CQM	2011 – 2016	2	Demersal trawl	Götz et al. (2015)	1) Evaluate and develop the reliability of information on discards by EM. 2) Test the feasibility of a management approach using a reversal of the "burden of proof".
2	German trial on bycatch registration of harbour porpoise and seabirds	2011-2013	3	Gill nets	Oesterwind and Zimmermann (2013)	Assess by-catch levels of harbour porpoise and sea birds in gill nets using EM.
3	Dutch North Sea cod CQM trial	2011 – 2015	12	Demersal trawl and Seine	van Helmond et al. (2015)	Evaluate the efficacy of EM as control tool for mixed bottom trawl fisheries.
4					van Helmond et al. (2016)	Provide insight into the effect of the landing obligations prior to implementation and investigate the effect of CQM on fishing behaviour.
5	Dutch trial on bycatch registration of harbour porpoise	2013 - 2017	12	Gill nets	Scheidat et al. (2018)	Assess the bycatch rates and numbers of porpoises in the Dutch commercial bottom-set gillnet fishery.
6	Dutch trial on pelagic freezer trawler	2014	1	Mid-water trawl	Bryan (2015)	Develop a methodology to use EM to confirm full retention of catch on board a freezer trawl vessel (compliance with discard ban).
7	Dutch sole EM trial	2015	2	Beam trawl	van Helmond et al. (2017)	Evaluate the efficacy of EM as control tool for discard of undersized sole in beam trawling.
8	Scottish CQM trial	2008 – current	6 – 27	Demersal trawl	Needle et al. (2015)	1) Focus on the science that can be achieved with EM systems. 2) Preferable system for monitoring the landings obligation (rather than alternatives such as on-board observers).
9					French et al. (2015)	Reduce the viewers' workload as much as possible by automating this tedious and expensive procedure

Table 3. Overview of European EM trials, including references and study objectives for the studies describing the trials. (continued)

Study	Trial	Years	Vessels	Fisheries	Reference	Study objectives
10	English CQM trials for otter trawls and gill nets North Sea and Western Channel	2010-2015	6-16	Long line, Otter trawl, gill net	Course et al. (2011); Marine Management Organisation (2013a, 2015c, 2016); Elson et al. (in prep.)	1) Test impact of a discard ban 2) Investigate the potential of using market grading data for reference fleet monitoring 3) Development of EM verification method for full documentation of plaice discards.
11	English CQM trials for beam trawls in the Western Channel	2011-2015	7-9	Beam trawl	Marine Management Organisation (2015a)	1) Explore the implications of the landing obligation in this mixed demersal beam trawl fishery; 2) Investigate European plaice discard levels by using EM verified self-reported data; 3) Explore CQM trial on demersal species.
12	English EM trials for vessels < 10 m.	2012	2	Demersal trawl	Marine Management Organisation (2013b)	Test the reliability of EM equipment on-board commercial fishing vessels, and to determine whether this technology could be used to monitor and quantify catches.
13	English CQM trials for Western haddock	2013 – 2014	1	Twin-rig otter trawl	Marine Management Organisation (2014a, 2015b)	To test impact of discard ban
14					Marine Management Organisation (2014b)	1) Provide insight into the level of high grading and discarding that is typical of the fleet 2) Explore measures to protect recruitment and reduce total haddock catches whilst maintaining profitable landings in the context of a landing obligation
15	English trial on video capture of crab and lobster catch	2014	4	Crustacean fisheries	Hold et al. (2015)	Evaluated the use of on-board camera systems to collect data from Cancer pagurus and Homarus gammarus.
16	Danish FDF trial for CQM	2008 – 2016	6-27	Trawl, Seine, gill net	Dalskov and Kindt-Larsen (2009); Kindt-Larsen et al. (2011)	Establish if EM can supply the sufficient documentation for a CQM. Discuss implementation of CQM, in regards to new technologies

Table 3. Overview of European EM trials, including references and study objectives for the studies describing the trials. (continued)

Study	Trial	Years	Vessels	Fisheries	Reference	Study objectives
17					Ulrich et al. (2015) Plet-Hansen et al. (2015)	Collate and assess the data collected during the FDF trials and estimate discard rates.
18					Bergsson and Plet-Hansen (2016) Bergsson et al. (2017) Plet-Hansen et al. (2019)	Development of EM as a documentation measure for fisheries applicable to the landing obligation. Assessment of whether data can be transmitted by means of 4G network, satellite, or WI-FI.
19					Plet-Hansen et al. (2017)	Describe specific areas of convergence or divergence of perceptions between fishery inspectors and fishers.
20	Minimizing discards in Danish fisheries (MINIDISC project)	2014 – 2015	14	Trawl, Seine	Mortensen et al. (2017a)	Analyse the effect of a free gear selection in a CQM setting, using EM as documentation tool. Analyse observer bias in EM
21					Mortensen et al. (2017b)	Evaluate the discard estimates made by EM video inspectors for several species and contrast the estimates with the reports of fishers and on-board observers to estimate precision and accuracy of the EM observations
22	Danish trial on bycatch registration of harbour porpoise	2010-2011	6	Gill nets	Kindt-Larsen et al. (2012)	Assess by-catch levels of harbour porpoise in gill nets using EM.
23	Swedish trial on bycatch registration	2008	2	Gill nets	Tilander and Lunneryd (2009)	To test if EM is more efficient in bycatch monitoring than on-board observers.

In the standard EM set-up, vessels were fitted with hydraulic pressure and drum-rotation sensors. Data from these sensors allow interpretation on gear use. This contributes to data review because it directly marks events of interest in the analysis software. The deployment and retrieval times are registered in the data flow, enabling accurate estimates of haul duration. Another purpose of sensors is to automatically start and stop camera recording outside of the active fishing operations, which could save storage capacity of the system or to respect the privacy of crew members. However, sensor data have not been systematically used. For example, in the English and Danish trials on trawlers, video recording started when fishing gear was deployed for the first time during a trip and stopped only when vessel returned to the port (Kindt-Larsen et al., 2011; Marine Management Organisation, 2013a). For another trial with gill net vessels, recording started when the net was hauled and stopped after 40 min because all catches in this fishery were processed rapidly and continuous recording was unnecessary (Course et al., 2011).

In all EM set-ups, GPS information was collected with high frequency (generally every 10 s) (Needle et al., 2015; Ulrich et al., 2015). This is a much higher temporal resolution than the typical 0.5- to 2-hr interval used in the obligatory EU vessel monitoring system (VMS) (Deng et al., 2005; Hintzen et al., 2012; Lee, South, & Jennings, 2010). The high spatial and temporal resolution of GPS position data, combined with the hydraulic and drum-rotation sensors, allows for accurate effort calculation for vessels equipped with EM. This was demonstrated in the study by Needle et al. (2015), pointing out the differences in perceived fishing activity as indicated by either VMS or EM data for a Scottish seine vessel. The VMS-derived fishing path underestimated the area impacted by the vessel, whereas the true path was accurately recorded by the EM data, showing the characteristic triangular pattern of seine fishing. Similarly, Götz, Oesterwind, and Zimmermann (2015) showed that haul durations indicated in fishing logbooks were imprecise when compared to those estimated using EM information. In their trial for two vessels, the towing times listed in the logbooks for one vessel were generally longer than the times recorded by EM (96% of hauls in 2012, 60% in 2013 and 86% in 2014), while for the other vessel the opposite was true (84% in 2012, 95% in 2013 and 89% in 2015).

Data storage

Data collected from the various sensors and cameras are all linked to a central computer, which files the data onto a hard drive. All trials started with EM data being stored on exchangeable hard drives. Once full, hard drives were replaced by empty drives to continue recording. Drives were usually replaced by authorized persons, for example fisheries inspectors (Götz et al., 2015; Needle et al., 2015) or by staff of the institutes responsible for the projects (Dalskov & Kindt-Larsen, 2009; Kindt-Larsen et al., 2011), although in some cases fishers were instructed to change hard drives themselves (Course et al., 2011; van Helmond et al., 2015). Particularly, in case of compliance monitoring data encryption is provided to ensure data protection in the chain of custody.

To avoid the manual replacement of hard drives, a new system was developed in Denmark that allows wireless transmission of data via 3G, 4G or Wi-Fi networks, and this was progressively implemented in the Danish trials. This switch to wireless transmission of data considerably reduced the operational costs of the EM compared with the exchangeable hard drive technology (Bergsson & Plet-Hansen, 2016; Mortensen et al., 2017; Plet-Hansen et al., 2019). However, wireless transmission is dependent on the availability of sufficient Wi-Fi networks and the quantity of data to transmit. A potential issue is that data reviewers are wanting more comprehensive data, while data transmission seeks lower volumes. West coast programmes in North America still rely on manual replacement of hard drives.

Supplementary information

Supplementary catch information, for example logbook, haul-by-haul catch and observer data, was collected in all trials, with the purpose to evaluate and compare the efficacy of EM in a variety of management and scientific objectives. In the case of catch quota management trials for cod, all catches, including undersize individuals, were recorded. During trials in Germany and Denmark, extra information on discards was provided in official electronic logbooks (Götz et al., 2015; Ulrich et al., 2015). In several trials, data from on-board observer programmes were used in comparison with EM data (Marine Management Organisation, 2013b; Mortensen et al., 2017; Needle et al., 2015). In the Netherlands and England, fishers were requested to record catches by species or size category on a haul-by-haul basis (Course et al., 2011; van Helmond, Chen, & Poos, 2017).

EM data analysis

Most of the EM studies have collected thousands of hours of video footage, thus requiring a structured approach for the review and interpretation of sensor and image data. Data analyses have been conducted by video observers, whose training have ranged from small introductory courses and cooperative training (Mortensen et al., 2017) to more formal training courses (Needle et al., 2015). Video observers were often trained at-sea fisheries observers (van Helmond et al., 2015, 2017) or have systematically been trained to recognize species and to operate the EM software. In some trials, they have also been trained in length measurement (Needle et al., 2015). This training improved the quality of the video review (Needle et al., 2015).

The analysis is generally aided by dedicated review software that merges the multiple data formats in EM (GPS, sensors, time, video, etc.), so that all can be visualized together. When inspecting EM data sets, users can fast forward, rewind or pause with synchronous views of all active cameras, along with normal video viewing tools such as zoom. The review time depends on the quality of the data set, the quality of the review software, the monitoring objective and the type of operation observed.

When monitoring for rare and highly visible events, such as the catch of cetaceans, all footage was reviewed when played at a higher rate (10–12 times faster than real time) (Kindt-Larsen, Dalskov, Stage, & Larsen, 2012). Monitoring catches of commercial species aboard demersal trawlers is generally time-consuming and in response to the large quantity of data most trials developed strategies where a random 10%–20% of the camera footage was validated against (self-) recorded catch data in logbooks (Course et al., 2011; van Helmond et al., 2015; Kindt-Larsen et al., 2011; Needle et al., 2015; Ulrich et al., 2015). Attempts to identify all fish and invertebrates discarded from one trip of a Scottish trawler resulted in prohibitively long review times: the trip took 1 week and the analysis took 3 months (Needle et al., 2015). This would clearly not be sustainable for ongoing monitoring purposes and budgets.

Different procedures have been used in improving estimates of catches from EM video material in the different trials (Table 4). The first approach required crews to sort discards into baskets (Figure 6) and show the baskets to the cameras before discarding (Marine Management Organisation, 2015a, 2015b; Ulrich et al., 2015). Viewers estimate discard quantities by counting the number of baskets, using a standard weight of 22–25 kg for full baskets. This approach relies on consistent and thorough sorting of the catch by the crew. The second approach aims to estimate discards directly on the sorting belt where possible (van Helmond et al., 2015; Marine Management Organisation, 2013a; Mortensen et al., 2017; Needle et al., 2015), which is a less invasive catch estimation method, because crews do not have to alter their workflow. However, challenges with estimating large volumes of catch were encountered in the Dutch studies (van Helmond et al., 2015). The use of the “on the band” estimation method is thus prompting the development of automated image analysis (French et al., 2015) and automated counting of fish being discarded. A third approach to monitor catches was also implemented in an attempt to improve the accuracy of video observations (van Helmond et al., 2017). A simple protocol was used in which individual specimens were arranged and clearly displayed on the sorting belt in front of the cameras after the catch was processed (Figure 7). Counts were recorded from footage taken during this process. When using this protocol, video review of undersized sole improved substantially, with a very high agreement observed between the discards recorded on-board and the video observations.

An additional advantage of the "on the band" approach is the possibility to make on-screen length measurements, which can then later be converted into weights. Careful planning is needed if making measurements from display because recorded imagery will have optical distortion. Several methods for making on-screen length measurements have been reported. The most straightforward method relied on comparing the length of each fish with a size reference in the picture frame, for example a colour-coded tape fixed alongside the sorting belt of the fishing vessel (van Helmond et al., 2015, 2017). Additional tools have been developed for the video inspection, such as on-screen length measurements or image capture by supplying the dimensions of the sorting band to the software and subsequently relating the length measurement to the known size of the sorting band (Marine Management Organisation, 2013a). In the Danish CQM trial, a digital grid overlay has been used in the video audit software. Based on the size of known objects at the conveyor belt, the grid overlay could be set to add lines at known intervals (Bergsson & Plet-Hansen, 2016; Bergsson et al., 2017). Additionally, a measurement line could be added to the grid and in cases where fish lay in a curved position, this line could be extended and wrought to fit the full length of the fish (Bergsson & Plet-Hansen, 2016; Bergsson et al., 2017; Plet-Hansen et al., 2019). Linear allometric models were used in cases where the total length of a fish cannot be observed in a video image; total length could be estimated by inference of lengths of other body parts (Needle et al., 2015).

Table 4. European EM video data analysis overview.

Trial	Method used to estimate catch from video recordings	Selection procedure of video data	Catch validation data	Monitored catch (species)
German North Sea CQM	Directly from sorting belt. Discards that were sorted outside camera view should be displayed by crew after the sorting process.	Random selected sequences were observed.	Official logbooks (eLog).	Landings and discards of cod
Dutch North Sea cod CQM trial	Directly from sorting belt / area.	Random selection 10% of hauls with sufficient image quality.	(self-)recorded catch by haul	Landings and discards of cod
Dutch trial on bycatch registration of harbour porpoise	Directly from net hauling and sorting table/ deck	Census of video data, played at a rate of 8 to 10 times faster than real time.	(self-)recorded bycatch by haul	harbour porpoise
Dutch pelagic freezer trawler trial	Directly from wet deck and in the factory (sorting belt/ area).	Census of video data, playback speed form frame-to-frame up to 16 times real-time.	Not applicable in this study	Discards (discarding events)

Table 4. European EM video data analysis overview. (continued)

Trial	Method used to estimate catch from video recordings	Selection procedure of video data	Catch validation data	Monitored catch (species)
Dutch sole EM trial	Landings directly from sorting belt. Discards sorted and displayed on sorting belt by crew after the soring process.	Random selection 5% of hauls with sufficient image quality.	(self-)recorded catch by haul	Landings and discards of sole
Scottish CQM trial	Directly from sorting belt / area	Random selection 20% of hauls	Scientific observer scheme	Discards of cod, haddock, whiting, saithe, hake and monkfish
English CQM trials for otter trawls and gill nets North Sea and Western Channel	Directly from sorting belt / area	Random selection 10% of hauls/ fishing operations	Observer trips, dock side monitoring and (self-)recorded catch by haul	Discards of cod, plaice, sole, hake, megrim and monkfish
English CQM trials for beam trawls in the Western Channel	Discards sorted in baskets and displayed by crew	Random selection 5% of hauls	(self-)recorded catch by haul	Discards of sole, megrim, monkfish and plaice
English EM trials for vessels < 10 m.	Directly from sorting belt / deck	A random selection of one haul per trip	(self-)recorded catch	Landings and discards of all fish species
English CQM trials for Western haddock	Directly from sorting process (counting haddock thrown into baskets)	Random selection 10% of hauls	Observer trips and (self-)recorded catch by haul	Landings and discards of haddock
English trial on video capture of crab and lobster catch	Pass catch across defined area under the field of view	Census of video data	Scientific observers	Crab and Lobster
Danish FDF trial for CQM	Catch/discards sorted in baskets and displayed by crew. From 2015 and onwards directly from sorting belt.	Random selection of minimum 10% of hauls	Official logbooks (eLog).	Discards of cod, from 2015 discards of cod, haddock, whiting, saithe and hake
Minimizing discards in Danish fisheries (MINIDISC project)	Catch/discards sorted in baskets and displayed by crew	56% of hauls was inspected in chronological order	(self-)recorded catch by haul	Discards of cod, hake, haddock, whiting, saithe, plaice and Norway lobster

Table 4. European EM video data analysis overview. (continued)

Trial	Method used to estimate catch from video recordings	Selection procedure of video data	Catch validation data	Monitored catch (species)
Danish trial on bycatch registration of harbour porpoise	Directly from sorting belt / deck (no interference of working processes on board)	Census of video data, played at a rate of 10 to 12 times faster than real time	Supplementary logbook	harbour porpoise
Swedish trial on bycatch registration	Directly from net hauling and sorting table/ deck	Census of video data. For one vessel footage was independently analysed by two different members of staff.	Fishing journal with recordings of fishing activities, catches, bycatches and seal and bird damage, following the protocols of the Institute of Coastal Research.	Harbour porpoise, seals and birds. In addition, damaged catch by seals and birds was recorded

EM performance

Most trials studied the performance of EM as a reliable source of catch information (Table 3). This performance depends on the technical reliability of the EM systems and the ability to correctly estimate catches. Technical EM failures and loss of data due to poor video quality were reported in 11 (out of 15) trials. However, not all technical errors were reported in similar detail. During the review, reported errors were classified in three different categories: system failure, storage failure and obstructed view. Where possible, errors were quantified as a percentage of data loss (Table 5). System failures were recorded in seven trials, with the main reason being broken cameras and non-functional drum-rotation sensors. Two studies (#12 and #22) mentioned system failure caused by power supply issues. Storage failure was recorded in three trials, caused by corrupted EM data, mainly video data, on the exchangeable hard drives. During the German trial, a hard drive began to burn during the copy process in the Institute and data were lost (Götz et al., 2015). Another form of storage failure occurred in the Dutch CQM trial; storage failure occurred because full hard drives were not replaced in time. This was not related to a technical failure of the EM system itself, but due to insufficient management of exchanging hard drives when vessels entered ports. A similar situation was described in the German trial where logistical and technical problems were encountered in relation to the exchange of hard drives, when vessels entered distant ports (Götz et al., 2015).

Nevertheless, no data losses were reported in this trial because of these situations. Obstructed view was reported in six trials. In these situations, the EM system worked properly; however, the footage recorded could not be used for further analysis because the view was blocked or unclear. The primary reported reason for EM data loss was unclear views because of dirty lenses, in some cases responsible for significant amounts of data loss, up to 48% (Table 5). The principal problem was the positioning of the cameras. To get a sufficient view of the catch and to be able to identify species, and count and measure individuals, the cameras were directed at the catch sorting areas. However, the working space in fishing vessels is generally extremely limited with low ceilings, and it can be difficult to position a camera in a way that can enable a wide, clear and undistorted view of the sorting area without the risk of water and fish waste splashing up onto the camera casing (Bergsson et al., 2017; Needle et al., 2015). Although the fishers had a duty to keep camera lenses clean, this was not always fulfilled. Another important factor that influences the usefulness of video data was crew that blocked the view on the sorting area, for example hands taking fish from the sorting belt (Plet-Hansen et al., 2019). Despite efforts to install cameras in the best positions, it was not always possible to prevent crew members accidentally or intentionally blocking the view. In particular, it was difficult to analyse footage on-board smaller vessels which sort directly on the open deck or use sorting tables (Marine Management Organisation, 2013b; Needle et al., 2015).

Figure 6. Sorting into baskets. Black basket contains discard and one basket has already been emptied on the conveyer belt. The picture also illustrates the issue with droplet formation on the glass dome of the camera

Van Helmond et al. (2017) concluded that to increase the technical reliability of EM, more emphasis should be put on the importance of camera maintenance (e.g. regular cleaning of the lenses and checks of EM systems). Plet-Hansen et al. (2015) found a steady decrease in the number of errors and data loss during the Danish trial. This suggested that there could be an adaption as fishers became acquainted with the presence of cameras, together with the increased training and experience of video auditors, increased experience in proper handling of EM equipment and optimization of maintenance of EM equipment. In addition, digital transfer of EM data via cellular (4G) and Wi-Fi networks eliminated malfunctions caused by incorrect hard drive exchange, damage to hard drives during transport or the loss of hard drives. Likewise, systems of this type have not been forced to stop recording because of insufficient disc space, as was the case in some other trials (Bergsson & Plet-Hansen, 2016). Overall, EM systems in European trials have been sufficiently reliable to fulfil the goals of the studies, provided there was ongoing attention to maintenance.

Figure 7. Placing individual specimens on the sorting belt (van Helmond et al., 2017)

All European trials had the objective to evaluate the ability of EM to estimate catches in commercial fisheries (Table 3). Different methods were used to estimate catch from video footage (Table 4). To test the efficiency of EM, catch estimates based on video review were compared with recordings of fishers and/ or on-board observers. In the Danish and German CQM trials, catch weights were obtained from EM with the use of fishing crews that collected catches in baskets and showed those to the cameras (Table 4). The Danish CQM trial observed discrepancies between fishers' and video observers' discard estimates that were often less than 5 kg per haul, without systematic bias and with clear improvements of the accuracy over time (Ulrich et al., 2015). The Scottish,

Table 5. Technical EM failures and loss of data for European trials.

EM failure description	Recorded in	Detailed information on failure, including estimated data loss (%), if reported†
System failure	7 trials	Camera failure: vessel A 2 – 8 %; vessel B 0- 25 % Hydraulic sensor: <1% vessel A (German CQM trial)
		35% EM data loss in total, system failure was mentioned as one of the reasons (Dutch CQM trial)
		21% data loss in total, system failure was mentioned as one of the main reasons (Dutch sole EM trial)
		17% due to failure of camera's, 12% due to rotation sensors, 7% due to control boxes, also insufficient power supply was mentioned (English CQM trial for trawls and gill nets)
		2.5%, rotation sensor and camera failure (English EM trial for vessels <10m)
		0.7% of catch processing set for audit had camera breakdowns or video gaps either rendering the video useless or hampering the audit. An additional 1.2% of all video footage was lost due to hard drives being damaged or lost while being transported from vessels to video audit. This loss stopped after 2014 when manual data transmission was replaced by transmission via the internet (Danish FDF trial for CQM)
		Unstable power supply (Danish trial on bycatch documentation for harbour porpoise)
Storage failure	4 trials	7% vessel A; 17% vessel B, corrupted hard drives (German North Sea CQM)
		Failed to replace full disks on time (Dutch CQM trial)
		13%, corrupted hard drives (English CQM trial trawls and gill nets)
		Corrupted files when power was switched off (Swedish trial in bycatch)
View obstructed	6 trials	Dirty lenses: 25 % (Dutch CQM trial)
		21% data loss in total, dirty lenses was mentioned as one of the main reasons (Dutch EM trial on sole)
		"Skipper's duty to keep lenses clean is not always been fulfilled"; "Droplets obscure image"; "View being obscured by fishers working" (Scottish CQM trial)
		Crew catch handling: 31% ; view obscured other than crew: 12%; lack of maintenance or cleaning: 48% (English CQM trial trawls and gill nets)
		"Image quality can be affected by a number of different factors including moisture in the lens, sun shield blocking view, water drops, low light conditions and bad sun glare." (Danish FDF trial for CQM)
		4.2% of catch processing set for audit had the camera view obstructed by crew; water droplets on lenses; sun glare and smudge on lenses. An additional 2.0% of the video footage had blurry imagery which hampered the discard estimates (Danish FDF trial for CQM)
		"...hauls with defected or dirty cam-eras were not analysed..." (Danish MINIDISC project)

†) percentages are calculated on different premises e.g. total number of hauls, fishing days, or fishing hours.

Dutch, German, English and in some years Danish CQM trials estimated catch directly from sorting belt or discard chute (Table 4). The English trials demonstrated good overall agreement between fishers' records and video observers (Marine Management Organisation, 2013a). In the Dutch trial, the video observations and logbook records for large cod catches were more strongly correlated than for the smaller catches, especially in highly mixed catches (van Helmond et al., 2015). This suggested that distinguishing small numbers of cod in large volumes of bycatch, particularly when similar-looking species are targeted in mixed fisheries, could be difficult. In addition, based on another Dutch EM trial, van Helmond et al. (2017) concluded that EM for small fish in mixed fisheries is not as effective as it is for large fish. Video review of the standard catch processing routines on-board bottom trawlers significantly underestimated the number of discarded sole less than 24 cm in length, while for landed sole greater than or equal to 24 cm, no significant difference was found between on-board records and video observations. Likewise, in Denmark Mortensen et al. (2017) found a tendency of EM to underestimate discards of smaller fish by 32% compared with on-board observations. This supports the findings in a few trials which suggest that, despite offering a promising way to use EM to monitor catch, the accuracy of video observation should be monitored and improved where needed (Needle et al., 2015; Ulrich et al., 2015).

The Scottish trial was able to estimate discards with no effective change to the catch processing systems used on each vessel (Needle et al., 2015). This was not the case in all trials, and protocols were developed to improve the registration of catches for vessels participating in EM in Denmark and in the Netherlands (van Helmond et al., 2017; Ulrich et al., 2015). Fishers were able to follow the protocols to improve video review, and when mismatches occurred, it has generally been sufficient to point to the issue in order to get the return to full compliance. These protocols substantially increased the accuracy of EM. However, for both trials it was reported that the protocol could be a burden for the crew. For example, the Danish basket system has been criticized by fishers, because it imposes additional work on crews. Moreover, baskets take much space on deck and they are heavy to move. In the Dutch case, the protocol required on average an additional 3 min of processing time per haul for a single species. Consequently, van Helmond et al. (2017) concluded that given the large number of species under the landing obligation for this fishery, implementing even a simple protocol come with a cost for the fishing industry; the extra time needed to conduct such a protocol under the landing obligation would exceed 12 hr per fishing trip. A reduction in this effort in a monitoring programme may be possible by means of industry-driven innovations.

Also, the use of EM video data to provide length–frequency data is not always straightforward, as it is not always possible to view the full body of each fish due to occlusion by other fish or waste materials (Needle et al., 2015). However, a morphometric length inference model for fish of which the full body was not visible on footage was successfully tested in the Scottish trial (Needle et al., 2015). Also, developments in automated measurement of fish by computer vision may improve length measurements based on video data even further (French et al., 2015; Huang, Hwang, Romain, & Wallace, 2018; White, Svellingen, & Strachan, 2006). Nevertheless, even fully accurate length measurements would have to be converted into weight using length–weight relationships rather than being weighed directly on-board, which could contribute to some discrepancies with observer estimates.

In summary, the EM performance depends critically on whether the operating specifications of the technology, the monitoring objectives, the vessel layout and the responsibilities of the vessel personnel in supporting the monitoring effort are considered.

Cost-efficiency

The price of an EM system per vessel, including installation, in the trials has been around 9–10.000 €, and systems in the trials have typically lasted between 3 and 5 years (van Helmond et al., 2015; Kindt-Larsen et al., 2011; Marine Management Organisation, 2013b; Needle et al., 2015). Running costs include data transmission costs, maintenance costs, data review and software licences. Unfortunately, the different components of running costs are not always explicitly documented in the different studies. Reported total running costs for systems where hard drives needed to be exchanged manually were in the order of 4,000–7,000 € per year per vessel (van Helmond et al., 2015; Kindt-Larsen et al., 2011; Marine Management Organisation, 2013b; Needle et al., 2015). If data transfer was arranged by manual exchange of hard drives by scientific staff, the costs for this transfer were a considerable part of the running costs. The transmission of data by 4G network allowed these transmission costs to be considerably reduced, down to ~100 € per year per vessel (Mortensen et al., 2017). However, the costs depend on the quantity of data, the operation area of the vessel and the possibilities to transmit data. Plet-Hansen et al. (2019) estimate the initial costs of fitting all Danish vessels above 12 m in length (396 vessels) with EM to 3.3 million € and estimate the total running costs to amount to 1.7 million € annually based on the setup used in 2016 for a Danish EM trial. Needle et al. (2015) concluded that, although the initial costs of EM are high, EM is a more cost-effective monitoring method than an on-board observer programme in the mid-to-long term as running costs are much lower, consequently, that would allow for a wider sampling coverage for a given monitoring budget along with truly random sampling. Another important aspect regarding the cost–benefit of EM is the involvement of fishers in reporting their catches. Electronic monitoring is often used to validate self-reported catches or discards. Even though only a minority of these reports are audited with video, the fishers do not know which hauls will be audited and when, which creates an incentive to report all catches accurately. Consequently, even with a low audit rate, observation costs are expected to be largely internalized by fishers (James et al., 2019). It should be noted, however, that these cost analyses were based on EM trials and that we did not encounter cost analyses based on large-scale monitoring programmes.

EM acceptance

All the reviewed EM trials have been based on voluntary participation, albeit with substantial incentives in most cases. The participation in CQM schemes has usually been good, with most vessels participating for several years in the trials (Course et al., 2011; van Helmond, Chen, Trapman, Kraan, & Poos, 2016; Marine Management Organisation, 2013a; Ulrich et al., 2015). In Scotland, the scheme ran in full from 2009 to 2016 (a reduced scheme is still in operation at the time of writing), and was always oversubscribed, with an average of 25 vessels taking part each year (Needle et al., 2015). Noticeably, incentives to participate in the North Sea CQM trials were enshrined in the EU TACs and quota regulation (EU, 2010), with participating fishers receiving additional national quota shares. In the initial CQM feasibility trial, a 100% quota increase was offered (Kindt-Larsen et al., 2011), which was then reduced to 30% after 2010 (EU, 2010). CQM vessels were also exempted from days-at-sea regulations in most trials. Other trials outside of the remits of the North Sea CQM offered a more diverse perspective on participation. In the Scottish trial, vessels were permitted to enter parts of the nationally imposed real-time closures intended to protect juvenile cod (Needle & Catarino, 2011). The trials by Mortensen et al. (2017) and van Helmond et al. (2017) offered an additional quota taken from the quota share reserved to scientific experiments. Meanwhile, the studies of Tilander and Lunneryd (2009) and Kindt-Larsen et al. (2012) show that EM trials can also be conducted without tangible reward; fishers participated only for the benefits of demonstrating that their by-catches of harbour porpoise (Phocoena phocoena, Phocoenidae) were minor.

The concerns voiced against EM are mainly of ethical nature, related to the potential misuse of video data and to the "Big Brother" intrusion of the constant presence of video equipment (Mangi et al., 2013). On the other hand, increase in public goodwill, better stock assessment and the possibility to induce a more sustainable fishery have also been stated as reasons for participation (Marine van Helmond et al., 2016; Scotland, 2011; Plet-Hansen et al., 2017). A notable observation in the Danish trials, described in the study of Plet-Hansen et al. (2017), was that fishers who had participated in EM trials were generally positive about EM and its possibilities; 58% of interviewed EM-experienced fishers expressed positive views on EM. In contrast, fishers without any first-hand experience with EM remain largely negative about it; 90% of the interviewed fishers without EM experience were against it. Whether this division resulted from participating fishers being more in favour of EM prior to trial participation or whether participation in the trial had changed the opinion of the fishers was not studied. The fact that fishers were rewarded to fish with EM in most trials may also have been an influence. In addition, some studies indicated that protocols to improve video review can be a burden on the crew (van Helmond et al., 2017; Ulrich et al., 2015). The success of monitoring the landing obligation with EM likely depends, at least for a large part, on the workload that it imposes on skippers and crews for monitoring and registration of catches. Similar observations were made during the process of EM data review and analysis of Götz et al. (2015) and Mortensen et al. (2017). However, the development of technologies to improve the implementation and reduce this burden of EM has been ongoing in the Scottish trial (French et al., 2015; Needle et al., 2015).

It is noteworthy that the first decisions to use EM in the EU did not come from the fishing industry, but from a strong political will. Based on the results of the first CQM trials in Denmark and Scotland, political representatives of Scotland, England, Denmark and Germany signed the Aalborg Statement on the 8 October 2009, which presented a joint position recommending the use of EM in fisheries monitoring. Following the Aalborg Statement, the Scottish Cabinet Secretary for Rural Affairs and the Environment emphasized that the intentions of the Scottish EM scheme were twofold: to facilitate monitoring of fishing and discarding activity for compliance purposes, but also (and equally) to provide valuable data to fisheries scientists to increase understanding of fleet dynamics, population distribution and structure, and ecosystem components (Needle et al., 2015). Also, the European Council mentioned the use of EM as a means to ensure compliance with the landing obligation in its regulations (EU, 2013). This top-down approach implies the fishing industry only got involved at the end of the implementation phase. However, based on Canadian EM studies in British Columbia, both Koolman, Mose, Stanley, and Trager (2007) and Stanley, Karim, Koolman, and McElderry (2015) emphasized the importance of involvement and participation of fishers already in the initial (design) phase of EM implementation. Also, the fact that EM is perceived as a compliance monitoring tool has a negative impact on the acceptance of EM within the fishing industry. A key aspect of this reluctance is the introduction of a (potentially) more robust monitoring of catches compared with the current reporting systems and thus a perceived higher probability of being caught if non-compliant. While only penalizing fishers in case of differences between logbooks and EM will be counterproductive, a continuous dialogue about these differences may help improve data quality and acceptance of EM as a monitoring tool.

In the context of the adoption of EM in Europe, there is still no obligation for EU Member States to use EM as a verification or monitoring tool. If EM is required in some Members States but not in others, there will be no "level playing field" between European fishers. This concept of a "level playing field" potentially imposes an extra obstacle for the implementation of EM in European fisheries management (Plet-Hansen et al., 2017).

The acceptance of EM will improve if benefits of EM for the fishing industry are greater than just improving compliance (Michelin et al., 2018). Such benefits could include improved data quality through EM, allowing for more efficient management measures and, eventually, improved financial performance for industry, and increased flexibility in regulations as a result of improved accountability from EM. The Danish trial on free gear selection (Mortensen et al., 2017) is a good example of this, alternative uses for EM data, for example, improved business analytics, such as identifying and avoiding bycatch hotspots, support of (eco-) certifications by increasing traceability in seafood supply chains.

EM objectives

Of the reviewed studies, 9 studies had the objective to evaluate the efficacy of EM as a monitoring tool (Table 3). Of these 9 studies, 8 concluded that EM is an effective monitoring tool compared with other existing monitoring methods such as at-sea observers, VMS and electronic logbooks (eLogs). One study of the 9 mentioned was not conclusive of the efficiency of EM as a monitoring tool compared with other methods, but indicated that EM delivered an appropriate coverage of fish catches and fishing time.

In addition, EM proved to be a successful tool to test alternative management regimes, for example catch quota management (CQM) trials and "unrestricted gear" trials (Mortensen et al., 2017). In several studies, changes in fishers' behaviour were observed because of a change in management regimes in combination with EM. In some cases, there was a shift in behaviour towards greater avoidance of undersized fish (van Helmond et al., 2016), reduced high grading (Kindt-Larsen et al., 2011) and generally greater compliance with rules and regulations in recording discards (Ulrich et al., 2015). Thus, EM triggered compliance and provided a rich source of information that can be used to inform on the outcome of management measures. In general, detailed spatiotemporal information on catches of unwanted fish and the ability to fully document fisheries with EM were of crucial importance for the evaluation of management measures in these studies, something that could only be achieved with on-board observers at substantially higher costs.

In the English trial, EM was used to assess the performance of new fishing gear (Marine Management Organisation, 2013a). As part of the English Marine Management Organization CQM scheme, a participating skipper voluntarily altered the selectivity of his trawl. Comparative catch weight data from the skipper using different net designs were corroborated using EM (Marine Management Organisation, 2015a). These data were used to optimize the modified trawl design prior to a detailed catch comparison trial. The validated skipper data supported results from the trial, demonstrating the efficiency of EM in evaluating and developing modified fishing methods or fishing gears. Considering the cost-efficiency in the midterm and long term (see above), EM could be a relevant monitoring method for gear trials in comparison with the more expensive onboard observer option.

In two of the reviewed trials, the Dutch CQM and the Danish MINIDISC trials (studies #4 and #20, Table 3), changes in fishing activity and behaviour were analysed when vessels were under different management regimes (van Helmond et al., 2016; Mortensen et al., 2017). The wider monitoring coverage of the fleet, in essence a 100% coverage (Kindt-Larsen et al., 2011), created a unique opportunity to investigate fishers' gear choices, mesh sizes and fishing locations at broader (macro) and finer (micro) geographical scale. Rather than relying on model predictions on the potential outcome of catch quota management, the 100% recording of total catch (landings and discards) and fishing activity allows the observation of actual fishing behaviour (van Helmond et al., 2016). This was further supported by interviews to help interpret the results, giving a detailed insight in the decision-making processes and reasoning of fishers in the study.

The monitoring of marine mammal by-catch represents a special case in the use of EM. Such monitoring is needed worldwide due to growing concerns regarding the population status of marine mammal species. In Europe, 4 trials (studies #2, #5, #22 and #23, Table 3) have been conducted to evaluate the feasibility of using EM to observe incidental by-catch of marine mammals or seabirds in gill net fisheries (Kindt-Larsen et al., 2012; Oesterwind & Zimmermann, 2013; Scheidat, Couperus, & Siemensma, 2018; Tilander & Lunneryd, 2009). Commercial gill-netters (10–15 m in length) were equipped with EM systems. The results revealed that harbour porpoises, seals and birds could easily be recognized on the video footage. The studies highlighted the importance of having one camera covering the position where the nets break the surface as many porpoise carcasses tend to drop out of the nets at that specific point due to their heavier weight in air. Comparisons between EM results and fishers' logbooks showed that the EM system gave reliable results. In the Danish trial, EM was more reliable since fishers, in many cases, did not observe the by-catch while working on the deck (as the by-catch had already dropped out of the net before coming on-board). Furthermore, the studies concluded that very high coverage percentages at low cost, compared with on-board observers, could be obtained with EM. Similar conclusions were drawn in a review on EM studies by Pierre (2018): EM has been widely tested and proven effective in monitoring protected species interactions in fishing gears.

Summary of European trials, operational benefits of EM

The three major benefits of EM perceived in the European trials were as follows: (a) cost-efficiency, (b) the potential of EM to provide much wider (and more representative) coverage of the fleet than any observer programme will likely achieve and (c) EM registration of fishing activity and position of much greater detail.

With the potential to enhance data collection programmes, EM has the ability to improve the scientific stock assessment and risk assessment processes. In particular, the assessments of data-limited stocks (DLS) would benefit from a system like EM, the wider coverage of the fleet enabling data collection from less abundant species or specific fisheries, for example long-distance or small-scale fisheries, which are notably difficult to cover with a traditional observer programme. However, age and maturity data can only be collected through direct physical sampling. Observers can also collect sex data for some species by external observation (e.g. plaice, Elasmobranchs and Nephrops) which is not possible with existing EM systems. Therefore, EM cannot fully replace all the data needs currently provided by observers and it should be explored how observer and EM programmes could be integrated, as this would enable the benefits from both approaches to be utilized. An alternate possibility would be to continue development of length-based assessment methods, which would not require age data to the same extent as currently used in stock assessment methods (Needle et al., 2015). In addition, EM species identification for similar-looking species was difficult for small species and when large concentrations of fish were processed (van Helmond et al., 2015). In contrast, observers can accurately identify all fish, crustacean and cephalopod species to the species level as required for stock assessments. However, there is potential for improving species identification in EM by making use of computer vision technology (Allken et al., 2019; French et al., 2015; Hold et al., 2015; Storbeck & Daan, 2001; Strachan, Nesvadba, & Allen, 1990; White et al., 2006).

The results of the EU review are summarized using a SWOT (Strengths–Weaknesses–Opportunities–Threats) analysis in the context of the current data collection framework (Table 6) of the EU. The strength of EM is the substantially higher sampling coverage compared with current monitoring programmes at the same costs. At the same time, EM offers a better estimation of fishing effort through high-resolution spatiotemporal GPS data combined with accurate recording of fishing activity, for example setting and hauling. The observations of the catches made by video can be independently verified by different reviewers by replaying the video material. The EM systems had a high approval rate among participating vessels in one of the trials (Plet-Hansen et al., 2017). This means that EM can incentivize compliance through fleet-wide monitoring, creating the same regulatory framework for all fishers. Thus, the current EM systems could be a valuable addition to existing personnel-intensive monitoring methods. However, there is a range of weaknesses that still needs to be addressed when discussing the applicability of the EM. First, switching to EM requires a substantial investment, especially when compared to the revenue of smaller fishing enterprises. Thus, despite being cost-efficient in the medium-to-long term, EM can represent an initial economic burden. Secondly, fishing vessels differ widely from each other in terms of size and set-up of working spaces, meaning that each EM system must be tailored to the individual vessel to provide optimal monitoring. Additionally, time has to be dedicated to adjusting the set-up after the first trips, and camera lenses have to be regularly cleaned, affecting the workflow of the crew. The set-up also requires decisions on whether to have high resolution with low frame rate or vice versa, with both options requiring a substantial data storage demand. Also, as with all technical systems, EM can fail resulting in missing data. Even with ideal EM set-ups, it can be difficult to distinguish similar-looking species in high volume catches of mixed fisheries. But above all remains the reluctance to have cameras on-board. As most fishers see the fishing vessel both as a place of work, but also as a place of privacy, EM can easily be seen as a “Big Brother” system, intruding on the sanctity of the fishing vessel and representing a governmental mistrust in the fishers. Nevertheless, EM is currently a viable alternative to on-board monitoring of CQM regimes. If the initial installation costs can be overcome, EM offers the potential for fleet-wide monitoring coverage, with substantially more data than currently gathered in the various monitoring schemes, including the potential for length-distribution estimation of target species and a mapping of by-catch. In summary, EM as monitoring tool contains a range of solid strengths, that are not diminished by its weaknesses and EM has the opportunity to be a powerful tool in monitoring fisheries, integrated with existing data collection programmes, as long as a range of issues are addressed.

Table 6. SWOT analysis of EM compared to the European data collection framework of the EU in the context of the EU landing obligation.

Strengths	**Weaknesses**
High and randomised coverage	Intrusion of privacy
Cost-efficient	Requires investment in equipment
High spatial and temporal GPS resolution.	Challenging setup on small vessels
High precision on effort estimation	Have to dedicate time to adjust setup to match work flow, setup unique to each vessel
Provides verifiability of observations (replay)	Cameras have to be cleaned
Support tool for eLog verification	High data storage demand.
Independent recording of catch information	Requires training of video inspection personnel.
High acceptance among former EM users.	High resource requirement for viewers (unless automated)
Equal playing field.	Can affect work-flow for crew
Inform on bycatch of marine mammals and seabirds.	Risk of system failures
	Difficult to distinguish similar looking species in mixed catches.
	Low acceptance in the fishing industry in general
Opportunities	**Threats**
Fleet wide coverage	Misuse of data
Better assessments, especially of data limited stocks	Hacking
Potential for obtaining length-frequency distribution	Confusion of data ownership
Non-invasive monitoring	Changing political interest in EM
Assist in a better planning of the individual fishery.	
Mapping of bycaught marine mammals and seabirds.	
Can be combined with existing observer programmes	

Discussion

Review of EM studies

There has been only limited coordination between the various trials between different regions in the world, and therefore, this review represents a step forward into synthetizing the outcomes of the various studies. Results of the studies have been documented in scientific peer-reviewed journals and technical reports. A challenge in this review was that not all trials have been well reported: some trials may never be documented, while others may not yet be documented because of a time delay in reporting results. Hence, it is not possible to include all trials in a global review. Another challenge in evaluating the performance of EM is that the technology has evolved over trials. Likewise, EM performance will evolve within trials and a perspective on the potential for EM may be more informed at the end of a trial rather than across a trial. Also, there is a difference in the level of detail in the methodology and results published in manuscripts or reports. Direct comparison between studies is, therefore, not always straightforward.

Successes of EM worldwide

Based on continuity and expansion, EM has been successful in several different regions around the globe. Currently, EM programmes in Alaska, British Columbia, West and East Coasts of the United States and Australia are already well developed with comprehensive sampling schemes covering up to 100% of fleets, in some cases involving hundreds of vessels and thousands of fishing days. Clearly, the technical weaknesses of EM that were revealed in European trials have been encountered and solved in these examples where EM has been operationalized. In those cases, acceptance from the fishing industry was a crucial element for successful implementation of a full EM programme. Fully implemented programmes are often driven by the existence of a strong compliance or management issue that needs to be solved, for example gear theft or rampant discards, an example being the British Columbia, "Area A" crab fishery programme. In this case, EM is the best cost-effective solution and the efficiency of EM for these fisheries is demonstrated (McElderry, 2006). Full programmes can be adopted optimally if three components are present: (a) acceptance in the industry, (b) a strong incentive to monitor and (c) proven efficiency of EM.

Another component of successful EM implementation is government support. Electronic monitoring trials in the United States are subsidized by the government. A good example is the EM programme on the US Atlantic Highly Migratory Species longline fishery that was designed, approved and implemented in a little over a year (Michelin et al., 2018); such speed can be attributed to this being a fully government-funded EM programme. This initial investment by the government can help EM programmes develop, even if the long-term plan is to transition to industry cost allocation once a programme is fully implemented. On the other hand, system maintenance and longevity tend to be increased when fishers are investing in the systems themselves. A general factor in all fully implemented programmes (Table 3) is that EM cannot work in isolation and is often integrated with other monitoring elements, such as dockside monitoring, self-reported logs, observers and dealer reports. Various data types can provide useful information each with different strengths and weaknesses (Stanley et al., 2015).

In the field of research on interactions or by-catch of marine megafauna in commercial fisheries, EM is generally accepted as a reliable tool (Kindt-Larsen et al., 2012; Pierre, 2018). The high level of spatial and temporal coverage and the fact that megafauna is easily spotted on video records makes EM a very efficient tool for this purpose. This efficiency of EM in the field of by-catch registration of cetaceans is also reflected in the increasing number of activities organized by the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS). The US regulatory programme to mitigate impacts on marine mammals in commercial fisheries potentially will also have an impact on the uptake of EM in the future (Michelin et al., 2018).

A fast-growing area of EM application is fisheries in remote areas, where monitoring fisheries is challenging, inefficient and costly. Examples are the West and Central Pacific Islands, Indian Ocean and South Georgia. Electronic monitoring is a solution for enhancing existing observer programmes in these fisheries where extreme weather conditions, high safety risks and long distances make administering observer programmes difficult and EM is much less of a financial burden than an on-board observer (Ruiz et al., 2015; Stanley et al., 2015). Also, issues of on-board accommodation, food, getting an observer in and out of remote locations do not exist with EM. In situations where the fishing industry has the responsibility, also financially, to monitor fishing activities, and where monitoring coverage is high, monitoring costs are a factor for an increased adoption of EM. In addition, EM put less constraints on the planning of fishing trips. Of course, when monitoring levels are minimal, the cost of buying and installing EM is higher than having an observer once every other year.

Uptake of EM worldwide

Despite the apparent advantages of using EM systems in pilot studies, and successful EM programmes in some areas, fleet-wide implementation in globally important fishing regions is progressing slowly. This slow uptake of EM can be attributed to several factors:

1. EM is often proposed as a compliance tool. This works well in situations when there is a common need to solve a compliance issue in the industry, for example the British Columbia, “Area A” crab fishery programme (McElderry, 2006) and the Groundfish Hook and Line Catch Monitoring programme in British Columbia (Stanley et al., 2015). However, in several cases EM was presented as a promising tool to monitor compliance in situations where full accountability seemed like an existential threat to the viability of the fishing industry (Michelin et al., 2018). This is especially true in fisheries with strong restrictions on discards and by-catches, like fisheries under the landing obligation in the EU, where fishers have become dependent on discarding the most limiting quota that would lead to early closures of the fishery, the “choke” species. Not surprisingly, EM has faced significant opposition from parts of the fishing industry in this region (Michelin et al., 2018; Plet-Hansen et al., 2017).

2. Costs of EM adoption are clear for the fishing industry, but the long-term benefits are not. While implementation costs are often covered through government funds, running costs and data analysis costs are generally at the expense of the industry (NOAA, 2017a). Meanwhile, potential benefits for individual fishers, for example market access, sustain-

ability claims, improved traceability and data licensing, are not well documented and not always of direct interest to them.

3. Most pilot studies were not designed to initiate broad implementation. Commitment on what successful trials would trigger was lacking, and there was no plan for further development into full EM programmes (Michelin et al., 2018).

4. Most fisheries government agencies lack capacity and expertise, for example people capable of programme design and video review, to run fully implemented fleet-wide EM programmes. The implementation of such programmes requires large IT infrastructures to deal with the amount of data that EM generates in, for example, data transmission, data storage and data review. Many fisheries management agencies have no experience in setting up these infrastructures and are hesitant to commit to this effort. In the absence of support, individual fishery managers or regulators can be reluctant to implement EM schemes at scale (ICES, 2019; Michelin et al., 2018).

5. There is a strong perception of intrusion on the fishers' privacy. Mangi et al. (2013) point out that a large proportion of the fishing industry is not supportive in using EM for this reason. Besides privacy issues, the industry fears sensational use of footage, for example dolphin by-catch, liability and video manipulation (Michelin et al., 2018). Also, liability issues in the context of safety standards of work environment on-board can be an issue for vessel owners in cases where government institutions are requiring footage to monitor occupational health and safety regulations. Reluctance against EM regarding privacy issues and mistrust of data use is stronger for the proportion of the fishing industry without experience with EM (Plet-Hansen et al., 2017). Once EM is implemented and fishers have actual exposure to EM, they generally have a more positive perception of the tool and it is easier to have an informed dialogue about applications (Michelin et al., 2018; Plet- Hansen et al., 2017). In other words, most fishers that are familiar with camera set-ups on their vessels did not experience an intrusion of privacy because of EM.

6. In some cases, EM raises concerns about employment impacts, especially when it is likely that at-sea observer sampling schemes will be scaled back with EM. These concerns are more concrete in regions with higher unemployment levels and where observer programmes enhanced job creation, but can be mitigated by employing experienced observers for video review, fisher liaison, data processing and following up on anomalies in imagery (Michelin et al., 2018). This may be preferable in the context of work–life balance, health and safety, since it allows staff to remain onshore.

EM and the European Landing Obligation

A phased implementation of a landing obligation (LO) (EU, 2013) is implemented in the context of the European Common Fisheries Policy (Borges, 2015; Holden, 1994). Fully implemented and enforced the LO require fishers to report all catches of TAC species to be deducted from the quota. However, in practice non-compliance is potentially introduced (Batsleer, Poos, Marchal, Vermard, & Rijnsdorp, 2013; Borges, Cocas, & Nielsen, 2016; Condie, Grant, & Catchpole, 2013; Msomphora & Aanesen, 2015). Fishers are incentivized to continue to illegally discard low-valued fish to retain quota to fish for more valuable catches of the same species later and to prevent exhaustion of the most limiting quota that would lead to early closures of the fishery, the so-called "choke" effect (Batsleer, Hamon, Overzee, Rijnsdorp, & Poos, 2015; Baudron & Fernandes, 2015; Eliasen, Papadopoulou, Vassilopoulou, & Catchpole, 2014; Hatcher, 2014; Mangi & Catchpole, 2013; Ulrich, Reeves, Vermard, Holmes, & Vanhee, 2011). Without additional or alternative tools for control and monitoring and/or a different set of incentives for fishers to fish more selectively, it has been anticipated that the LO will thus introduce more uncertainty into stock assessments and potentially jeopardize the chances of success of achieving the maximum sustainable yield (MSY) objective.

Electronic monitoring is often considered a potential candidate and, more importantly, the only financially affordable alternative, for full catch documentation under the LO (Aranda et al., 2019). An important constraining factor of implementing a full EM programme, within the context of the LO, is that EM is considered as a mechanism to monitor compliance. Such compliance-driven measures involving EM were only successful when there was support from the fishing industry. Incentives to gain support for EM would potentially improve the situation under the LO. For example, experiments with increased flexibility in gear choice (Mortensen et al., 2017), individual quota uplifts (van Helmond et al., 2016; Kindt-Larsen et al., 2011; Needle et al., 2015) and permission to enter closed areas (Needle & Catarino, 2011) have proved that incentives can make EM successful.

With regular feedback to the fishers, EM data can be used to inform on discard avoidance, and spatial distribution of unwanted catches, and could be disseminated on knowledge sharing platforms (Bergsson & Plet-Hansen, 2016; Bergsson et al., 2017; Needle et al., 2015). Electronic monitoring systems would have the potential to become a valuable information stream, for example, for the fishing industry to enable them to avoid unwanted catches or inform each other about real-time move-on rules.

Enhancing the implementation of EM

Electronic monitoring as a monitoring tool contains a range of solid strengths that are not diminished by its weaknesses and EM has the opportunity to be a powerful tool in the future monitoring of a wide range of different types of fisheries. Electronic monitoring can be used to fully document a fishery or be integrated with existing data collection programmes, for management and compliance purposes or scientific data collection. Nevertheless, the viability of EM depends largely on how a range of threats are dealt with. Changes in the political landscape make the future of EM unpredictable; the end of the Fully Documented Fisheries programme in Denmark was the result of governmental change with a different view on fisheries management. Another important liability is its very low acceptance by the fishing industry. If EM is to be implemented as a monitoring tool, then turning this threat into an opportunity is the biggest challenge for EM, shifting the perception that EM is only fit for fisheries management and compliance objectives. In other words, changing the association of EM from being a "Big Brother" perspective to "giving the responsibility back to the fishing industry" in a results-based approach. During the whole process of implementation, including the design and planning phases, involvement and participation of fishers are crucial (Stanley et al., 2015). In such a results-based approach, fishers are accountable for the impact they create on the marine environment (full documentation of catches), and EM should be used as a way for them to prove the reliability of their documentation, in the spirit of the "black boxes" used in trucks and flights. Also, a marketing role is foreseen for EM: consumers would like to know the provenance or sustainability of the product they are buying. A growing number of seafood retailers are planning to link EM with traceability systems that allow for complete and transparent "net-to-plate" origin stories (Michelin et al., 2018). As part of this paradigm shift, additional issues such as hacking and data misuse will need to be addressed before a wide implementation can be completed, which requires discussions on data ownership, data storage facilities and access. Another underlying threat is the lack of evidence that EM is, in fact, less expensive than on-board observers in large-scale monitoring programmes.

In summary, EM as monitoring tool contains a range of solid strengths, that are not diminished by its weaknesses and EM has the opportunity to be a powerful tool in the future monitoring of the fisheries, integrated with existing data collection programmes.

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Data availability statement

The data, summarized information subtracted through literature review, that support the findings of this study are available from the corresponding author upon reasonable request.

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CHAPTER 6

6

General discussion

Globally, the percentage of stocks fished at biologically unstainable levels increased, especially over the last decades (FAO, 2022). Improvement is needed and therefore making fishers more accountable for their catches is considered an important step in the framework to resolve the problems of unsustainable harvesting of fish stocks. Advanced monitoring technologies, such as video-based monitoring, also known as Electronic Monitoring (EM), are often seen as a key element within this context: Improved monitoring of fishing activity and catches eventually leads to sustainable fisheries management.

The introduction of EM in European fisheries was predominantly driven by the implementation of the catch-quota management (CQM) trials on North Sea cod (chapter 2; Kindt-Larsen et al., 2011; Needle et al., 2015; Ulrich et al., 2015). During these trials fishers received additional quota and increased flexibility on effort regulations. In return, participants were held accountable for the complete catch of cod, including the undersized unwanted and unmarketable part of the catch. Because of these trials, the feasibility of EM in registering fishing activity and catches, is well documented for fisheries in Denmark, England, Germany, Scotland and the Netherlands. During the trials EM successfully provided the 100% monitoring coverage necessary for the control and enforcement of the CQM trials. The full documentation through video recording in combination with the knowledge that control agencies had full access to recorded footage, was the trigger to ensure registration of catches, discards included (Kindt-Larsen et al., 2011; Ulrich et al., 2015).

The individual increase in cod quota, motivated many fishers to participate in CQM trails (Kindt-Larsen et al., 2011, Needle et al., 2015). In return, all cod catch, including the undersized discarded part, were registered and deducted from their individual quota. In their attempt to maximize their available quota an incentive was created to avoid catching smaller, i.e. juvenile, cod (chapter 3). This observed behavioural change in combination with the full monitoring coverage by EM introduced new ideas and concepts for a more innovative fisheries management approach. Possibly, in the situation where EM becomes the tool of choice for monitoring fisheries, this could potentially initiate a paradigm shift in fisheries management, such as increased flexibility for technical regulations and a shift towards result-based management (Needle et al., 2015; Mortensen et al., 2017a; Michelin et al., 2018). Also, in the context of the European landing obligation this could be a realistic scenario. The landing obligation, one of the key elements of the reformed Common Fisheries Policy of the European Union, requires that the complete catch of species under quota regulations, including the unmarketable undersized part of the catch, needs to be reported and landed (EU, 2013; Uhlmann et al., 2019). Currently the compliance level of the landing obligation are low (EFCA, 2019). Reliable methods to accurately monitor catches, in particular the unmarketable normally discarded part of the catch, on board commercial fishing vessels are a crucial element for successful implementation. Already, EM is often presented as the solution to control the recording of discards under the landing obligation (Kindt-Larsen et al., 2011; Mangi et al., 2013; Msomphora and Aanesen, 2015; Needle et al., 2015; Ulrich et al., 2015). However, the European experience with EM is only based on smaller, mostly scientific driven, trials. Of course, in North America and Australia, EM is already successfully implemented and integrated in the management for several fleets in different fisheries (chapter 5). But the scale of implementation on a pan-European level, covering, in total thousands of vessels in different countries for a considerable number of different type of fisheries, has not been done before. Indeed, based on the results of the trials, it can be concluded that EM has advantages in monitoring certain aspects of fisheries, and has major benefits compared to conventional at-sea monitoring methods, e.g. patrol vessels, onboard observers, conventional position recording system, like VMS. EM is more cost-efficient, provides more detailed registration of fishing activity and has considerable increased level of spatial and temporal monitoring coverage (chapter 5; Needle et al., 2015; Michelin et al., 2018). But, there are some limitations to EM, certainly in the context of the landing obligation. The EM objective for the landing obligation to control, or verify, the recording the discarded part of the catch for multiple species, can be complex, labour-intensive, and therefore, difficult to implement at large scale (chapter 2 and 4; Needle et al., 2015; Ulrich et al., 2015). In addition, it remains to be seen to what level fishers are able to adapt and accept the introduction of EM into European fisheries regulations (chapter 4; Mangi et al., 2013; Plet-Hansen et al., 2019). To support the landing obligation there is a need for a robust monitoring system, with the ability to accurately record discards at sea and with support of the fishing industry. Whether EM can fill this gap is discussed in detail in the following sections, answering the questions 1) is it feasible to record landings and discards in the Dutch bottom trawl fishery and 2) what are the behavioural changes of Dutch fishers under a CQM.

The feasibility of EM to record discards.

Discards are considered to be a waste product. After the commercially valuable specimens, are sorted from the catch, discards are dumped back into the sea, and, for the majority of the species, with low chances of survival (Catchpole et al. 2005; Kelleher, 2005; Depestele et al., 2014). A practise considered to be unsustainable, since, in general, the main part of the discards consists of juvenile specimen, not being able to spawn and contribute to the future of the population. Monitoring discards is one of the most challenging aspect of fisheries data collection; happening at sea, it evades the eye and goes often unrecorded (Uhlmann et al., 2014). To monitor discards, samples of the discarded catch are taken on board, after which species are identified, sorted, measured and quantities recorded. In general, this procedure is conducted by on-board observers, trained (scientific) personnel often being part of regional or national adopted onboard observer programmes. Onboard sampling of discards is considered to be a labour intensive and inefficient, as a consequence, monitoring intensity often covers less than one percent of the total fleets fishing activity in days at sea (Cotter and Pilling, 2007; Ulleweit et al., 2010; Feekings et al. 2012; Poos et al. 2013; Uhlmann et al., 2014).

With the ability to increase sampling coverage, EM has the potential to improve discard monitoring. Cost-efficiency and increased sampling effort in space and time, i.e. a wider sampling coverage within reasonable budgets, creates opportunities in monitoring discards beyond the traditional observer monitoring schemes. The automated computer system on board provides the possibility of constant monitoring and, integrated in a vessel's system, doesn't use lots of space on board. Good examples are EM implementation to monitor discarding in long-distance and small-scale fisheries, which are notably difficult to cover with on board observers (chapter 5). With the ability to provide a 100% monitoring coverage on all vessels, EM would indeed be the right candidate to facilitate control and enforcement in recording discards under the landing obligation (Kindt-Larsen et al., 2011). Besides increased sampling coverage, correct species identification and accurate estimation of catch quantities, e.g. weights, volumes and numbers, are also important. Indeed, the results of this study appear to be encouraging for using EM to record discarding on board commercial fishing vessels. In general, the Dutch pilot studies (chapters 2 and 4) and the review of similar European EM trials (chapter 5) demonstrate successful reporting of discard quantities. Strong agreement between onboard observer discard sampling and EM recordings were observed in several studies (Kindt-Larsen et al., 2011; Course et al., 2011; Marine Management Organisation 2015; Mortensen et al. 2017b).

Still, a review of EM data in the trials also show that low image quality has a direct negative effect on the performance level of EM, i.e. the ability to properly monitor discards on board. If there is no clear view of the cameras, EM is unable to accurately record catch quantities. The primary reported reason for poor image quality is dirt on the camera lens (chapter 5; Mangi et al., 2013). Scales, muck and water drops stick to the lens cover and (partially) block the view. Other limitations are caused by external factors like poor light conditions or reflections on the wet surface of the fish, and damaged camera housing, e.g. scratches on the transparent lens covers. Also, camera positioning proved to be of crucial importance for EM, since crew members can unintentionally block the view temporarily when they sort and pick the catch from sorting belts or remove parts of the catch before they come into view. During the European EM trials, dirty lenses and blocked view was responsible for significant amounts of data loss, varying between 4 to 48% of the collected footage (chapter 5). Cleaning camera lenses is a constant point of attention, which is underpinning that fishers need to conform to the operational practices on board to facilitate the success of EM (van Helmond, 2021). In other words, the willingness of fishers to get involved and participate is of crucial importance for the efficiency of EM in recording discards.

Another, more fishery dependent, issue for misreporting discards is that simply not all individuals could be spotted on the footage, even if the conditions are optimal. When catches are processed in such a manner that it is easy to detect individual species, e.g. hook-and-line fishing, trap fishery for crab and lobster, EM is a reliable and accurate method to estimate catches, and discards, on board vessels (Ames et al, 2007; Hold et al., 2015). Fish is more difficult to observe in fisheries where large volumes of catch are processed on deck, with a mixed species composition, consisting of similar looking species (and sizes), such as the bottom-trawl fishery (chapter 4; Mortensen et al., 2017b). In addition, occlusions of fish and other organic material make it difficult to provide accurate length frequency data, because it is not always possible to view the full body size of a fish. An important and crucial limitation, because length is the only biological parameter that can be directly obtained from EM video footage (Needle et al., 2015).

To overcome this issue and improve the ability to record the discarded part of the catch, several protocols were implemented during Danish and Dutch EM trails. Examples are the Danish EM study to record discarding of cod, *Gadus morhua*, by Ulrich et al. (2015) and the Dutch study testing the feasibility of EM to detect sole, *Solea solea*, discards, being part of this thesis, chapter 4. According to the Danish protocol fishers must collect cod discards in standardized baskets and hold them in front of the camera for a few seconds before discarding. In the Dutch trial fishers were asked to display all undersized (below minimum reference size, <24 cm) sole separately on the sorting belt, e.g. no overlap, after the catch was processed. The accuracy of discards estimates based on video review with and without the protocol in displaying discarded sole was considerable: Without the protocol the recorded discarded weights by EM were underreported: EM estimated catch was 2.4-fold lower than logbook records. With the protocol implemented, there was no significant difference between logbooks and EM and high agreement (chapter 4). An additional advantage of this method is the ability to accurately measure the lengths of the individual fish and to provide a length frequency distribution of the discarded catch. However, both studies also reported that the protocols to display discards in front of the cameras is time-consuming manual labour, e.g. sorting, basketing, lifting, and, therefore, imposed additional burden to the crew (chapter 4; Ulrich et al., 2015). The simple protocol of displaying the discards after the sorting process only takes three extra minutes on average, however, eventually, over all hauls, for multiple species, it adds up to the workload. For just sole, an additional 2 hours is needed during one trip (chapter 4). During the landing obligation, an average bottom trawler in the North Sea has to report discards for at least six different species, given the regulated number of species and mixed nature of the catch. The total of additional time needed is estimated at 12 hours per fishing trip, which equates 20% of the duration of an average fishing trip of a Dutch bottom trawler. The success of monitoring the landing obligation with EM likely depends on the burden that it imposes on skippers and crews. Additional workload for fishers will hamper an effective implementation of EM. The decreasing efficiency of EM in analysing bulk of fish is a relevant element within the European context, as a substantial part of the demersal fish stocks in northern European waters are fished with bottom trawlers or gears with considerable volumes of discards (Catchpole et al., 2008; Ulleweit et al., 2010; Uhlmann et al., 2014).

The overall conclusion is that EM is feasible in accurately reporting discards, under the condition that EM systems are well maintained, e.g. lenses are regularly cleaned, and, if necessary, protocols are implemented to display discards, depending on discard volume and type of fishery. In the current setup, EM could already be a powerful asset in existing scientific data collection programmes, also for mixed bottom trawl fisheries. The main advantage of EM over the traditional onboard observer schemes for scientific data collection is the increase in spatial and temporal sampling coverage. EM provides more reliable and accurate spatial distributions of fishing activity and catch information, both at vessel and fleet levels, than has been available to date using at-sea observer programmes and conventional vessel monitoring systems (Needle et al., 2015; Suuronen and Gilman, 2020). It is argued that detailed EM data allow understanding what fishers are doing and why, thereby supporting advice on sustainable and productive fisheries (Needle et al, 2015).

However, for more management driven monitoring purposes, which are, more likely, top-down implemented and inclusive for a large number of vessels or fleets, such as the European landing obligation, further development of EM is still required. The feasibility of EM to accurately record discards still heavily depends on the involvement of fishers and their willingness to support the EM process on board. EM systems on board need constant maintenance and cleaning of camera lenses to be fully functional. In the situation where EM is implemented as a compliance the support of fishers to keep a vessels' EM system operational is an Achilles heel for its success. Of course, the responsibility of full functioning clean EM systems could, or perhaps should, lie with the fishers and may well be part of EU fisheries technical regulations, being one of the conditions that have to be met, when allowed to fish or even penalized for not maintaining EM systems. But, even for the most cooperative fishers water droplets will, now and then, stick to camera lenses in the generally humid conditions of a fishing vessel.

Also, the manual review of video footage complicates the implementation of EM on a large scale. Review time mainly depends on the quality of the data set, the monitoring objective and the type of operation observed. When monitoring for occasional, but highly visible events, e.g. the bycatch of cetaceans, video review can be conducted at a higher rate (10–12 times faster than real time) (Kindt-Larsen et al., 2012). But, monitoring discards onboard demersal trawlers is generally time-consuming and labour intensive exercise (Kraan et al., 2013; Uhlmann et al., 2014). In response to the time and costs needed to process large quantity of video data alternative strategies are developed. The most commonly method used is the audit approach, where a random selection of video data, covering 10%–20% of the fishing activity per trip, is used to validate compliance of the fishers to accurately record catches in the logbook. If the recorded catch in the logbooks match the catch estimates from the video review, it is assumed that the fisher correctly recorded all catches in the logbook. Even though only a minority of the fishers catch registration is audited with video, the fishers do not know which hauls will be audited and when, which creates an incentive to report all catches accurately. Nevertheless, validating logbooks from a complete fleet still requires a considerable amount of manpower, which would certainly be the case when the level of compliance is low and, as a consequence, a considerably larger part of EM data needs to be reviewed. More importantly, in the context of the landing obligation, this audit model implies extra workload on the fishing crew, because the recording of the discards is largely internalized by fishers. To be able to record the complete catch, fishers need to sort and weigh the undersized fish by species. Because the undersized catch is unmarketable, this will, most likely, be perceived as just an additional burden to comply with the regulations and adds up to the already existing unwillingness to comply with the landing obligation (chapter 4 and 5; Ulrich et al., 2015). Mis-recording of species, unintentional or intentional, could be a significant control issues for the landing obligation. In self-reporting trials, errors were observed in data from non-scientific personal, e.g. fishing crew (Mortensen et al., 2017b). Validation through video review of EM data could cause problems for similar looking species (chapter 2).

Integrating computer vision technology is the logical next step in facilitating the implementation of EM on a larger scale, i.e. pan-European level (van Helmond, 2021). The application of this technology in combination with smart engineering makes EM more practical and will, eventually, increase the effectivity in recording discards on board fishing vessels. Successful development and application of computer vision technology would reduce the workload, and costs, of video review and the burden of fishers to facilitate EM on board, i.e. improve the visibility of discards (Michelin and Zimring, 2020; van Helmond, 2021). First trials indicate the potential of this technology to automate the process of counting fish by species and size without interference of the sorting procedures on board. The algorithms, which form the basis for this technology, showed the ability to recognize and record fish correctly during the sorting process on the conveyer belt, also is situations where fish overlap or are partly covered with debris and benthic organic material (French et al., 2019; van Essen et al., 2021). Also, the ongoing innovation about dirt detection on camera lenses is a promising development in being less dependent of onboard crew to maintain the cameras contributes to the development of more self-sufficient and robust EM systems.

Allowing for onboard video processing is a crucial step for real-time transfer of catch data, which is currently constrained by transmitting large volumes of video data, footage is now wirelessly transferred on 4G network or through physical collection of hard drives (Michelin et al, 2018). Reducing the EM output to automatically generated catch reports of counts or weights per species, only a string of numbers needs to be transmitted, makes implementation of EM on larger scale easier, without the currently needed large IT infrastructures, to store and process all the video data (chapter 5). In addition, direct processing (without storing) of privacy sensitive video data takes away the legal privacy related barriers (General Data Protection Regulation) that complicate EM implementation at institutional levels. Extensive advancements in computer vision technology will facilitate the implementation of EM, reduce costs and the burden of fishers to keep EM operational onboard, and, eventually, make EM applicable for monitoring discards in a larger share of fisheries (van Helmond, 2021; ICES, 2022).

Changes in fishing behaviour - Are fishers adapting their fishing practices with EM?

The result of the presented studies point out that the constant presence of cameras creates an incentive to accurately report all catches (chapter 3). Another good example is the recording of catches in the Danish cod fishery, vessels equipped with EM recorded more realistic discard volumes in their logbooks than vessels without EM on board (Ulrich et al., 2015). Also, the average size composition of the landings was changed, landings from vessels with EM comprised significantly larger proportions of smaller cod compared to vessels without EM systems on board. This suggested that the latter group discarded smaller cod, less valuable, but above the minimal landing size, without recording this part of the catch in the logbooks, an illegal practice referred to as high-grading (Kindt-Larsen et al., 2011; Ulrich et al., 2015).

In the Dutch CQM trial for cod fisheries, the proposed management regime in combination with EM created a strong enough incentive for fishers with larger vessels to change their behaviour and successfully maximized their available cod quota, a distinct shift in fishers behaviour towards avoidance of catching juvenile cod was observed (chapter 4) Remarkably, fishers with smaller vessels did not change their behaviour, because they were not able to turn the new management regime into their advantage. Based on interviews with participating fishers, it was concluded that larger vessels, compared to the smaller vessels, had more financial leverage to create the flexibility needed to adapt to the new management situation (chapter 3).

The observed behavioural change in combination with the full documentation of catches triggers the idea of investigating a paradigm shift in fisheries management: from a top-down management approach based on rigid technical conservation measures towards more flexible result based fisheries management. In this case, result based management (RBM) implies that results, outputs, e.g. catch quantities, is provided as feedback, input, to management design that regulates the fisheries. This could therefore mean that only catch limits are required to control the fisheries, and a flexible approach could be adopted to less, input regulated, technical control measures (Mortensen et al., 2017a). The current amount if technical regulations for gears, species, season, areas, catch compositions, discard exemptions, etc. is considerable and are perceived as complex and difficult to control (Plet-Hansen et al., 2017). Based on this idea, several fishers were challenged to test their own solutions to reduce discards during a Danish study: The opportunity was given to choose gear and mesh size without any stringent technical regulation for a period of six months, under the condition the catch was fully documented by EM (Mortensen et al., 2017a). The overall outcome from this trial showed that free gear choice resulted on average on a slight increase of landings and slight decrease of discards. Each fisher conducted its experience in its own way, with different levels of success in the outcomes (Mortensen et al. 2017a). During the study the majority of the fishers indeed managed to alter their catch composition and reduced the discard ratio, but overall, the effect was masked in the average by several fishers that increased their discard rate considerably. This indicated the possibility of individual fishers to adapt fishing operations and gears to comply, for example, with the regulation of a landing obligation, without dramatic loss of revenue on the short term. The difference in adaptability to management measures between groups of fishers highlights the challenge for alternative management regimes based on a result-based approach. RBM requires an accurate and detailed documentation of catches, e.g. per fisher, in order to be operational and controllable.

From a more practical point of view, these trials proved that EM is a successful tool to test alternative management strategies. In general, models are used to conduct fisheries management strategy evaluations (MSE). These model studies forecast vessel fishing behaviour based on the premise that fishers optimize a utility function. Simplifying assumptions have to be made when defining a utility function and net revenues are often used as proxies for the actual utility function of the fisher (Vermard et al., 2008; Batsleer et al., 2013). Another simplifying assumption is that fishers with similar gears and vessels respond similarly to changes in management systems. Knowledge, experience, vessel constraints, regulation, enforcement, market and information sharing proved to be important drivers of the behaviour of fishers, it is not possible to define these individual differences between fishers in models. However, the results of these EM studies point out that changes in behaviour vary considerably between individual fishers (chapter 3). Rather than relying on model predictions on the potential outcome of alternative management schemes, the 100% recording of total catch (landings and discards) and fishing activity allows the observation of actual fishing behaviour (chapter 3). The ability of EM to collect information and measure changes in practice of catch composition as a result of fisher's choice in gear, mesh size, fishing location on an individual (micro) level , but also on a broader (macro) geographical scale points out the advantage of EM over the commonly used model-based approach to evaluate potential changes in fishers behaviour under alternate management strategies.

Although potential paradigm shifts in fisheries management towards RBM are yet to come in European fisheries, EM already played a crucial part in the significant change of management, and fishers behaviour, in other parts of the world. In the commercial groundfish fisheries in British Columbia, a complex and inefficient management system resulting in wastage as different fleets and groups of fishers retained its targeted species, while discarding the target species of the other fleets. In cooperation with the industry the responsible government agency decided to change the situation by implementing a system of individual transferable quotas (request of the industry), in combination with full catch accountability supported with three key monitoring data collection elements, logbooks, dockside-monitoring and EM for all vessels (request of the government). The programme has surpassed expectations in providing accurate, defensible, and timely estimates of total catch for all quota and many non-quota species (Stanley et al., 2015). The provision of credible discard estimates and therefore total catch estimates had the immediate impact and improved management of annual quota targets and removed the need to move to more precautionary approaches to compensate for what were previously unknown overages (Stanley et al. 2015). Fishers also pointed out that their greater attention to logbook recording and the feedback on the accuracy of their recordkeeping, because of EM, have made their logbooks more useful to themselves. With better records, they find it easier to optimize fishing opportunities and cope with the ever-increasing complexity of management regulations (Stanley et al., 2011).

The bottlenecks of EM implementation

While EM has proven to be an effective tool for a variety of monitoring purposes, the adoption of EM has been relatively slow during the last two decades. Since the introduction in the Dungeness crab fishery in the late 1990's EM is gradually growing, but never reached the expected rapid increase in uptake (van Helmond, 2021). This is remarkable considering the monitoring needs in fisheries worldwide (chapter 5; Michelin and Zimring, 2020). Still, ICES categorizes over sixty percent of the European fish stocks as information-limited.

In Europe, none of the 26 EM pilots studies, conducted in different fisheries in 7 countries, evolved in a fully integrated EM programme (van Helmond, 2021). All studies ended after several years, involving a variable number of fishing vessels, ranging between 1 up to a maximum of 28 vessels equipped with EM systems . In retrospect it was realized that most of these scientific trails lacked the plan and inclusion of national or EU-wide management implications. To ensure adequate implementation of EM responsibilities between industry, scientific and administrative institutions should have been clarified and all stakeholders should have been involved form the beginning of the project (Stanley et al., 2015;Ulrich et al., 2015). Currently, the government agencies lack capacity and expertise to run fully implemented fleet-wide EM programmes. This lack of experience in combination with the uncertainty about whether EM will solve their monitoring challenges and at what cost, results in a bias towards inaction (Michelin and Zimring, 2020). Which eventually results in a lack of the necessary administrative infrastructure, e.g. policy standards, legislation around data ownership and privacy, legal requirements to implement EM. On top of that, implementation of large EM programmes requires large IT infrastructures to deal with the amount of data that EM generates, e.g. data transmission, data storage and data review capacity, which require a considerable investment (chapter 5).

Besides the shortcomings from the administrative side, other more fundamental barriers are also at play. Firstly, there is an initial sense of distrust on behalf of a large part of the fishing industry. Fishers see EM primarily as a compliance tool with no benefits for them (Michelin and Zimring, 2020). Frequently provided statements by fishing industry representatives are EM being a waste of time and money, since the technology would not be sufficient to monitor vessels at sea and collected footage can be misused to discredit the industry (Plet-Hansen et al., 2017). Secondly, there is a strong perception of intrusion on the fisher's privacy (Mangi et al., 2013). This perception is unjustified given that numerous EM studies worldwide have shown that EM can be used for control purposes while warranting privacy security standards regarding video data (chapter 5; Kindt-Larsen et al., 2011; Ulrich et al., 2015). A more thorough consultation and interviews with fishers reveal that the main EM-worries are the constant means surveillance and the lack of 'an equal level playing field' in case not all vessels have EM systems installed (chapter 3; Plet-Hansen et al., 2017). Indeed, in the context of the reformed EU fisheries policy, the worry for constant surveillance is plausible. The transition towards the landing obligation, imposes a shift from maximizing the value of the part of the catch that can be sold to minimizing the volume of the part of the catch that cannot be sold (Mortensen et al., 2017a). This shift in management strategy most likely results in short term economic loses, since fishers need time to adapt or won't be able to adapt at all (chapter 3). It can be expected that fishers respond to management regulations by trading off economic gain against the cost of noncompliance (Batsleer et al. 2013; Msomphora and Aanesen 2015). In other words, with a low probability of being caught, e.g. no EM system on board, it is profitable for fishers to cheat the system and discard less valuable catches. In practice, there are no reasons to assume that all fishers by default do not obey the regulations, but there are indications that fishers have difficulty to stop discarding and comply with the landing obligation (Ulrich et al., 2015; Borges, 2021). As there are reason to believe that the transition to the landing obligation can be complicated for a fisher, it is understandable that fishers are not in favour for constant surveillance, certainly not when there is a no equal level playing field when not all vessels have EM installed (Plet-Hansen et al., 2017). Vessels without EM would have the advantage of "bending" the rules compared with vessels under constant surveillance that will constrain their fishing operations. Lack of an equal playing field could certainly causing uneasiness between with fleets outside the EU fishing in the same waters and the EU fleets, e.g. the United Kingdom and Norway.

Traditionally, within Europe, control and enforcement has always been considered as an exclusive governmental task. This is different in the United States of America (USA) and Canada , where the fishing industry themselves are, at least partial, responsible, also financially, for the control of their fisheries. Costs for on-board accommodation, food, getting an observer in and out of remote locations do not exist with EM. When monitoring coverage is high, monitoring costs are a factor for an increased adoption of EM (chapter 5). Under the circumstances where the fishing industry, involved in a full monitoring programme, requiring a 100% monitoring coverage, was given a choice, EM preferred over an observer on board each trip. In addition, EM put less constraints on the planning of fishing trips, an advantage of not having the burden of picking up an observer before going out for a fishing trip. Shifting the responsibility of monitoring towards the fishing industry sets a different baseline for EM implementation in the USA and Canada, than in the EU. A transition from limited at-sea monitoring without any involvement from fishers, as is currently the case in Europe, to complete documentation of catch and fishing activity with full commitment of the industry is an enormous step. The starting point, i.e. the actual management regulations in place and the level of responsibility of the fishing industry, dictates the level of acceptance and the ability to implement EM in a region or particular fishery.

Another point of concern about EM are the costs and who will pay for it (Michelin and Zimring, 2020). In fisheries with already high observer coverage, e.g. 100% monitoring programmes in USA, EM may reduce overall monitoring costs by substituting the observers (human) coverage needed. In most cases, however, EM is being considered in fisheries with limited monitoring coverage and therefore the costs of an EM programme will be almost entirely additional to current monitoring costs (Michelin and Zimring, 2020). Which is exactly the case on monitoring the landing obligation in EU fisheries and creates a barrier in EM development. While the up-front costs, i.e. EM equipment, installation and software, will not be a bottleneck for most national European governments, the ongoing costs of running an EM programme are typically higher over a longer period of time (Needle et al., 2015; Plet-Hansen et al., 2019; van Helmond, 2021). When manual review remains the standard, labour costs for reviewing footage, including the facilities needed, e.g. computers, office space, and the costs on logistics and IT infrastructure needed to collect and store data will be considerable, also when only a selection of the collected data is reviewed (audit-model). The best possible way to reduce costs is automatization of the manual review process. Computer vision technology to automatically and immediately analyse the collected video data of catches onboard fishing vessels is developing (French et al., 2019; van Essen et al., 2021). The expectation is that computer vison technology, more broadly described as artificial intelligence (AI), will be capable of preforming species identification and volume estimation onboard vessels, cost-effectively delivering "real-time" data on catch and fishing activity (chapter 5; Michelin and Zimring, 2020). In other words, with this technology in place recording could be achieved by the computer directly counting the fish passing the cameras and only generating a list of species in the catch as output. This would mean that the transmission of large amounts of video footage from a vessel at sea to servers on land, to allow for further data analysis will not be necessary anymore (Michelin et al., 2018). An additional benefit is that the potential issues around intrusion on the fisher's privacy will become redundant, as only the computer can "see" the footage.

Outlook

The future of EM depends on the development and technology and, in particular, of the ability to automatically record catch from collected video data. In case, implementation of AI will be accomplished, cost will be reduced, which, eventually, makes EM accessible for a large share of the world's fisheries (Michelin et al., 2018). Review of EM studies worldwide indicated that developments on automated catch registration through computer vision technology are picking up (van Helmond et al., 2021). So far, preliminary results of projects to integrate computer vision technology are promising, also when the conditions to register catch per species are more challenging, such as detecting and counting demersal fish species in complex, cluttered, and occluded environments that can be installed on the conveyor belts of fishing vessels (van Essen et al., 2021; ICES, 2022).

To catalyse the uptake of EM means to create incentives and win-win situations for fishers and management (chapter 5; Michelin et al., 2018). Direct incentives offered to fishers to participate in EM trials consisted of individual quota uplifts, direct payments, increased days at sea, access to closed areas and increased flexibility in gear choice (chapter 3; Kindt-Larsen et al., 2011; Needle et al., 2015). However, in order to roll out EM over a larger scale, e.g. European fleet, a more intrinsic motivation is required. This can be fuelled by indirect incentives, such as increased market access through eco-labelling and certification, but also by experiencing advantages in terms of better fishing opportunities, e.g. data sharing and increased insight in fishing activity, increased transparency, real-time fisheries management, result-based management (Michelin et al., 2018; Michelin and Zimring, 2020; van Helmond et al., 2021; Steins et al., 2022). These circumstances can only be realised with implementation of AI to establish a considerable reduction in running costs of EM and rapid data analysis. An example of real-time data enabling more efficient management comes from the Atlantic fishery on highly migratory species in the USA. Management of this fisheries is dealing with species, e.g. tunas, sharks, swordfish, and billfish, that travel long distances and often cross national and international boundaries. Time and area closures have been the management tool to limit bycatch of the endangered bluefin tuna. Closures proved to be a relatively coarse tool to manage the bluefin bycatch. Managers found that high-risk areas were not consistent, and, therefore, difficult to predict and plan. Besides, closing areas for fishing activity resulted in loss of fishery-dependent data, eventually leaving the managers in the dark about the effect of closures and if the "right" areas were being closed (Michelin and Zimring, 2020). After EM implementation real-time data on bluefin tuna was provided, allowing managers a more flexible approach on closures, realizing that EM is giving them the confidence that they are meeting the bycatch objectives of this fishery (Michelin and Zimring, 2020).

AI will improve the accessibility of EM for the industry themselves. Besides the reduced costs of data collection, the quality of the data, e.g. species identification, length measurements, catch weight estimates, will be secured by trained and validated algorithms. Meaning that the expertise of trained (expensive) personal on board or to review EM footage will become redundant or only used for AI training purposes. Automated catch registration will increase the accessibility of EM for a larger group of vessels and fleets and creates opportunities for an innovative, potentially, more efficient result-based management approach. Also, data ownership could shift the responsibility to the fishing industry. Becoming an agent in a result-based management regime would mean a paradigm shift in fisheries management, and, in case of Europe, potentially provides a workable solution, for the difficult implementation of the landing obligation. Complete and automated catch registration enables fisheries managers an alternative on the obligation to land all unmarketable catches, realizing that EM is giving them the confidence that all catch is registrated.

Another advantage of EM is improved traceability and transparency, two aspects that are becoming increasingly relevant, since consumers show an increasing interest in sustainably produced fish (chapter 5). To service this growing market an increasing number of seafood retailers are supporting sustainability labels such as Marine Stewardship Council (MSC). However, the current data quality standards of eco-labelling organisations do not include EM as a the preferred, or required, data collection instrument. Involving EM to get certified will be step forward (Michelin and Zimring, 2020). Only with cost-effective on-the-water monitoring can provide the confidence to costumers that seafood products are caught legally and sustainably (Michelin et al., 2018). EM can help to increase transparency and provide the complete “net-to-plate” overview costumers are asking for, this will also support increased market access and potential economic benefits for the fishers prepared to catch fish in a sustainable manner.

Support of the fishing industry is, and will be, a crucial element to be able to implement EM on a larger scale (Stanley et al., 2015). If the situation continues where EM is frequently proposed as a tool to ensure compliance of fishing regulations, particularly in circumstances where EM seems like an existential threat to the viability of the fishing industry, e.g. the EU landing obligation, the uptake of EM will remain low (Michelin et al., 2018). The prospect for the fishing industry that EM will be used against them, has also a negative impact on the level of participation in research projects. Consequently, lack of EM support on the fishing industry will also effect further development and innovation of EM. If a policy target or management measure does not make sense for the fishers, they will be less willing to work towards achieving it (Eliasen et al., 2014; Kraan and Verweij, 2020; Steins et al., 2022). Besides the ability to implement EM, e.g. financial, technology, infrastructure, there should also be a sense of willingness of fishers, which is strongly linked to the extent to which fishers consider policy goals and regulations as legitimate (Steins et al., 2022). In the context of the European landing obligation, EM requires a different narrative, shift away from constant video surveillance to detect illegal activities to a supporting tool for economical viable sustainable fisheries.

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APPENDICES

A

Appendices

Summary

Electronic monitoring (EM) systems are computer controlled systems that automate the process of data recording on board commercial fishing vessels. EM systems generally consist of various activity sensors, GPS, computer hardware and digital cameras, which allow for video monitoring and documentation of catches and detailed fishing effort estimation without requiring additional on-board personnel, e.g. at-sea observers. The different sensors, e.g. movement sensors on the net drums and sorting belt, detect fishing activity on board and trigger the video system to start (and stop) recording. Data are transferred from the fishing vessel, through manual collection, or wireless transmission to a central data base, from where data is made available. Subsequently, the recorded data and footage is reviewed to obtain catch information, for example species composition, numbers, volume and lengths.

Within the last two decades, electronic monitoring (EM) has emerged as an innovating technology for documenting catches in commercial fisheries. While the initial development of EM systems was largely an industry-led process in the British Columbia crab fishery, it was quickly recognized that EM could potentially improve monitoring and control for fisheries management, which is, generally, challenged by poor coverage of at-sea observations. European EM trials started in 2008. Several EU member states tried to incentivize North Sea cod, *Gadus morhua*, discard reductions by making volunteer fishers accountable for their total catches rather than for their landings, as so called catch-quota management (CQM) scheme. In exchange, participating fishers received increased quota shares and, in some cases, exemptions from the effort reductions. Consequently, several EM trials were funded in order to verify declared catches. Such a CQM-trial could also be interpreted as a test case for the, at that time, forth coming landing obligation under the Common Fisheries Policy of the European Union (EU). The landing obligation requires that the complete catch, landings and discards, of species under quota and/or minimum fish size regulations (MCRS) need to be reported and landed. Within this context, the Dutch Ministry of Economics, Agriculture and Innovation decided to conduct a pilot study on the Dutch flatfish fleet, which marked the start of a series of EM trials on the Dutch demersal fisheries, and eventually resulted in this PhD study. The two main objectives of the study are: 1) determine the feasibility of EM to record catch, landings and discards, in the Dutch bottom trawl fishery, and 2) investigate the potential behavioural change of Dutch fishers in avoidance of catching juvenile cod under a CQM regime with EM.

All vessels in the pilot studies participated on a voluntary basis. To create an incentive for participation fishers, fishers received a 30% increase in individual cod quota and a deroga-

tion on the effort regulations, which meant more flexibility since there was no cap on total allowable fishing days. Two groups of bottom trawl vessels participated during the period 2009-2013. The first group, the small vessels, consisted of six vessels with 221 kW engine power, using a wide range of mesh sizes between 20 to 130mm. The second group, the large vessels, consisted of six vessels with engine powers between 677 and 1471 kW, using a range of mesh sizes between 80 and 130 mm, depending on season and target species. Both groups of bottom trawlers differed from fisheries in other countries where EM was proven to be a successful method, since relatively large volumes of bycatch are generated. The amount of cod catches in the Dutch bottom trawl fishery strongly depends on the fishery season and mesh size used, with larger mesh sizes, 120 mm or more, typically being used to target cod. When flat fish is the main species of interest, smaller mesh is used, between 80 and 100 mm, then amount of cod in the catches is lower and the bulk of (by) catch of other species is higher. EM was able to correctly record cod catches when larger mesh size were applied, but was considerable less effective when the smaller mesh sizes are applied and larger catch volumes of other fish are caught. In other words, distinguishing small numbers of cod in catches of mixed bottom-trawl fisheries is challenging.

The trial also provided the opportunity to observe actual changes in fishing behaviour under a catch quota management (CQM) regime, or, landing obligation, for cod. Behavioural changes are analysed through a before-after-control-impact (BACI) analysis of catch and fishing activity data of peer vessels within the same fleet that are not part of the EM trials. Semi-instructed interviews are used to summarize experiences of fishers during the trial period, which provided essential background information to evaluate the outcomes of the BACI analysis. Under CQM all cod, including the undersized, not marketable, part of the catch, were registered and deducted from their individual quota. To be successful fishers should be able to maximize their individual quota increase to avoid catching small, i.e. juvenile cod. In this case a remarkable difference was observed between the two groups of vessels in the study. The results showed that the CQM regime had no effect on fishing behaviour of the small vessels. In contrast, large vessels significantly increased their cod landings and avoided undersized cod. Fishers with smaller vessels did not change their behaviour, because they were not able to turn the new management regime into their advantage. Based on interviews with participating fishers, it seemed that larger vessels, compared to the smaller vessels, more easily adapted their behaviour to the new management regime. In the context of the implementation of the EU landing obligation, this difference in response of different fleets suggest that fleet characteristics, and financial leverage of (groups of) fishers should be considered.

Based on the results of the pilot studies of cod and the forthcoming landing obligation, knowledge on the ability of EM to detect smaller, and for Dutch fisheries economically important, flatfish species became more relevant. Therefore, an additional EM trial was conducted on two beam trawlers to test the efficacy of EM in recording different size classes of sole, *Solea solea*. In line with the previous EM trial on cod, the results indicated that EM of small individuals in mixed fisheries is not as effective as it is for large individuals of sole. More importantly, Not being able to accurately detect the smallest size class, below the minimum conservation reference size (below 24 cm), with EM, is a strong indication of the potential challenges the EU will run into after the implementation of the landing obligation at a larger scale. Based on the current set up of EM on board fishing vessels, adjustments or protocols during the catch handling process are necessary to make use of the full potential of EM in this type of fishery. But, the implementation of even a simple protocol of displaying the undersized catch in front of the cameras comes with a burden on the fishing crew in the form of extra time needed to record the catch. Most likely, additional workload for fishers will hamper an effective implementation of EM under the landing obligation.

In this thesis I showed that EM is feasible in accurately reporting discards, under the condition that EM systems are well maintained and, if necessary, protocols are implemented to display discards, depending on discard volume and type of fishery. I also showed that alternative management regimes in combination with EM can created strong enough incentives for fishers with larger vessels to change their behaviour under catch quota management. These fishers improved their use of available cod quota by avoiding juvenile cod. Remarkably, fishers with smaller vessels did not change their behaviour, because they were not able to turn the new management regime into their advantage. Based on interviews with participating fishers, it was concluded that larger vessels, compared to the smaller vessels, had more financial leverage to create the flexibility needed to adapt to the new management situation.

Since the introduction of EM in British Colombia its implementation is steadily growing and is continuing to proof its effectivity for meeting a variety of monitoring functions, e.g. gear deployment, effort, catch, in different parts of the world. Fully implemented EM programmes exist in Canada, the United States of America, Australia and Chile, covering fleets of more than 200 vessels. However, the uptake of EM on a global scale never reached its expected acceleration point. Currently, there is still no fleet wide implemented EM programme in Europe. Even though, EM is moved forward as the potential candidate for full catch documentation under the EU landing obligation. So far European managers have remained reluctant to EM implementation in their fisheries. There are challenges to overcome and possibly EM will not be as effective in each type of fishery (see chapter 2 and 4), but there is success with EM in other relevant fisheries regions in the world. To get a better understanding of the state of play of EM worldwide a review was conducted on 100 EM trials and 12 fully implemented programmes from 25 different countries. Based on the outcomes of the review it is concluded has the opportunity to be a powerful tool in the future monitoring of fisheries, also for the EU landing obligation. However, the slow uptake of EM can be attributed to several factors: An important element is that EM often is proposed as solely a compliance tool. Potential benefits, e.g. increased transparency, improved data quality and, as a consequence of that, opportunities in eco-labelling, sustainability claims and increased market access, are not well explained or presented to the fishing industry. Another factor is the strong perception of intrusion on the fisher's privacy. Reluctance against EM regarding privacy issues and mistrust of data use is stronger for the proportion of the fishing industry without experience with EM. Once EM is implemented and fishers have actual exposure to EM, they generally have a more positive perception of the tool and it is easier to have an informed dialogue about EM. The reluctance to implement EM from a fishery managers point of view is the lack of capacity and expertise available with the government agencies. The implementation of such programmes requires large IT infrastructures to deal with the amount of data that EM generates in, for example, data transmission, data storage and data review. In the absence of support, individual fishery managers or regulators can be reluctant to implement EM schemes at larger scale. Another important element, particularly for the lack of EM implementation on European level, is that the scientific EM pilot studies were not designed to initiate broad implementation. Commitment on what successful trials would trigger was lacking, and there was no plan for further development into full EM programmes.

The viability of EM depends largely on how these range of threats are dealt with. During the whole process of implementation, including the design and planning phases, involvement and participation of fishers are crucial. The perception that EM is only fit for fisheries management and compliance objectives should be changed. To catalyse the uptake of EM means to create incentives and win-win situations for fishers and management. Turning the liability of low acceptance levels of the industry into an opportunity for fishing industry is the biggest challenge. Further innovation of EM and involvement of Artificial Intelligence (AI), i.e. computer vision technology, plays an important role here. AI will improve the accessibility of EM for the industry themselves. Besides the reduced costs of data collection, the quality of the data will be secured by trained and validated algorithms. Meaning that the expertise of trained (expensive) personal on board or to review EM footage will become redundant. Automated catch registration will increase the accessibility of EM for a larger group of vessels and fleets and creates opportunities for an innovative, potentially, more efficient result-based management approach. Also, data ownership could shift the responsibility to the fishing industry. Becoming an agent in a result-based management regime would mean a paradigm shift in fisheries management, and, in case of the EU, potentially provides a workable solution for the landing obligation.

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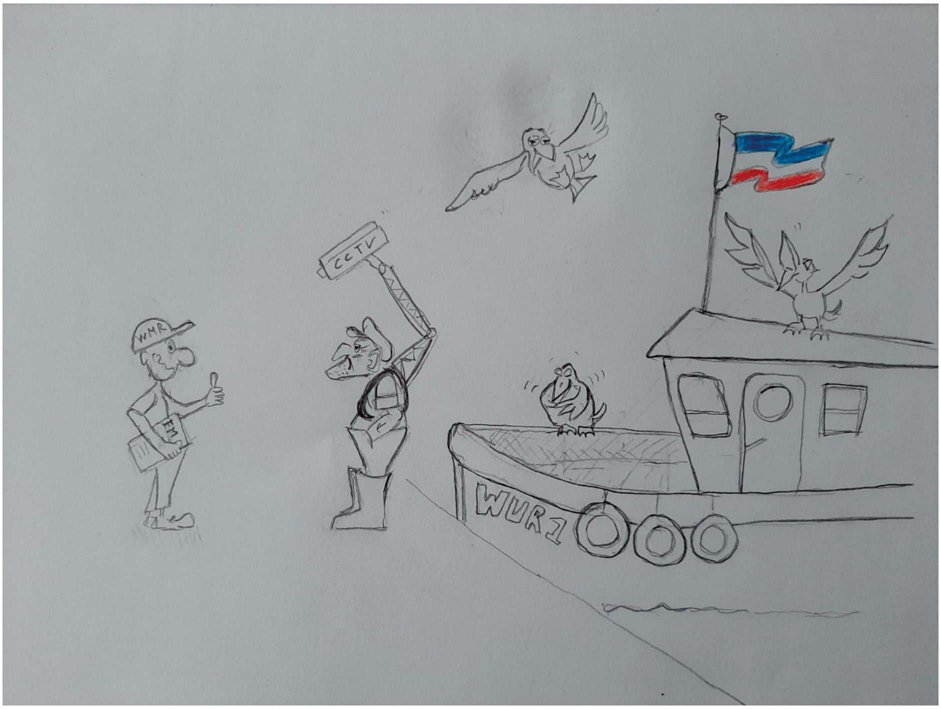
Electronic Monitoring in Fisheries



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