

Workshop on electronic technologies for fisheries

Part II: Electronic monitoring systems



Fisheries



RESEARCH FOR PECH COMMITTEE

Workshop on electronic technologies for fisheries

Part II: Electronic monitoring systems

Abstract

This study is the second research paper in a series of three, prepared for a PECH Committee Workshop. It provides a global overview of the latest developments, as well as potential benefits and risks of Electronic Monitoring (EM). Worldwide experiences with EM are discussed in light of the European context. During the period 2008 to 2019, altogether 26 EM trials were conducted within the EU. Despite promising results, none of the trials evolved into a fully integrated EM programme. Still, lessons learnt from these trials are valuable and show potential for implementing EM on larger scale in the EU.

This document was requested by the European Parliament's Committee on Fisheries.

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LIST OF ABBREVIATIONS

AFMA	Australian Fisheries Management Authority
CCTV	Closed Circuit Television
CFP	Common Fisheries Policy
COVID-19	Coronavirus disease
CQM	Catch Quota Management
DCF	Data Collection Framework
DLS	Data Limited Stocks
EFCA	European Fisheries Control Agency
EM	Electronic Monitoring
ET	Electronic Technology
EU	European Union
FDF	Fully Documented Fisheries
GHLCMP	Groundfish Hook and Line/Trap Catch Monitoring Program
GPS	Global Positioning System
HMS	Highly Migratory Species
ICES	International Council for the Exploration of the Sea
IT	Information Technology
ITQ	Individual Transferable Quota
LO	Landing Obligation
LPUE	Landings per Unit of Effort
MMO	Marine Management Organisation
NGO	non-governmental organizations
PECH	The European Parliament's Committee on Fisheries

TAC	Total Allowable Catch
TEPS	Threatened, Endangered and Protected Species
UK	United Kingdom
USA	United States of America
WGTIFD	Work Group on Technology Integration for Fisheries-Dependent Data

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EXECUTIVE SUMMARY

KEY FINDINGS

- Since 1999, the use of camera-systems on board, commonly referred to as **Electronic Monitoring (EM)**, has emerged as an **innovative approach** for **documenting catches** in fisheries.
- The number of vessels involved in **EM is steadily growing**, and estimated at approximately **1 900** fishing vessels worldwide in 2019. Canada, the United States of America, Australia and Chile have successfully **implemented EM** in their **national fisheries management administrations**.
- During the period 2008 – 2019, **more than twenty EM trials** were conducted in the EU. Despite promising results, **none of the trials evolved into a fully integrated EM programme**. Still, valuable lessons are learnt on EM implementation in European fisheries.
- **EM improves monitoring coverage** without a considerable increase in the monitoring budgets.
- **Involvement of fishers is crucial for EM implementation**. Fishers need to conform to the operational practices on board to facilitate the success of EM.
- In the context of the **EU Landing Obligation** and the requirement to **record discards**, **further work on development is still needed**. Detecting **smaller fish specimens** in large volumes of catch is still **challenging**.

Background

In 1999, after a first trial with CCTV (closed-circuit television) camera systems on board fishing vessels to cope with management reforms and gear theft in British Columbia, Canada, it was quickly **recognized that cameras on board fishing vessels could be used for monitoring and control in fisheries**. Since this first trial of this Electronic Technology (ET) the use of camera systems on board, commonly referred to as Electronic Monitoring (EM), has emerged as an innovative approach for documenting catches in fisheries. A typical EM system consists of various **activity sensors**, Geographical Positioning System (**GPS**) recording device, **computer** hardware and **cameras**, which allow for **video monitoring of catches**, and **detailed fishing effort registration** without requiring additional on-board personnel.

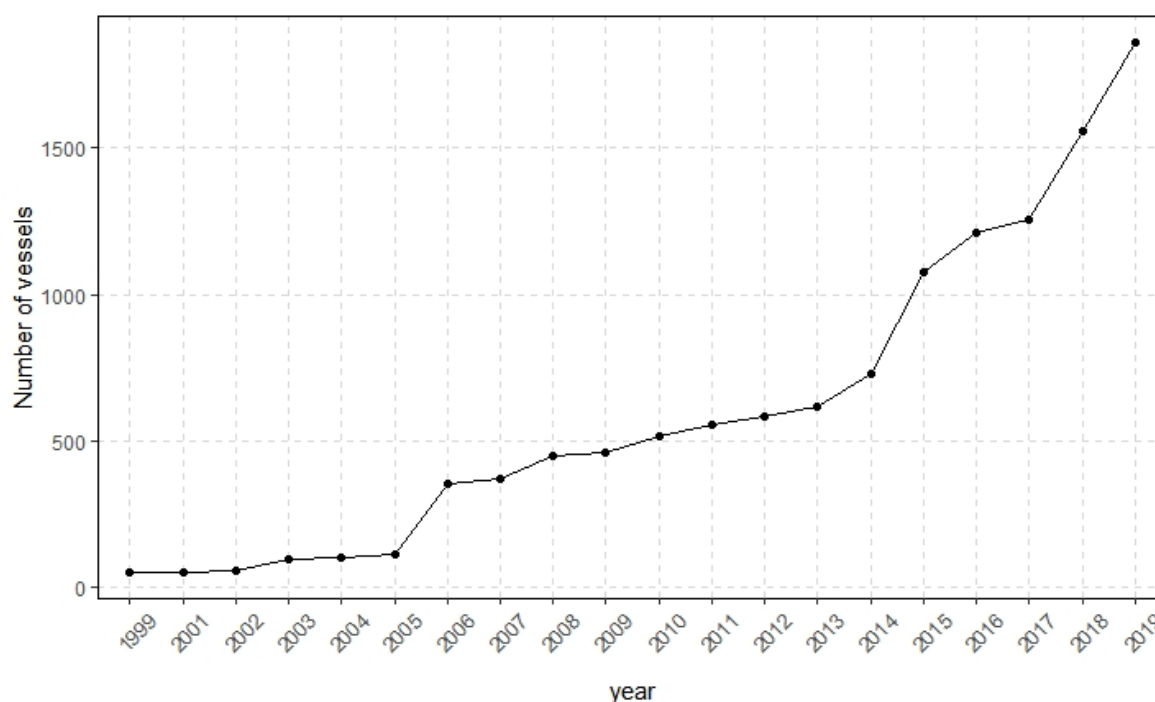
EM already demonstrated its ability to cost-effectively transform **management and compliance** in several fisheries. The aim of this report is to review **the current status** of EM and provide an **overview of the latest developments** in European fisheries, as well as potential **benefits and risks** of EM in fisheries.

State-of-play of Electronic Monitoring worldwide

The implementation of EM in fisheries is **steadily growing**. Currently, the total number of vessels, that are or have been, involved in EM schemes is estimated at approximately **1 900** (Figure 1). **Fully implemented EM programmes** exist in Canada, the United States of America (USA), Australia and Chile. These full programmes are defined as **management-driven** monitoring schemes, where **EM is officially** used for **compliance monitoring** purposes. Vessels under these regulations are required to have an EM system on board. Other remarkable EM implementations are the **fishing industry driven**

French and Spanish tropical **tuna purse seine programmes** in the Atlantic and Indian Ocean, where fishers **voluntarily** adopted a full EM programme, **covering 100% of fishing activities**.

Figure 1: Increasing number of vessels involved in Electronic Monitoring worldwide



Source: Author based on data collected during review.

Electronic Monitoring in European fisheries

In European fisheries a total of **26 EM trials** carried out by seven different countries (Denmark, France, the Netherlands, Germany, Spain, Sweden, and United Kingdom) were encountered during the review. The more comprehensive EM trials involve **more than ten vessels**. So far, **none of the trials have moved to full implementation**.

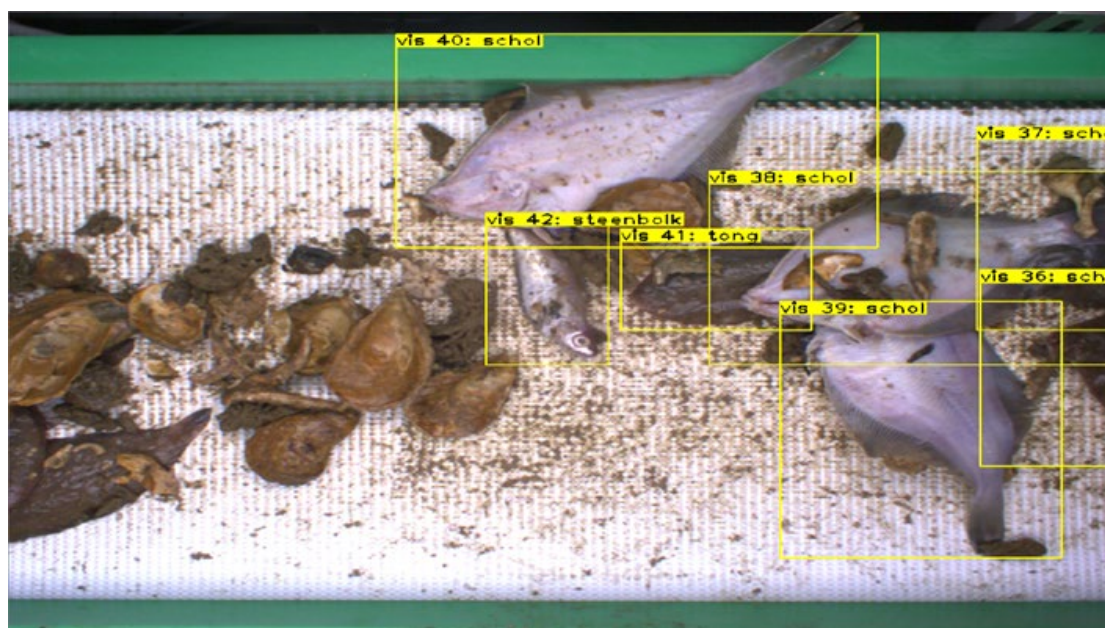
EM trials were executed in a **variety of fishery types**, from larger beam trawlers and seiners to small inshore fishing boats of less than 10 metres in length. EM proved to be an efficient monitoring tool in **catch quota management (CQM)** trials for cod in Denmark, Germany, the Netherlands and the United Kingdom.

Benefits and Risks

The biggest advantage of EM is the **increase of sampling coverage** and the level of detailed fisheries information that can be collected **without an extreme increase in monitoring budgets**. However, it should be emphasized that **EM is not a “plug and play” system**. Firstly, the **involvement of the crew on board fishing vessels** is crucial for a successful EM implementation. Fishers need to conform to maintenance of the EM systems, camera lenses need to be cleaned on regular intervals as footage collected from dirty cameras is useless. Secondly, the manual review of video EM data is labour intensive. Automated species recording systems, through **computer vision technology**, seem the logical next step in **reducing time and manual labour** needed for video review (Figure 2). Such technology is currently still under development. Furthermore, the implementation of EM on a large scale requires sufficient **IT infrastructure** data storage and processing.

In contrast with the in general negative attitude of the fishing industry around EM, the majority of the **participating fishers in EM trials were positive and supportive of using EM** for fisheries management purposes. Although, in some cases strong incentives to participate were provided (e.g. substantial quota uplifts).

Figure 2: Computer vision technology in practise: Example of automated classification of fish species on the sorting belt of a beam trawler



Source: Wageningen University & Research

Note: 'schol' = plaice, *Pleuronectes platessa*; 'tong' = sole, *Solea solea*; 'steenbolck' = pouting, *Trisopterus luscus*

Conclusions

Experiences and lessons learnt from EM trials are valuable and useful for **implementing EM on a larger scale in European fisheries**. In the context of the EU landing obligation and the requirement to record discards, further work on **EM development is still needed**. Processing large amounts of video data and detecting **smaller fish specimens** in large volumes of catch with video review can still be challenging. **Computer vision technology** is a possible solution to facilitate processing large amounts of EM data and improve fish detection.

Policy recommendations

- **Support the development of technical innovation in Electronic Monitoring.** Facilitate research on species recognition through computer vision technology; support networking between fisheries research, EM providers and robotics, e.g. (technical) universities and private sector; develop strategies to process large amounts of EM data (video data).
- **Build fishing industry support for Electronic Monitoring.** Demonstrate EM benefits and best-practise examples; facilitate communication around EM between stakeholders; develop "win-win" scenarios through alternative uses of EM data.
- **Create a European Electronic Monitoring infrastructure.** Provide legal guidelines around EM (e.g. privacy, data ownership); facilitate workgroups or committees with experts representing all stakeholder parties when implementing EM in a particular fleet or fisheries. Provide **legal requirements** and **governing framework** for Member States to implement EM.

1. INTRODUCTION

KEY FINDINGS

- EM is a **cost-efficient monitoring tool** with the potential to provide better representative **coverage of a fishing fleet** than any observer programme.
- EM is put forward as the best possible technology to **control the EU landing obligation**.

European Parliament's Committee on Fisheries (PECH) commissioned Wageningen Marine Research (WMR) with the present study to conduct a research project for a PECH Committee Workshop on electronic technologies for fisheries. The primary aim of this study is to provide a global overview of the latest developments, as well as potential benefits and risks of Electronic Technology (ET) systems for Electronic Monitoring. It shall also assess the **latest developments** in this field, as well as identify potential **benefits and risks** of EM in fisheries.

By summarising outcomes and evaluation of programmes and studies for countries leading in EM, a detailed **state of play** on **global EM implementation** is generated: describing the year of implementation, number of vessels involved and objectives of the trials and programmes. Considering the context of this study, the request of the European Parliament's Committee on Fisheries (PECH), information on all European EM studies will be collected to produce a detailed overview of EM implementation in European waters.

Best practice examples and experiences are explored in a set of four case studies representing European standards: 1) EM on board **small gillnet fishery**, 2) EM to implement a **catch quota management scheme** for North Sea cod, 3) EM on board **large pelagic trawlers**, 4) integrating **computer vision technology** in EM.

Based on the reviewed experiences worldwide, and in Europe in particular, the **main benefits and risks** of EM for control, fishing industry and science are identified in relation to **costs, technology, data review** and **storage, standards and protocols, data integrity**, and **data integration**. In conclusion, the report provides the European Parliament with **policy recommendations** on EM.

Starting point of this study is a previous conducted **global review** on EM trials and fully implemented EM programmes, published on January 2020 in the scientific journal of 'Fish and Fisheries' by van Helmond *et al.* This study created an **overview of EM implementation** from the beginning in **1999 to the end of 2018**. The present study **updates the former review** by adding the most recent published literature to the already existing overview from the previous study.

For this study a similar methodology was used as in van Helmond *et al.*, 2020: **Scientific 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 input**, e.g. (unpublished) reports, project descriptions, from principal scientists involved in EM trials worldwide. Eventually, the overview was completed with the latest information available from the annual Work Group on Technology Integration for Fisheries-Dependent Data (**WGTIFD**) of the International Council for the Exploration of the Sea (ICES, 2019). Studies using **video monitoring techniques** to capture images of catch or by-catch, but not necessarily described and referred to as EM, were also included in this report.

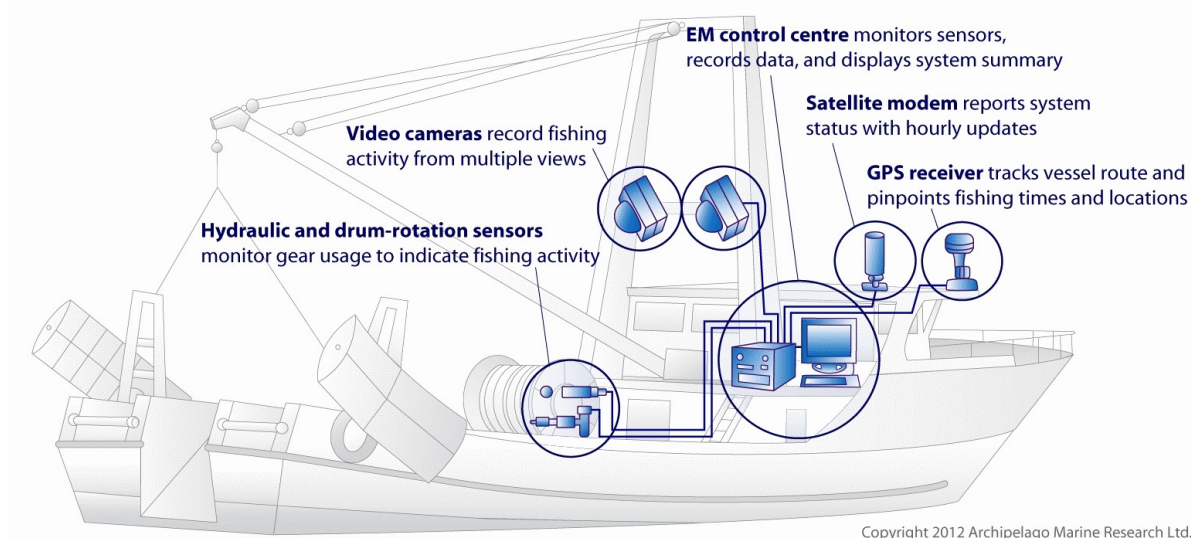
1.1. Electronic Monitoring in fisheries

After the first trial with CCTV (closed-circuit television) camera systems on board fishing vessels to cope with management reforms and gear theft in the British Columbia crab fishery (Ames, 2005), it was quickly recognized that **cameras** could be used for **monitoring and control in fisheries** that are challenged by poor coverage by at-sea observations (McElderry et al., 2003). Since 1999, the use of camera systems on board, commonly referred to as **Electronic Monitoring (EM)**, has emerged as an innovative approach for documenting catches in fisheries (Ames et al., 2007; Kindt-Larsen et al., 2011; McElderry et al., 2011; Stanley et al., 2011; van Helmond et al., 2020). A typical EM system consists of various **activity sensors**, **GPS** recording device, **computer hardware** and **cameras** (Figure 3) which allow for video monitoring of catches, and detailed fishing effort registration **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 (van Helmond et al., 2020).

In general, **EM is used to support management driven monitoring schemes**, e.g. effort, catch, discard monitoring, by-catch registration of protected species, monitoring of by-catch mitigation, and catch-handling measures. Currently, the total number of fishing vessels that are involved, through fully implemented monitoring programmes, or have been involved, during pilot studies, is estimated at approximately **1 900 vessels**.

EM already demonstrated its ability to cost-effectively transform **management and compliance** in several fisheries. Examples of successful EM integration in fisheries management regimes are the British Columbia, Groundfish Hook and Line/Trap Catch Monitoring Program (GHLCP) and the Atlantic Tuna Longline Highly Migratory Species (HMS) Fishery Monitoring Programme. In both examples EM plays an important role in the management process of these fisheries by providing full coverage monitoring solutions, i.e. **to maintain a catch quota system** in case of the GHLCP and **bycatch registration** for Bluefin tuna in case of the HMS programme.

Figure 3: Overview of a standard remote electronic monitoring system set-up



Source: van Helmond et al., 2020

EM appears to be at a critical moment in its development in European fisheries. Thus far, several pilot studies have been conducted in different countries and few of them are still ongoing. Based on the results of these studies it was concluded that **EM is a cost-efficient monitoring tool** with the potential to provide more **representative coverage of a fishing fleet** than any observer programme. However, in spite of the obvious advantages of EM, **the uptake of EM in Europe so far has remained low**. The fishers consider EM an **intrusion in their private workspace** (Baker et al., 2013; Plet-Hansen et al., 2017) and argue that camera surveillance reflects a **governmental mistrust** against them (Mangi et al., 2015). Nevertheless, the European Commission and the European Fisheries Control Agency (EFCA) put EM forward as the best possible **candidate to control the EU landing obligation** (the European Commission's proposal to revise the fisheries control system, centred on the amendment of the Control Regulation 1224/2009).

2. STATE OF PLAY OF ELECTRONIC MONITORING

KEY FINDINGS

- The number of **vessels involved in EM** is steadily **growing**, and estimated at approximately **1 900 vessels worldwide** in 2019.
- **Canada**, the **United States** of America, **Australia** and Chile are **leading in EM** implementation, with well-developed comprehensive catch sampling schemes covering 100% of fleets.
- **None** of the considerable number of pilot studies conducted within the EU resulted in a **fully implemented EM programme in European waters**.

Since the first application of EM in the Alaskan Dungeness crab fishery in 1999, there has been a **steady increase in the number of EM systems deployed on vessels worldwide** (Figure 4). In total, over a hundred EM trails have been conducted in many different parts of the world (van Helmond et al., 2020). The region of **North America**, United States of America (USA) and Canada, showed the **most expanded growth in number of vessels involved in EM** during that period (Figure 5).

2.1. Implementation of Electronic Monitoring in fisheries management

The majority of fully implemented EM programmes, 11 out of 16 (69%) worldwide, are implemented in the **North America region**. Currently, approximately 285 and 520 vessels, for Canada and USA respectively, are involved in these **permanent monitoring schemes**. This advancement in EM, compared to other regions in the world, is supported by a growing commitment and focus on electronic technologies from both national and regional fishery management councils. These **full programmes** are defined as **management-driven** monitoring schemes, where EM is officially used for **compliance monitoring** purposes. Vessels under these regulations are **required to have an EM system on board**. Examples of the most comprehensive fully implemented EM programmes are: The British Columbia Groundfish Hook and Line Catch Monitoring programme in 2006 (approximately 200 vessels), the Atlantic Highly Migratory Species programme for pelagic longlines in 2015 (112 vessels), and more recently, Electronic Monitoring Program for Small Fixed Gear Vessels in Alaska in 2018 (173 vessels).

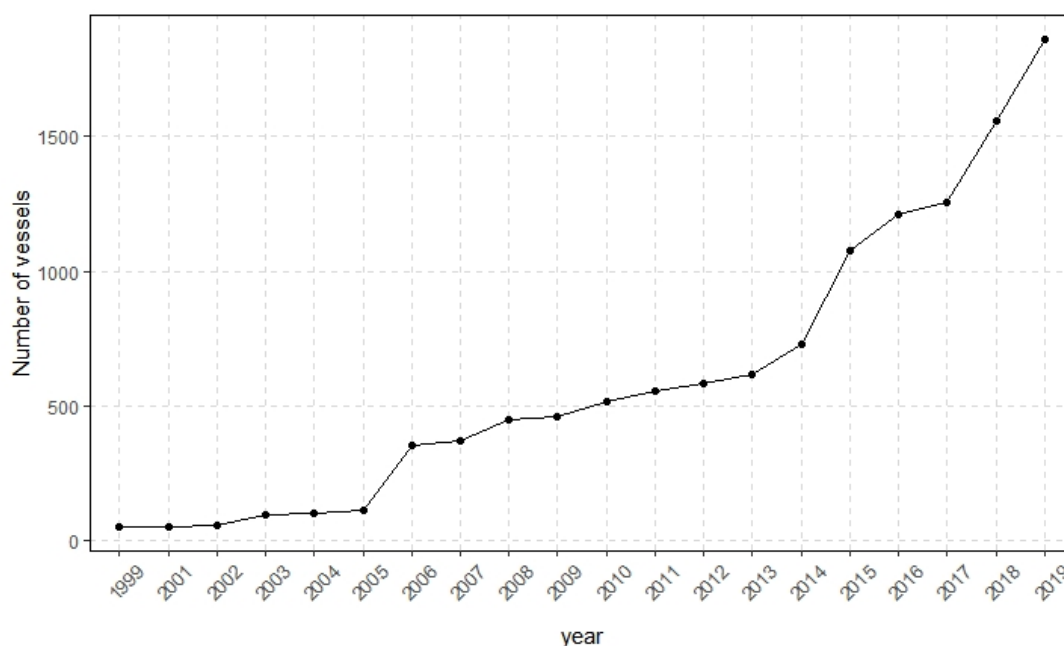
A proof for the extending reach of EM into other regions in the world is the implementation of the **Australian** Fisheries Management Authority (AFMA) EM programme in 2015, covering the Eastern Tuna and Billfish Fishery, Western Tuna and Billfish Fishery, and the Gillnet Hook and Trap fishery for scalefish and shark. EM 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. The programme 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% (van Helmond et al., 2020).

More recently, the **Chilean** government implemented a **fleet-wide EM programme** to monitor compliance as part of the “by-catch law and mitigation plans” (Cocas, 2019). In 2019, **140 vessels** were fitted with EM systems and are in full operation.

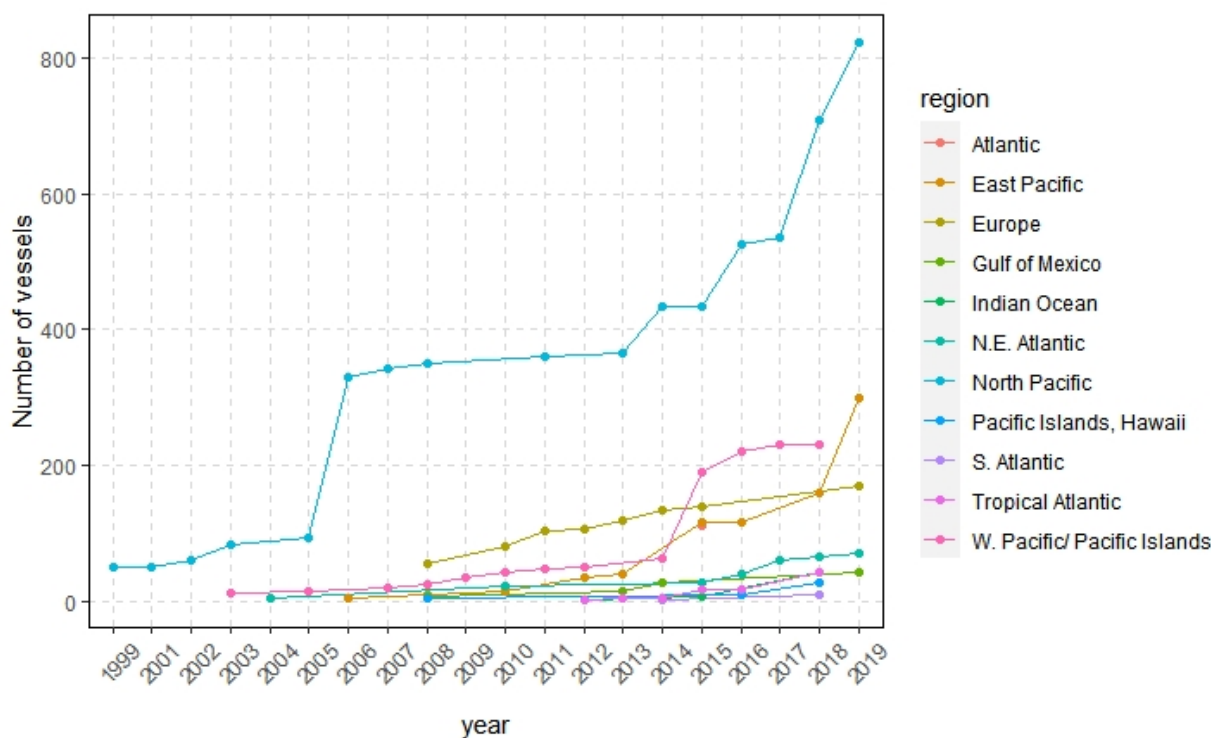
In 2018, the **French and Spanish tropical tuna purse seine fisheries** in the **Atlantic and Indian Ocean** adopted a **full EM programme**, covering 100% of fishing activities. Both programmes are remarkable since these are not directly managed by national or subnational management bodies, but are **initiated by the fishing industry** and all fishers participate on a **voluntary basis**. EM proved to be a valuable tool to increase the coverage and sampling required to obtain scientific information in order to provide better management advice for target and bycatch species in these fisheries (Briand et al., 2017; Ruiz et al., 2016).

Common to these EM programmes is that all started as pilot studies on significant smaller part of the fleets. Through **gradual implementation** and **cooperation of all stakeholders** involved the pilot studies became successful comprehensive fleet wide monitoring schemes. Through these EM programmes fishers can show they are responsible operators and follow fisheries management arrangements. On the other hand managers indicated that the impact of EM leads to **better data collection** in support of management decisions and enhanced **compliance** of regulations.

Figure 4: Increasing number of vessels involved in Electronic Monitoring worldwide



Source: Author based on data collected during review.

Figure 5: Number of vessels involved in Electronic Monitoring worldwide by region

Source: Author based on data collected during review.

2.2. Electronic Monitoring trials

The three main **objectives** to trial EM in fisheries around the world are:

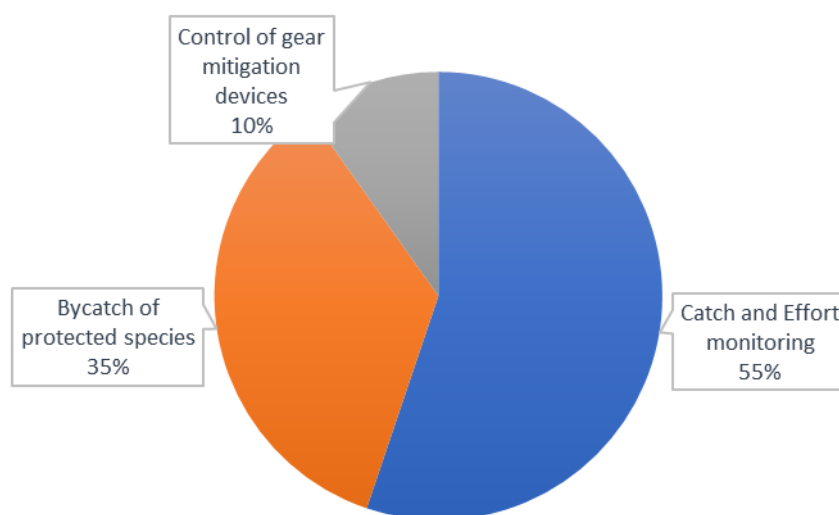
- 1) to improve catch and effort **monitoring**,
- 2) to improve **bycatch** registration predominantly for endangered and protected species, and
- 3) to improve the **control of gear mitigation devices**.

The objective for the majority of the EM trials encountered during the review, was to test the **feasibility of EM in recording fishing activity, catch and discard composition**, in some cases with the aim to complement or (partially) replace on-board observers (Figure 6). Although the focus of the objectives could differ between the different regions. For example, **EM trials in Australia and New Zealand** were mainly set up to test feasibility in **monitoring bycatch of threatened, endangered and protected species (TEPS)** in fisheries (Pierre, 2018). During these trials EM also proved to be an effective application to monitor handling of TEPS after capture, e.g. **observing mandatory catch handling and releasing procedures on board** to increase survivability (Pierre, 2018).

Besides catch and effort monitoring EM is also successfully trialled on **monitoring gear handling or gear modification measures**, i.e. gear mitigation devices. A remarkable example is the long distance South Georgia Patagonian Toothfish fishery. Located 1 400 km East Southeast of the Falkland Islands, the sub-Antarctic Island of South Georgia is home to a vast number of **rare and endangered seabirds**. To avoid interactions between seabirds and longline fishing vessels a set of **gear regulation measures** are implemented. These measures require fishers to attach weights to their lines to keep gear below the water surface as long as possible, set gear only at night (under minimal lighting), and deploy gear adjustments with colourful streamers to help scare birds away from baited hooks (Archipelago n.d.).

Because of **extreme weather conditions, the remoteness of the region and long trip durations, EM proved to be the best possible solution to monitor compliance with the regulation.** Due to the requirement to set gear at night (using minimal lighting), infrared cameras were required (Archipelago n.d.).

Figure 6: Relative proportion of the three main EM objectives in trials worldwide



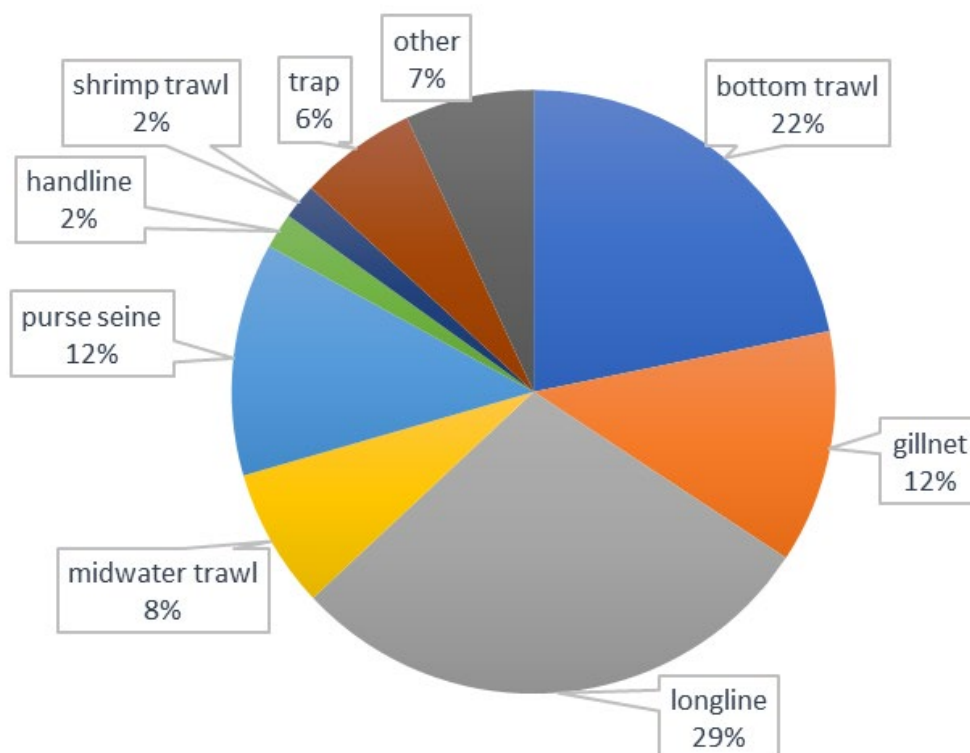
Source: Author based on data collected during review.

Since 2015, **EM became increasingly important for tuna fisheries in the Southwest Pacific** (Hosken et al., 2016). Trials were conducted in the Fiji Islands, Cook Islands, Solomon Islands, Palau, Federated States of Micronesia and the Republic of the Marshall Islands. Fisheries monitoring with **onboard observers or at-sea patrols** in the **vast area** of the Southwest Pacific, with roughly **2 700 tuna vessels** fishing in the region, is **challenging, inefficient and costly**. EM is seen as the possible **cost-effective solution**, making the Southwest Pacific a potential fast growing area of EM application (van Helmond et al. 2020).

Possibly driven by the plans and eventually the fleet-wide implementation of EM of the Chilean government, EM has been trialled in several small-scale fisheries in other parts of **South America**. The development of **low-cost EM systems** (see also section 3.14.), **will enhance EM implementation** in this region (Michelin et al., 2018). Besides a few smaller trials, EM has not yet extended to Asian countries on a larger scale.

2.3. The diversity of fisheries involved in Electronic Monitoring

Longline and bottom trawlers are the main fishery types for which EM trials have been conducted (Figure 7). The number of trials on demersal (bottom) 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 (longline) and gillnetting. It is believed that, because of occlusions, not all fish and species are completely visible on video for a mixed catch brought on deck at once, as is the case for trawlers (van Helmond et al., 2015). Nevertheless, for many **pilot studies on trawlers EM proved to be a useful tool to monitor catch** for a wide range of species (van Helmond et al., 2020).

Figure 7: Relative proportion of gear types involved in EM worldwide

Source: Author based on data collected during review.

2.4. Innovations in Electronic Monitoring

Recent developments in **computer vision technology**, in combination of improving computer processing power, making it possible to use software to automatically filter large volumes of video for key events or species recognition. The aim is to achieve automated registration of fish counts **to reduce the workload of the labour intensive and time-consuming video review process**. In 2014 and 2015, a series of American projects was initiated to develop automated image analysis for EM systems (Huang et al. 2017, 2018; Wallace et al., 2015; Wang et al., 2016; Wang et al., 2017). Also, more recently, European studies are getting more advanced in integrating computer vision technology in EM set ups on board (French et al., 2019). These are **crucial first steps to achieve real-time transfer of EM data**, which is currently constrained by the cost of transmitting huge volumes of video from vessels at sea to servers on land, to allow for further data analysis (Michelin et al., 2018).

Another element that will enhance the uptake of EM in fisheries management is the development of low-cost EM systems. **Low budget EM systems** could help addressing the challenging management issue related to the **lack of data in small scale fisheries** in the globally significant fishing regions, like Asia and Southern Europe (Michelin et al., 2018). EM studies on small scale fisheries were conducted in Peru and Mexico. 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 gillnet fishery (Bartholomew et al., 2018). Other examples are, a Mexican trial using the "Fly-wire Camera System," a low budget EM system developed for small-scale and artisanal fisheries using high-quality video linked to a GPS and a very basic low-cost EM application, just using a camera mounted on a small fishing vessel and video recording the complete fishing trip, to monitor protected species interactions in an Indonesian hand-line fishery (Kennelly & Borges, 2018).

2.5. Electronic Monitoring in European waters

In total, **26 EM trials** from seven different countries (Denmark, France, the Netherlands, Germany, Spain, Sweden, and United Kingdom) were encountered during the review. So far, **none of the trials has moved to full implementation**. Trials were mainly conducted in demersal fisheries using bottom trawls, seines and gillnets. Different types of vessels have been involved, from larger beam trawlers and seiners to small inshore fishing boats of less than 10 metre in length. The trials often lasted several years and generated large amounts of data. The more comprehensive EM trials, involving more than 10 vessels, started in Denmark and Scotland in 2008. Overall, **the number of vessels involved in an EM trial varied between 1 and 27 vessels**. Evaluating the efficiency of EM as a catch, discards and effort monitoring tool was the most common research objective among the studies. In seven studies, this objective was combined with an evaluation and **feasibility study of a catch quota management (CQM) regime or landing obligation**. Research objectives of other studies were: scientific data collection, testing increased flexibility in technical fisheries measures, estimation of discards quantities, and development of automated image review through computer vision technology.

2.5.1. Denmark

With trials in place since 2008, Denmark was the first nation in Europe to promote the use of EM (Ulrich et al., 2015). EM was successfully used in a **catch quota management (CQM)** trial to **reduce and avoid discarding of cod**. During this trial **all cod catches were counted against available quota, including catches of individuals below minimum landings size**. The results showed that the **EM system could provide the documentation required to support a CQM scheme** and that it was an incentive for the participating fishers to avoid discarding (Kindt-Larsen et al., 2011). Soon other countries followed the Danish example and started to equip vessels with EM systems to investigate the possibilities. An additional study by Ulrich et al., 2015, concluded that EM is a considerable more cost-effective than observers if good monitoring coverage is required.

Even though several European studies briefly described **the acceptance of EM in the fishing community**, there is only one comprehensive study on this aspect, which was conducted in Denmark by Plet-Hansen et al. (2017). A remarkably result of this study is the **differences in acceptance level of EM between fishers** that already participated in EM trials, who do not display strong antipathy against EM, in contrast to fishers with no experience to EM, where the majority has a very negative point of view on EM (Plet-Hansen et al., 2017). **Common issues fishers have with EM**, regarding the study: **the constant surveillance**, the worry of not having “**an equal playing field**” if not all vessels have an EM system installed and **the feeling being criminalised** (Plet-Hansen et al., 2017).

Recently, Denmark rolled out a new EM project on the Nephrops fishery (Table 1). **The project objective is to monitor compliance with the landing obligation**. First 12 vessels participate on a voluntary basis. The aim is to have the entire fishery covered by the end of 2022.

Table 1: EM trials in Denmark

EM trial	Year	Objective	Max. no. vessels*	Gear type
Fully Documented Fisheries, trial on catch quota management	2008 - 2014	Catch and effort monitoring. Test the ability of EM to support a catch-quota management pilot on cod. Review efficiency of EM data to estimated cod discards.	27	Bottom trawl, purse seine, gillnet
Trial on bycatch documentation of harbour porpoise	2010 - 2011	Evaluate the feasibility of using EM to observe incidental bycatch of marine mammals, increase the monitoring levels and reduce costs.	6	gillnet
Seabird by-catch in gillnet fisheries	2010 - 2018	Assessing incidental seabird bycatch by using EM.	3	gillnet
Minimising discards in Danish fisheries (MINIDISC project)	2014 - 2015	Evaluate the efficiency of EM to estimate discards estimates in mixed fisheries.	14	Bottom trawl, purse seine
Free gear choice in a Danish result-based management trial	2014 - 2015	Evaluate the option of free gear choice to reduce discarding. Trigger changes in selectivity by removing the prevalent technical constraints. EM used to guarantee full monitoring coverage.		Bottom trawlers
Nephrops fishery	2020 - ongoing	compliance with the landing obligation	12	Bottom trawl

Source: Kindt-Larsen et al., 2011, 2012; Ulrich et al., 2015; Mortensen et al., 2017a, 2017b; Glemarec et al., 2020

Note: *) Vessels with EM systems likely participated in more than one trial, therefore, the actual number of vessels equipped with systems could be lower

2.5.2. The Netherlands

Following the success of the Danish and Scottish CQM trials, the first Dutch EM trial was implemented in 2011. In total 12 vessels were fitted with EM systems **to monitor a CQM scheme for cod in the North Sea**. EM proved to be **accurate in detecting cod in the mixed catch of Dutch bottom trawlers** with a relative high volumes of discards (van Helmond et al., 2015). Soon, successful EM trials followed on a wide range of different fisheries, e.g. **large pelagic trawlers** (> 100 m. length) to **small scale inshore gillnetters** (< 10 m. length), to investigate a diversity of research objectives, see Table 2.

Currently, two Dutch EM projects are ongoing: **The development of a fully (automated) documentation of catch registration**. Primarily focussed on recording of discards of species subjected to the landing obligation. By **integrating the latest available computer vision technology** it is the aim to completely automate this process, and **create a truly fully documented fishery**. The second project investigates the potential of EM to increase the availability of catch information for **data limited rays stocks**. Detecting different, similar looking, ray species, on dorsal and ventral side, is one of the key challenges.

Table 2: EM trials in The Netherlands

EM trial	Year	Objective	Max. no. vessels*	Gear type
Dutch North Sea cod catch quota management	2011 - 2015	Evaluate the efficacy of EM as monitoring tool for a catch-quota management scheme in mixed bottom trawl fisheries.	12	bottom trawl
EM trail in small scale fishery	2011	Test reliability of EM in monitor and quantify catches.	1	Gillnet
Bycatch documentation of harbour porpoise	2013	Assess the by-catch rates and numbers of porpoises in the Dutch commercial bottom-set gill net fishery.	12	Gillnet
Dutch Freezer Trawler	2014	Develop a methodology to use EM to confirm full retention of catch on-board a freezer trawl vessel (compliance with discard ban).	1	midwater trawl
Dutch EM trial on <i>Solea solea</i>	2015	Evaluate the efficacy of EM as control tool for discard of undersized sole in beam trawling.	2	bottom trawl (beam trawl)
Fully Documented Fisheries	2019 - ongoing	Development of a complete catch registration system based on EM in combination with computer vision technology.	8	bottom trawl (beam trawl)
EM trial on monitoring by-catch of rays	2019 - ongoing	Develop an EM procedure to monitoring rays for scientific and management purposed. Investigate computer vision technology possibilities for automated ray registration.	3	bottom trawl

Source: Bryan and Batty, 2015; van Helmond et al., 2015, 2016, 2017; Scheidat et al., 2018

Note: *) Vessels with EM systems likely participated in more than one trial, therefore, the actual number of vessels equipped with systems could be lower

2.5.3. United Kingdom (UK)

As part of trials to determine the efficiency of a **land-all policy for North Sea cod**, in a similar setup as the Danish CQM trial, the first EM systems were installed on seven Scottish demersal vessels in 2008. Vessels were permitted **additional days-at-sea** and cod quota, and were **obliged to land all cod caught** in the North Sea. This arrangement has been renewed each year, and while the list of vessels involved has not remained constant, **it reached a maximum amount of 27 vessels** (Needle et al., 2015). During the following period, several CQM trials were conducted on different English fisheries on the North Sea and Western Channel on a range of species, e.g. cod, plaice, sole, megrim, hake angler fish. Just recently, 2020, the first phase of an **EM trial on Scottish scallop dredgers was implemented** (Table 3).

Overall, **the studies concluded that EM was a reliable tool to monitor catches**, particularly when good monitoring coverage of the fleet is required, which was the case for all of the CQM trials (MMO, 2013 a, b; 2014 a, b; 2015 a, b; 2016). **EM provides a rich source of information for science as well as for compliance and management** (Needle et al., 2015).

A **first attempt to automate the process of video review by integrating computer vision technology with EM** was conducted on the Scottish trial. Although, the operational environment presents a significant challenge, **the results from the first experiments were promising** (French et al., 2015). The development of the technology to automatically counting number of discarded fish by species continued and is still work in progress, see also French et al. (2017).

Table 3: EM trials in the United Kingdom

EM trial	Year	Objective	Max. no. vessels*	Gear type
Scottish catch quota management EM trial	2008 - 2016	Reduce stock mortality for cod by incentivising increased selectivity by imposing a cod discard ban to participants. EM used to ensure compliance with scheme conditions.	27	Bottom trawl
English catch quota management trials for otter trawls and gill nets	2011 - 2012	Evaluate possible impact of discard bans. Develop EM as a potential monitoring tool in the context of full catch documentation.	19	Bottom trawl, gillnet
Catch quota management trials for Southwest beam trawls	2011 - 2013	Explore the implications of the landing obligation. Evaluate efficiency of EM to estimate plaice discards.	9	Bottom trawl (beam trawl)
EM trials for vessels < 10 m	2011 - 2012	Test reliability of EM in monitor and quantify catches on small commercial fishing vessels (< 10m).	2	Bottom trawl, gillnet
Southwest haddock fully documented fishery scheme	2013 - 2014	Evaluate possible impact of discard bans. Develop EM as a potential monitoring tool in the context of full catch documentation.	1	Bottom trawler
Video as an alternative for observers on crustacean fisheries.	2015	This study evaluated the use of on-board camera systems to collect data from small-scale inshore <i>Cancer pagurus</i> and <i>Homarus gammarus</i> fisheries.	4	traps
Modernisation of the Scottish Inshore Fishing Fleet (Phase 1 – Scallop dredge fleet)	2017 - ongoing	Ensure that Scallop dredging is compliant with all relevant regulations. Promote transparency and accountability within the fleet to allow for safer and closer alignment of activity around MPAs.	20	dredge
Scientific trial of electrofishing for razor clams.	2018-ongoing	Ensure compliance with trial conditions including fishing only in waters classified for shellfish harvesting. Mapping the spatial distribution of fishing effort and evaluating the suitability of EM to derive LPUEs for analysis of stock trends.	28	Hand dived behind towed electrodes

Source: Needle et al., 2015; MMO, 2013 a,b; 2014 a,b; 2015 a,b; 2016; Hold et al., 2015; ICES, 2020

Note: *) Vessels with EM systems likely participated in more than one trial, therefore, the actual number of vessels equipped with systems could be lower

2.5.4. Other EM trials

Other EM trials were conducted in **Sweden**, being one of the EM pioneers, testing EM for **bycatch registration for gillnetters** in 2008. Also **Germany**, tested EM in two smaller projects (Table 4). However, despite some promising results both countries did not continue to investigate possibilities or implement further trials with EM.

In the context of European EM trials, it should be noted that both **France and Spain were involved in several larger EM trials on tuna purse seiners outside European waters**, Atlantic and Indian ocean, see section 3.1 “EM implementation worldwide”.

Currently, France is in the process of setting up an EM trial on a gillnet fishery in the Bay of Biscay.

Table 4: EM trials in Germany, Sweden and France

EM trial	Year	Objective	Max. no. vessels*	Gear type
Swedish EM trial on bycatch documentation	2008	To test whether EM is more efficient in by-catch monitoring than on-board observers.	2	Gillnet
German North Sea catch quota management EM trial	2011 - 2016	Evaluate the reliability of EM on discards registration. Test the feasibility of a management approach using reversal of the "burden of proof."	2	bottom trawl
German EM trial on bycatch registration	2011 - 2013	Assess by-catch levels of harbour porpoise and sea birds in gill nets using EM.	3	Gillnet
French EM trial on gillnetting	2021 - ongoing	Assess the data collection capabilities on these small vessels.	4	gillnet

Source: Tilander and Lunneryd, 2009; Oesterwind and Zimmermann, 2013

Note: *) Vessels with EM systems likely participated in more than one trial, therefore, the actual number of vessels equipped with systems could be lower

3. REPRESENTATIVE CASE STUDIES: DIFFERENT APPLICATIONS OF ELECTRONIC MONITORING

KEY FINDINGS

- EM **improves monitoring coverage** without a considerable increase in the monitoring budgets.
- **Involvement of fishers** is crucial for a proper EM implementation. Fishers need to conform to the operational practices on board to facilitate the success of EM.
- **Computer vision technology** is the logical next step to facilitate processing vast amounts of **EM data**.

The presented case studies in this chapter provide **examples on EM applications** in different types of fisheries and the use of EM in different situations, but with relevance to the EU landing obligation focussing on registration of fishing activity and catches. For each case study an **introduction**, **objective**, short **description** and main **conclusions** are provided. Finally, based on all case studies the lessons learnt are summarised.

3.1. Electronic Monitoring in a small-scale gillnet fishery

3.1.1. Introduction

Based on the Data Collection Framework (DCF) of the European Commission the Netherlands is obliged to monitor its commercially most important fisheries. Traditionally information on catches, particularly the discarded part of the catch, is collected onboard different types of commercial vessels through a **scientific observer programme**. Trained personal boards a fishing vessel for the duration of one trip and collects representative samples of both, the landed and discarded part of the catch. However, as the **space on board of the vessels of the Dutch coastal gillnet fishery is limited**, placing an observer on board these vessels is from a practical point of view and for safety reasons not the preferred option. **Replacing the onboard observer with an EM system** could be a potential alternative to monitor the different catch fractions on board coastal gillnetters.

3.1.2. Objective

This study investigated if EM is a **suitable alternative for an onboard observer** to monitor the different catch fractions of a Dutch coastal gillnetter. To test the efficiency of EM in recording the catch, comparisons by species were made for a number of trips between the data collect by EM and the on board observations (van Helmond and Couperus, 2012).

3.1.3. Project description and results

An EM system was installed on board a gillnet vessel of less than 10 metres in length. The vessel operated along the Dutch coast, within a range of 15 nautical miles from its home port. The EM system consisted of two **analogue cameras**, GPS, an onboard computer, and a winch and hydraulic sensor to record fishing activity. EM data was stored on **transferable hard drives** which were collected on a regular basis. In total 34 fishing trips were recorded with EM. All EM footage was **manually reviewed** and compared with onboard observations.

For the **cod** (*Gadus morhua*) catches there was a **high level of agreement between the on board recordings and EM**. There was an **acceptable level of agreement** between onboard observations and EM for **turbot** (*Psetta maxima*). There was **no level of agreement**, a weak correlation, between onboard observations and EM **for brill** (*Scophthalmus rhombus*), **smaller flatfish species**, e.g. plaice (*Pleuronectes platessa*), dab (*Limanda limanda*), sole (*Solea solea*), and **smaller round fish**, e.g. whiting (*Merlangius merlangus*), pouting (*Trisopterus luscus*).

3.1.4. Conclusions

EM proved to be a reliable alternative for an onboard observer to monitor the catch of larger fish species on board of a Dutch coastal gillnetter. There was a strong agreement between EM and on board observations for cod, and a moderate, but sufficient, agreement for turbot, both relatively larger species in gillnet catches. Based on these findings it was concluded that EM would also be a reliable alternative for monitoring gillnetting on seabass, another relatively larger recognisable fish species such as cod (van Helmond and Couperus, 2012). Similar findings on the efficiency of EM in recording cod catches in gillnet fisheries were published in Denmark (Ulrich et al., 2015). **EM was less efficient in monitoring the catch of smaller fish (species)**, e.g. plaice, dab, sole, whiting, pouting. **Misidentification of species** was pointed out as the main reason.

There was a good view on the hauling of the nets. Providing a good estimate of the total catch. However, there was **no fixed discard location on board**, making it **difficult to exactly estimate discards quantities**. As a result, similar problems were encountered in other EM trials on board small vessels (Needle et al., 2015; Mortensen et al., 2017).

Once EM is installed **sampling coverage could be significantly increased without a severe increase of the monitoring budgets**, providing a much more detailed data on cod catches in the Dutch coastal gillnet fishery.

3.2. Electronic Monitoring in Catch Quota Management regimes

3.2.1. Introduction

For several years, low Total Allowable Catches (TAC) for cod led to substantial under reporting of cod catches in European fisheries. Over quota catches were discarded or landed on the black market. As a result cod catches were not sufficiently monitored, which undermined stock assessments and in turn led in annual reductions of TAC advice (Ulrich et al., 2015). In 2008, Denmark presented a proposal for the EU Council of Ministers to implement **a fully documented catch quota regime for cod**, stating that all catches, landings and discards, should be counted against quota. Eventually, this resulted in the possibility for EU Member States to start with trials on **Catch Quota Management (CQM) regimes** for cod, under the conditions that vessels **use EM to document all catches**, and all cod catches, including discards, are counted against the available cod quota (Ulrich et al., 2015).

3.2.2. Objective

Since 2010, a number of EU Members States, Denmark, the Netherlands, United Kingdom (England and Scotland) and Germany, developed their own CQM trials, in which EM should play a **key role in recording all cod catches at sea**. The main objective of these trials was to **investigate the efficiency of EM as a monitoring tool** for CQM schemes.

3.2.3. Project description and results

Varying between countries, from two to 27 vessels participated in the trials for a duration of at least two years (for details check tables in section 3.2). All vessels were permanently equipped with EM systems consisting of four **cameras**, analogue or digital, **GPS**, fishing activity **sensors** and **onboard computer**. Data was stored on transferable hard drives or on the onboard computer and transferred over wireless networks. Catch weights (kg), landings and discards, per haul were recorded in a logbook for each haul and trip. **All cod catches were subtracted from the national cod quota**. In order to profit from the advantage of the CQM and maximise their quota by **avoiding undersized cod**, a **30% extra individual cod quota** was handed out to the participants of the pilot study. In some cases, an additional derogation on national effort control regulations was provided to create some extra necessary flexibility for participants to be able to operate in a catch-quota system. To verify if logbooks were filled out correctly, a so called **EM audit-model was applied**: For a random selection of hauls, 10% of the total number of hauls per trip, video observations on the catch were obtained to verify catch recordings in the logbooks. The estimated discard weight by video review was compared with the discard estimates reported in the logbooks. Additional targeted control could be performed if irregularities were detected.

3.2.4. Conclusions

Overall **EM proved to be an adequate tool**, being considerably **more cost-effective than observers**, in case good monitoring coverage is required, as is necessary in a CQM scheme (Needle et al. 2015). Some **trials required additional protocols** to be able to estimate discard quantities, e.g. in the Danish trial fishers had to collect cod discards in standardised baskets and hold them in front of the cameras for a few second before discarding (Ulrich et al., 2015). Results from the Dutch CQM trial in mixed bottom trawling pointed out **that distinguishing small numbers of cod with EM in large bycatch volumes of similar looking species was problematic without protocols** (van Helmond et al., 2015).

The **CQM trials proved that fishers**, with the incentive to optimize the catch selectivity, were able to **change their behaviour to avoid catching undersized cod**. The Danish trial observed a significant reduction in discarding marketable cod, so called high grading (Kindt-Larsen et al., 2011). However, the ability to change fishing behaviour differed for different fleets and individual fishers. It seemed that larger vessels, companies, had more flexibility in adapting their behaviour to a CQM regime, mostly caused by available (financial) resources, e.g. number of crew members, transport, longer trips, etc. (van Helmond et al., 2016).

The collection of sufficient EM information heavily depends on good cooperation of the participating fishers. Firstly, there is the extra burden on the crew. All trials reported that, recording cod discards in the logbooks, which implied **sampling and weighing of undersized cod catch, was time-consuming manual labour** (Ulrich et al., 2015; van Helmond et al., 2016). Secondly, **maintenance of the EM systems on board was a key element of the success of the trials**, without properly functioning EM systems, including clean camera lenses, video review is not possible.

Vast amounts of EM data were generated during the CQM trails. Most trials ran for several years involving multiple vessels, e.g. the Scottish trials ran for eight years involving 27 vessels in total (see also section 3.2.3). Reviewing and analysing **required a significant amount of manual labour**, even when the audit-model was applied and only a random selection of the EM data was analysed.

3.3. Electronic Monitoring on board pelagic trawlers

3.3.1. Introduction

Before the EU landing obligation for pelagic fisheries became fully enforced in 2015, the pelagic trawler association decided to investigate the **use of EM to comply with the required monitoring objectives**, i.e. full documentation of catches, including discards. In 2014, an EM system was installed on board a freezer trawler, of 117 metres in length. Data collection with the EM system occurred for a period of five months.

3.3.2. Objective

The objective of the project was to **demonstrate the feasibility of EM** on board a freezer trawler fishing vessel to document discard quantities in compliance with the regulations under the EU landing obligation.

3.3.3. Project description and results

During the trial all catch that normally would have been discarded was retained and kept separately. EM data was collected for the entire trips to capture all catch sorting and discarding events. The EM system consisted of digital cameras, GPS, hydraulic pressure sensor, net drum rotation sensor, onboard computer. **Eight cameras were used:** Six on the deck showing the catch handling and net pumping operations (pelagic net is too large to lift on deck) and close up to the agreed discarding zone. Two cameras were located in the factory, showing the sizing and sorting area. **The factory on board a pelagic freezer trawler is a large and complicated operation to monitor**, no effort was made to supply enough cameras to cover all areas at that stage of catch handling (Bryan and Batty, 2015).

During EM data review discard **weight was estimated based on the number of standardised baskets**, in which the crew collected the discards (Bryan and Batty, 2015). Discard weights were categorised in classes (0-49 kg, 50-99 kg, 100-499 kg, 500-999 kg, 1 000 kg and above).

3.3.4. Conclusions

This trial was **successful at providing a general EM methodology**, as for equipment set-up and catch-handling requirements, developing data review protocols for estimating discards, and developing a reporting system to **demonstrate compliance with the landing obligation** (Bryan and Batty, 2015). EM showed to be **efficient in monitoring large amounts of fishing activity** in a cost-effective way; fishing trips averaging 23.5 days with 36.5 tows could be fully reviewed and reported in about 24 hours of labour (Bryan and Batty, 2015). **The skipper and crew conformed to the operational practices required to facilitate the success of EM for data collection and reporting.** It was expected that conformance would improve over time as modifications in fishing practice necessary to support EM (e.g., catch handling) and become mainstream as was seen in other trials (McElderry et al., 2014; Stanley et al., 2011; 2015). Nevertheless, there was never a follow up on this trials nor an upscaling to a larger number of vessels. Afterwards the pelagic freezer association explained that **the lack of an equal playing field**, in particular with other international pelagic fisheries was the main reason no follow up of this study occurred.

3.4. Integration of computer vision technology into Electronic Monitoring

3.4.1. Introduction

The Dutch government initiated a project called **Fully Documented Fisheries** (FDF) that commenced in 2019 and is still ongoing. The implementation of the **EU landing obligation**, with the requirement to **record all catches** of species subjected to the TAC and quota regulation, **increases the workload onboard**. The FDF project aims at **using EM to fully document** catches and fishing activity, **without interference of fishers**. In other words, it seeks to create a system that **automatically records all catches** onboard. **Releasing the burden on the fishers** by not weighing and recording discards of several species on a haul-by-haul basis, which can be substantial in a **mixed bottom trawl fishery**, will ease the implementation of the landing obligation. A consortium of researchers and fishing industry representatives investigates the possibility to **innovate EM review strategies**, involving **computer vision** and **machine learning technology**, i.e. training algorithms in correctly identifying the different fish species.

3.4.2. Objective

Within the given timeframe of this project it is the aim to deliver **a first prototype of an autonomous catch recording EM system**. This prototype should be able to record the complete catch of quota restricted species under the landing obligation on board a beam trawl vessel.

3.4.3. Project description and results (preliminary)

In total eight **beam trawl vessels** are involved in the project and **equipped with EM systems**, containing five digital **cameras**, **GPS**, fishing activity **sensors** and an **onboard computer**. To facilitate the development of computer vision technology in the initial phase of the project a test or '**laboratory setup**' was created, consisting of an exact **copy of a conveyer belt** used on board beam trawlers to

Figure 8: Laboratory setup for the development of computer vision technology



Source: Wageningen University & Research

Note: An exact copy of a conveyer belt used on board beam trawlers to facilitate the development of computer vision technology to automatically identify fish catch

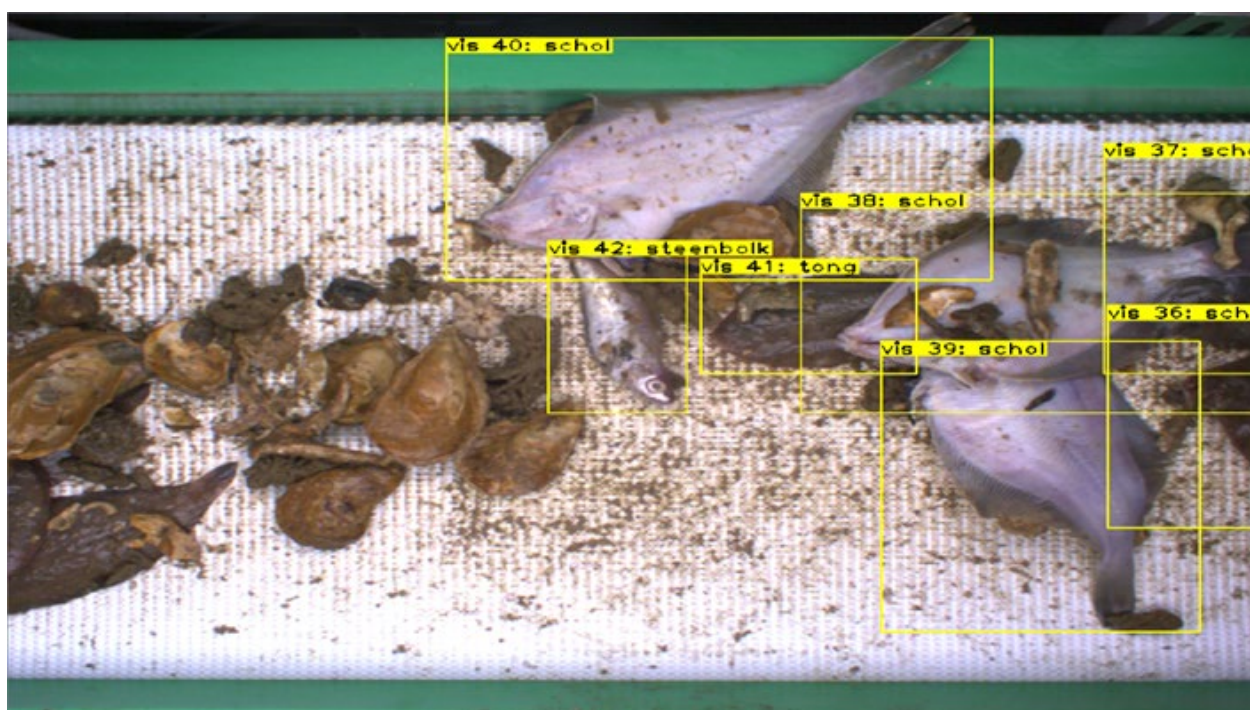
sort catch and a frame to mount lights and different camera types (Figure 8). To enable testing with catches on land the device is made transportable and can be used at different locations, e.g. research labs, landings sites, ports, fish auctions, etc.

To **test the performance of the algorithms** in correctly identifying the different fish species against manual EM review, recordings of both methods of the same catch are compared and validated against the ground truth, established by a complete sorting of the catch.

Recently a first trial on board a beam trawler was conducted. Footage of several hauls was collected and is currently analysed (Figure 9).

Eventually, the **automated recording system** will be **integrated in an EM system on board**. At that stage, discard numbers should be directly recorded by species, without storing large amounts of footage on board.

Figure 9: Computer vision technology in practise: Example of automated classification of fish species on the sorting belt of a beam trawler



Source: Wageningen University & Research

Note: 'schol' = plaice, *Pleuronectes platessa*; 'tong' = sole, *Solea solea*; 'steenbolk' = pouting, *Trisopterus luscus*)

3.4.4. Conclusions (preliminary)

Controlling the external variables, e.g. sufficient lighting, dirt, salt water, on board fishing vessels is the main challenge to create the high quality footage needed for the algorithms to identify fish species. Unstable light conditions, dirt on lenses, and potential other **external variables** could have an influence on the performance levels of the algorithms.

During the trials the algorithms showed **high performance levels in detecting and tracking fish** on the collected footage, comparable with the manual (human) EM review. Most errors during the trials were made by missing fishes, predicting background instead of fish species and misinterpretation between similar looking species, dab and plaice, and, whiting and pouting, occurred more frequent.

In order to compare performance levels of the automated recording system, manual EM review is needed. Complete review of catches with EM is a **labour intensive task** and results in a relatively minor, but structural, **underestimation of discards for smaller specimens**, e.g. plaice and sole. Similar results were encountered in previous studies (Needle et al., 2015; Mortensen et al., 2017; van Helmond et al., 2017). Reasons for inaccurate observations are **misinterpretation of similar looking species and blocked view**, e.g. overlapping fish in the catch caused by occlusions on the sorting belt.

3.5. Lessons learnt: Implementation of Electronic Monitoring under the landing obligation

All case studies described above **collect and examine experiences in the perspective of using EM under the landing obligation**. Within this context, efficiency of EM to register catch, in particular discards, and upscaling to fleet level were considered as the main points in evaluating the presented case studies.

- None of the case studies, or any other European EM trial, evolved in a fully implemented EM programme. **The proper integration of EM into national sampling schemes is not straightforward and requires specific focus** (Ulrich et al., 2015). For several of the European CQM studies on cod there was the potential to evolve into a fully integrated management scheme. However, in retrospect, it was realized that **the status of the CQM pilots remained unclear**, being considered a scientific trial but with national and EU-wide management implications. In such a case, **it is important to clarify the distribution of responsibilities** between the scientific and control institutions to ensure adequate quality proofing and use of the data (including, for example, storage and access to data, legal obligation to delete videos, choice of hauls to be monitored, estimation methods, coupling data with e-log information, etc.). Also, the daily follow-up and feedback process with the participating vessels must be carefully planned (Ulrich et al., 2015).
- The biggest advantage of EM is the **increase of sampling coverage and the level of detailed fisheries information that can be collected** without an extreme increase in monitoring budgets. However, it should be emphasized that **EM is not a “plug and play” system**. EM system set up, communication with fishers, protocols onboard, coordination of EM supplies and maintenance require effort and time. Problems would only be solved with hard work, creativity, cost, and compromise.
- Fishers need to conform to the operational practices required to facilitate the success of EM. **Camera lenses need to be cleaned** on regular intervals, footage collected from dirty cameras is useless. In the common set up for full documentation trials, as was the case for the CQM trials, EM is used to verify self-reported catches (the **EM audit-model**, section 4.2.3). **Recording discards on a haul-by-haul basis is an extra burden on the crew**, this implies that on top of the landed part of the catch, discards should also be sorted and weighted. Discard registration of multiple species, as would be the case for a mixed bottom trawl fishery under the Landing Obligation, would imply a severe increase of workload on the crew. **Involvement of fishers is crucial for a proper EM implementation**.
- **EM is very accurate in detecting larger fish** in the catch (Needle et al., 2015; Ulrich et al., 2015; van Helmond et al., 2015; Mortensen et al., 2017). However, **EM seems to have its limitations in accurately detecting smaller species or individuals**, e.g. discards. The presented case

studies confirmed findings of previous studies (Mortensen et al., 2017; van Helmond et al., 2017). Despite the potential of EM to monitor discards onboard development in **improving view and image quality is still needed** (Needle et al., 2015; Mortensen et al., 2017; van Helmond et al., 2017).

- For longer running projects, i.e. several years, involving multiple vessels, **EM generates vast amounts of data**, potentially too large for manual analysis. Care will need to be taken to **ensure that science monitoring and analysis resources do not become overwhelmed** (Needle et al., 2015). Implementation of EM on a larger scale most likely requires **a well organised infrastructure for data storage and processing**. In line with the current developments, **computer vision technology** is the logical next step to facilitate processing vast amount of EM data.
- The majority of the **participating fishers in EM trials were positive and supportive of using EM** for fisheries management purposes. In some cases strong incentives to participate were provided, e.g. extra quota.
- **The COVID-19 pandemic** revealed an additional benefit of EM in the currently running EM study in the Netherlands. Due to corona measures, all scientific monitoring programmes using observers on board commercial vessels are temporarily on hold. Not requiring extra personnel on board proved to have **an unforeseen advantage** of EM compared to at-sea observer programmes.

4. BENEFITS AND RISKS OF ELECTRONIC MONITORING: CONTROL, INDUSTRY AND SCIENCE

KEY FINDINGS

- The major benefit of EM is the potential to provide much **wider and more representative monitoring coverage of a fleet** than any other monitoring method will likely achieve **at the same costs**.
- **Manual video review is labour intensive and time consuming**. The so called ‘**audit approach**’, a random check, e.g. 10–20% of the camera footage validated against (self-) recorded catch data in logbooks, is the most common video review method to reduce review workload and costs.
- Estimated **annual EM running costs** for the entire **Danish fleet** is estimated at **1.7 million EUR annually**.
- Managing the **large volume of privacy sensitive data** EM generates requires thoughtful decisions about how to store data, for how long, who will be able to access the data and how often it **requires a comprehensive IT infrastructure**.
- Besides the ability to support and control management driven regimes, **EM has the potential to enhance a wide range of other data collection programmes or initiatives**, like stock assessments of data limited stocks or increase traceability in seafood supply chains.

4.1. Benefits of EM

The findings of the review show that the **three major benefits of EM** are the following: (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 position (van Helmond et al., 2020). Based on these benefits, **EM facilitates fisheries management improvements**, e.g. allows for improved catch documentation compared to the conventional methods such as onboard observers, incentivise better compliance and discard reduction, enables monitoring in vast and remote areas, and improves the coverage of monitoring of threatened, endangered and protected species. However, other **biological information** needed in stock assessments, such as age, maturity, sex, fecundity cannot be collected with EM. Therefore, some level of **integration with human based programmes** will always be required. Similar to EM, **self-sampling** can significantly increase monitoring coverage and improves representative sampling. However, self-collected information by fishes is often **considered biased** and not always collected in a sufficiently rigorous manner (Kraan et al., 2013). EM is often combined with self-sampling of catches. The potential of verifiability is likely to create a **deterrent effect on logbook misreporting**.

4.2. EM providers

The first company and creator of EM products is originally based in Victoria, British Columbia, Canada, but provides EM systems globally and started offices in USA, Europe, Norway, and Australia. With the growth of EM worldwide, several new providers have also entered the market, **providing EM consulting services** or making **EM products**, including the **software** that **supports the systems on board**, as well as for **analysing EM data**. Open source software packages are not available. Even with the recent developments, the **EM market remains small** and fragmented, and limits the appetite of

firms to make considerable investments in research and business developments (Michelin et al., 2018). An overview of EM vendors and service providers is presented in the Annex – Table A.

4.3. EM system set up, data transmission and reliability

In general, an EM system set-up consists 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 an onboard **computer**, which saves the footage on board the vessel (van Helmond et al., 2020).

In all reviewed studies, the cameras were usually installed in a way that the crew **workflow was minimally affected**. The number of cameras, the resolution (pixel density) and the frame rates were considered against the specific monitoring objectives and the size and the specific characteristics of the vessels. Locations of the cameras on board the vessels were chosen in order to **maximise the vision given the vessel layout**, the **workflow** and the **position of the crew**, while **avoiding moisture, dirt and blind spots**. Typically, four cameras are used for an averaged sized fishing vessel. The general EM set up has at least **one camera pointed directly at the discard chute** and sorting belt, **one camera to cover the processing area** or the deck on board smaller vessels, one camera to cover net hauling and one camera to cover the catch in the hoppers. On board 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 board small vessels with open decks (MMO, 2013; Mortensen et al., 2017; Needle et al., 2015; van Helmond et al., 2020). Also, the availability of electrical power on board small vessels may be limited by battery capacity when the engine is not running, thereby limiting the scope for implementation on board some smaller inshore vessels. Meanwhile, (smaller) autonomous systems have been developed that are powered by solar panels and batteries (Bartholomew et al., 2018; van Helmond et al., 2020).

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, and with that a very accurate record of fishing effort. 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** (van Helmond et al., 2020). In some studies, other sensors, e.g. movement of the sorting belt, or triggers, like marked borders around the harbour, picked up by GPS when the vessels leaves port and automatically activates the EM system to record.

In almost all reviewed studies EM data is stored on **exchangeable hard drives**. Once full, hard drives were replaced by empty drives to continue recording. Drives were usually replaced by authorised persons, visiting the vessels in the harbour. Although, in some studies fishers were instructed to change hard drives themselves and send the drives by mail (Course et al., 2011; van Helmond et al., 2015).

To avoid the manual replacement of hard drives, new systems are developed that allow **wireless transmission of data** via 3G, 4G or Wi-Fi networks. This was progressively implemented in the Danish trials. The 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; van Helmond et al., 2020). However, wireless transmission depends on the availability of **sufficient Wi-Fi networks** and **the quantity of data to transmit** (van Helmond et al., 2020). A potential issue is that data reviewers want more comprehensive data, while data

transmission seeks lower volumes. Remarkably, the first fully implemented EM programmes, the West coast programmes in North America, still rely on manual replacement of hard drives.

EM **performance depends** very much **on the technical reliability of the systems** and **the ability to correctly estimate catches**. Technical EM failures and loss of data due to poor video quality are regularly reported. Based on the review, reported errors can be classified in three different categories: **system failure**, **storage failure** and **obstructed view** (van Helmond et al., 2020). System failure is the most obvious form caused by all possible malfunctioning of different parts of the system (e.g. cameras, sensors, transmitters, wiring, etc.) often caused by **the hostile environment for electronics**: saltwater and ship movement in combination with heavy machinery on board. Data storage failure is often related to software related issues. Although, few studies described situations of storage failure due to insufficient management of exchanging hard drives: full drives were not replaced in time. **Logistical challenges of changing hard drives** can be encountered when vessels enter remote ports. The primary reported reason for EM data loss is obstructed view, caused by dirty or wet (droplets) lenses. The principal problem is 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, cameras are directed at the catch sorting areas. However, the working space on board fishing vessels is generally extremely limited with low ceilings, and it can be difficult to position a camera in such a way that a wide, clear and undistorted view of the sorting area is enabled without the risk of water and fish waste splashing up onto the cameras (Bergsson et al., 2017; Needle et al., 2015; van Helmond et al., 2020). 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 (MMO, 2013b; Needle et al., 2015; van Helmond et al., 2020). Van Helmond et al. (2017) concluded that **more emphasis** should be put **on the importance of camera maintenance** on board by the fishing crew (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 and **understanding the need for clean lenses** and maintenance of EM equipment.

4.4. Catch estimation and species identification

Different **procedures** have been used **for estimating catch quantities** from EM footage in different studies. One approach requires crews **to sort discards into baskets** and show the baskets to the cameras before discarding. Viewers estimate discard quantities by counting the number of baskets (Ulrich et al. 2015). This approach **relies on consistent and thorough sorting** of the catch by the fisher crew. Another approach aims to **estimate discards directly on the sorting belt** where possible, also named the “on the band” estimation method. This is a **less invasive** catch estimation method because crews do not have to alter their workflow, but is **challenging from the review perspective** with estimating large volumes of catch (van Helmond et al., 2020). The use of the “on the band” estimation method is thus prompting the development of **machine learning technology to automated image analysis** (French et al., 2015, 2017) and automated counting of fish. One study used a simple protocol in which **individual specimens were arranged and clearly displayed** on the sorting belt in front of the cameras after the catch was processed (Figure 10). This was used for scientific purposes, but would be a **considerable burden on the crew** when implemented on larger scale (van Helmond et al., 2017).

Figure 10: Displaying fish according to protocol

Source: van Helmond et al., 2017

Overall, most studies demonstrated good results for species identification. **Good overall agreement between onboard records and video observations**, for **relatively large species** like North Sea cod, was shown. This species was easy to identify on video and was frequently the main objective in EM trials. Although, estimates of smaller quantities of cod in **highly mixed catches** were **often less accurate** than larger quantities of cod in clean catches, i.e. not mixed with other species (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. Also, other studies found **a tendency of EM in underestimating discards and smaller fish** (e.g. sole below 24 cm) compared with on-board observations (van Helmond et al., 2017; Mortensen et al., 2017). The accuracy of video observation should be monitored and improved where needed (Needle et al., 2015; Ulrich et al., 2015; van Helmond et al., 2020).

There is potential for **improving species identification** in EM by **making use of computer vision technology**. Machine learning applications based on **deep learning with neural networks** are under development (French et al., 2015; Allken et al., 2018). Remarkably, one study points out that the performance of **algorithms** in recognising different ray species on digital images, is potentially **more accurate than the human review** of ray images (Nguyen et al., 2019).

In the context of a landing obligation, the English trials observed **that EM was even more suitable as a control tool when no discards of any sort are allowed**. It is more difficult to monitor and control discards that need to be quantified and reported at species level, rather than controlling that no discarding takes place at all (assuming that there are no blind spots) (Dörner et al., 2015; Ulrich et al., 2015).

4.5. Costs

The average price of preparing a fishing vessel for EM, based on the review of European pilot studies, **varies between 10 000 and 19 500 EUR** (Table 5). This includes EM equipment, installation, analysis computer, staff training, and installing equipment. In the reviewed trials EM systems typically lasted between 3 and 5 years. In addition, annual **running costs** that include **data transmission** costs, **maintenance** costs, **data review** and **software licences**, but exclude data analysis cost by experts, are

needed. **An important driver of the running costs is the manual exchange of hard drives** on board to store the collected information, e.g. video footage. Reported total running costs for systems where hard drives needed to be exchanged manually were in the order of **EUR 4 000 and 6 500 per year and vessel** (Table 5). If data transfer is arranged by manual exchange of hard drives by scientific staff, the costs for this transfer will be a considerable part of the running costs. Making use of **local facilities**, like service points in harbours, will **significantly reduce** these costs. Also, the transmission of data by 4G network allows costs on data transfer to be considerably reduced, down to about EUR 100 per year and vessel (Mortensen et al., 2017). However, the transmission costs depend on the quantity of data, the operation area of the vessel and the possibilities to transmit data (van Helmond et al., 2020).

Table 5: Estimated installing and annual running costs for EM per vessel, in EUR

Pilot study	Installation costs (EUR)	Annual running costs, excluding data analysis (EUR)
Danish trial on Fully Documented Fisheries	10 200	4 100
Scottish catch quota management trial	19 155	6 500
English Catch Quota Trial	11 735	2 640
Dutch North Sea cod catch quota management trial	10 000	4 000

Sources: van Helmond et al., 2015; Kindt-Larsen et al., 2011; MMO, 2013b; Needle et al., 2015

Plet-Hansen et al. (2019) estimate the initial costs of fitting all Danish vessels above 12 metres in length (**396 vessels**) with EM to be **3.3 million EUR** and estimate the **total running costs** to be **1.7 million EUR annually**. Calculations were based on an EM setup that originates from 2016, with an average devaluation period of 3 to 5 years. Needle et al. (2015) concluded that, although the **initial costs of EM are high**, EM is a **more cost-effective** monitoring method than an onboard observer programme **in the mid-to long term**. **EM running costs are much lower than onboard observers** (van Helmond et al., 2020). In addition, Needle et al., (2015) concluded that for **the same monitoring budget EM would allow for a wider sampling coverage and improve truly random sampling schemes**. In the situations where EM is used to validate self-reported catches or discards (a so called audit model), another important, often not recognised, aspect regarding the cost-benefit of EM will become apparent: the involvement of fishers in reporting their catches. 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 internalised by fishers** (James et al., 2019). It should be noted, however, that these cost analyses were based on EM trials and not based on large-scale monitoring programmes (van Helmond et al., 2020).

The **funding for fully operational EM programmes** varies between the different programmes and countries. 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 (the National Marine Fisheries Service – NMFS) and fishing industry. In Alaska, a **combination of federal and industry funds** is used for EM deployment, but this too will transition to 100% industry funding over time (van Helmond et al., 2020).

4.6. Data review and timeliness

EM collects thousands of hours of video footage and requires 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 were systematically trained to recognise species and to operate the EM software (van Helmond et al., 2020). **The data 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 visualised 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 but 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 et al., 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; van Helmond et al., 2020). This **‘audit approach’**, a random validation of logbook recordings, is commonly used around the world, **but requires involvement of fishers**. Meaning, the actual data on catch/discards is collected by fishers and only a small (random) selection is validated with EM information. Collecting detailed information on other catch components, e.g. discards of other species, which are normally not recorded can cause a significant amount of extra workload to the crew (Ulrich et al. 2015; van Helmond et al., 2017).

The levels of monitoring coverage varies among the different programmes: some programmes have **100% EM coverage** of all trips on board all vessels. Other programmes 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 programmes, for example in the Alaskan small boat fixed gear fishery.

A complete review of all footage for one trip can result in prohibitively long review times. For example, **attempts to identify all fish and invertebrates discarded** from one Scottish trawler trip to 1 week and data analysis took 3 months (Needle et al., 2015). Such an approaches would clearly not be sustainable for ongoing monitoring purposes and budgets (van Helmond et al., 2020).

4.7. Lack of policy and standards

International agreements or published policies and standards, in for example data exchange, were not encountered during the review. **The lack of data and quality assurance standards** of EM were already expressed in New Zealand for monitoring interactions between threatened, endangered and protected species (Pierre, 2018). Also, the **development of training materials**, e.g. catalogued photos and videos, to **improve data and review quality standards** should be supported. A platform, like the established expert working group on Technology Integration for Fisheries-Dependent Data (WGTIFD) of the International Council for the Exploration of the Sea (ICES), could play an essential role in developing policies and standards.

On board protocols and standards, e.g. to improve video review and catch registration, are tested and evaluated in several studies. **Fishers were able to follow these 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, following protocols could be a **burden for the crew**, as it interferes with and **adds time and workload** to the normal workflow on board (Ulrich et al., 2015; van Helmond et al., 2017).

EFCA (2019)¹ published a **guidance document** on the minimum technical requirements and standards for EM systems which could be used as a tool to monitor and document compliance with the landing obligation in EU fisheries.

4.8. Data integrity

Currently, one of the more challenging issues for EM is the **management of data ownership** and **privacy concerns** related with the collected information. Managing the **large volume of privacy sensitive data** that EM generates requires thoughtful decisions about how to store data, for how long, who will be able to access the data and how often. **The longer the storage time, the higher the costs**. For example, annual data storage costs of the HMS EM programme (122 vessels involved) were estimated at 194 000 dollars in 2016 (Michelin et al., 2018).

Efficiently dealing with **data management and integrity** for larger EM programmes requires **large IT infrastructures**. EM generates **large volumes of video data**, which requires considerably more **storage capacity** than for example VMS, AIS or e-logbook information. The **lack of experience** of fisheries management agencies in setting up these infrastructures, and hesitance to commit to this effort, potentially **hinder EM implementation** (van Helmond et al., 2020).

Examples of data tampering were not encountered in the review.

4.9. Data integration

With the potential to enhance data collection programmes, **EM has the ability to improve management and stock assessment**. In particular, the assessments of **data-limited stocks (DLS)** could benefit from applications like EM, the cost-efficiency and the wider monitoring coverage of the fleet enabling **data collection from less abundant species or specific fisheries**, for example long-distance or small-scale fisheries. However, other biological information, such as 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 to a lesser extent possible with existing EM systems. An alternate possibility would be to continue the **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; van Helmond et al., 2020).

While EM has primarily been a management-regulatory-driven tool, there is growing interest on the **potential market benefits** that EM can provide the **fishing and seafood industry**. EM can validate compliance with buyer requirements, e.g. sustainability demand, legality, and can also be a tool to support eco-certifications. **Traceability in seafood supply chains** has received increasing attention over the past several years. **Linking EM with traceability systems** will allow for complete and transparent from net-to-plate origin stories (Michelin et al., 2018).

¹ European Fisheries Control Agency (2019) Technical guidelines and specifications for the implementation of Remote Electronic Monitoring (REM) in EU fisheries. EFCA key document, Vigo, Spain. 43 pp.

Other areas of interest of EM integration are **verification of compliance** with **international trade standards** or regulations, e.g. verify the source and legality, prove the effectiveness of **bycatch mitigation** measures. EM can potentially also facilitate **accident** investigations, **claims** processing, and **liability reduction**, and potentially integrate EM in **insurance policies** (Michelin et al., 2018).

5. CONCLUSIONS

KEY FINDINGS

- **More than twenty EM trials** were **successfully completed** within the EU.
- **None** of the EM trails evolved into a **fully integrated EM programme**.
- Experience and lessons learnt should be used for **implementation of EM on a larger scale** in European fisheries in support of the **EU landing obligation**.
- **Innovation of EM** is still ongoing in the EU. In line with the current developments, **computer vision technology** is the logical next step to facilitate EM implementation.

This report summarises the current **state-of-play of EM globally** and provides the most **up-to-date and detailed status of EM in Europe**. However, it should be kept in mind that it was a challenge to include all EM undertaken worldwide as some trials may never be documented, while others may not yet be documented because of a time delay in reporting results (van Helmond et al., 2020). Moreover, as **EM is still in development**, direct comparison between studies is not always straightforward. Consequently, it is not always possible to compare results from studies undertaken twenty years ago to those from more recent studies.

5.1. The absence of an EU Electronic Monitoring programme

EM has been successfully implemented in several different regions around the globe. Currently, EM programmes in Alaska, British Columbia, West and East Coasts of the United States, Australia and Chile, are already well developed with **comprehensive sampling schemes covering up to 100% monitoring of fleets**, in some cases involving hundreds of vessels and thousands of fishing days.

Within the EU, **more than twenty EM trials** were **successfully completed**. The majority of the trials presented similar **positive outcomes** on the potential of EM for **science, management and control**. However, so far, **no fully implemented EM programme** exists in the EU. Some of the CQM trials were implemented for several years on multiple vessels, but **never evolved into permanent management schemes**. In retrospect, Ulrich et al. (2015) realised that the final status of the **Danish** case, which was initiated as a **scientific trial** with, eventually, national and EU-wide management implications, was not clearly defined. In this particular case it would have been better to **clarify the distribution of responsibilities** between scientific and control institutions to ensure an adequate programme structure (Ulrich et al., 2015). Like the Danish case, the **trials in the other EU countries** (United Kingdom, the Netherlands, and Germany) were, at least initially, managed by **research institutes** with the objective to investigate the efficiency and possibilities of EM in a **scientific** context. It was not intended to transform these trials into long term **management** schemes. When the trials were designed, **long term solutions** for data storage and access, legal obligations to keep or delete video data, standards and protocols of estimation methods, selection procedures of fishing activities (e.g. hauls) to validate logbooks with EM, integration of EM with other sources of information (e.g. e-logbooks), were **most likely not considered**. Still, during these trials, of which several are still ongoing, important **lessons are learnt** and **valuable information is collected**. The gained knowledge can be used for **wider implementation of EM on a larger scale in European fisheries** in support of the CFP and the landing obligation.

5.2. Valuable lessons learnt from Electronic Monitoring trials

The presented case studies show that **commitment of fishers is crucial for a proper EM implementation**. Fishers need **to conform to the operational practices on board** to facilitate the success of EM. This involves the obvious practical aspects, such as **maintenance** (e.g. clean camera lenses), but also, in case EM is used to validate discard recordings, extra sorting and weighing. This **extra workload** can be a burden for the crew and possibly requires additional personnel on board when it involves multiple species.

EM is very **accurate in detecting larger fish** in the catch (Needle et al., 2015; Ulrich et al., 2015; van Helmond et al., 2015; Mortensen et al., 2017). However, EM seems to have its **limitations** in accurately detecting **smaller species or individuals**. Consequently, in the context of the landing obligation and the requirement to record all catch, including discards, **further work** on development is still needed. Improving **image quality**, development of **review technology** or **computer vision technology** are possible solutions.

EM generates **large amounts of video data**. Manual review is **labour intensive**, even if only a random selection of the collected footage is reviewed. **Computer vision technology** is a possible solution to facilitate **processing large amounts of EM data**. Even more, fast data processing allows for direct automated image reviewing on board. In other words, with this technology in place **real-time catch 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).

The majority of the participating fishers in the EM trials were **positive and supportive** or at least did not display strong antipathy against EM. However, one should consider that, for some trials, **strong incentives to participate were provided**, e.g. extra quota. Although, the worry of not having an equal playing field, in case EM was not implemented on the entire fleet or at international level was mentioned. In contrast a strong **objection against EM was observed with fishers without any EM experience**, i.e. never participated in one of the EM trials. **Mistrust** and the level of **intrusion** caused by the feeling of **constant surveillance** were identified as main reasons (Plet-Hansen et al., 2017).

Other **incentives** than quota uplifts, could also be **good motivators and gain support for EM** in EU fisheries. For example, experiments with increased **flexibility** in gear choice (Mortensen et al., 2017), implementation of individual transferrable quotas (Stanley et al., 2015), **data ownership**, increased **transparency** (Michelin et al., 2018), **permission** to enter closed areas (Needle & Catarino, 2011) have proven incentives can make EM successful.

6. POLICY RECOMMENDATIONS

KEY FINDINGS

- Support **innovation** of EM, e.g. improved species identification, computer vision technology, data processing.
- Build on fishing **industry support for EM**.
- Create a **European infrastructure** to facilitate **EM implementation**.

The following policy recommendations may help to improve the implementation of EM for EU fisheries:

6.1. Support the development of technical innovation in Electronic Monitoring

- **Improve the efficiency of EM in detecting smaller specimens**, i.e. discards in large catch volumes.
- **Support research on species recognition through computer vision technology** (e.g. machine learning, deep learning, and convolutional neural networks) as this will make EM implementation possible **on a larger scale**.
- Create a pan European **data base on fish and catch images**; a data base with correctly identified and annotated fish species accelerates the process of **developing algorithms**.
- **Facilitate networking** between fisheries research, EM providers and robotics, e.g. (technical) universities and the private sector. Because the use of computer vision technology is new in fisheries research (and management), experts of the different disciplines need to become acquainted with each other.
- **Develop strategies** to process **large amounts of EM data** (video data).

6.2. Build fishing industry support for Electronic Monitoring

- Provide support for **better communication on EM between all stakeholders**. Currently there is a lot of **mistrust** between **fishing industry** and **control agencies as regards EM**. Regularly, current exchange platforms do not include all relevant stakeholder parties (i.e. industry, management, national control authorities, NGO's, EM providers, science, technology, IT) that are involved in EM.
- Demonstrate **EM benefits** and **best-practise examples**. The primary benefits of EM is improved data quality, which enables more efficient management, e.g. near real-time, increase transparency, more flexibility around regulations (including the landing obligation).
- Develop “win-win” scenarios through **alternative uses of EM data**. This could include use for stock assessment, e.g. data limited stocks, but also information that is directly beneficial for fishers. Support development of applications data support fishing operations, e.g. locate discard hot spots, business analytics.

6.3. Create an European Electronic Monitoring infrastructure

- The implementation of EM on a large scale requires large **IT infrastructures** to deal with the **large amount of video data** that EM generates. Such an administration should support data transmission, data storage and data review.
- **Create guidance and policy standards** around EM, considering specific legislative **EM data matters**, e.g. privacy, ownership, storage, data access, delete and keep information, evidence, etc..
- Create expert **working groups or committees** representing all stakeholder parties when **implementing EM on a particular fleet or fisheries**. Stakeholder representatives should not only contribute with advice but also decide on information and data requests to address real needs and constrain unnecessary requests. A more regionally targeted approach, with regional working groups, are potentially better fit to deal with regional trade-offs.
- Provide **legal requirements** and **governing framework** for members states to implement EM as at-sea sampling scheme.

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ANNEX

Table A: EM equipment and service vendors

Vendor	Overview
Anchor Lab	Anchor Labs is based in Copenhagen, and its systems have been used primarily in trials in the EU.
Archipelago Marine Research (AMR)	Based in Victoria, British Columbia, AMR was the first vendor of EM systems and accounts for roughly half of the EM systems installed globally. Key markets include Canada, the US, and Australia. Recently, Archipelago transferred all of their EM products to Marine Instruments who, going forward, will develop and manufacture the systems while Archipelago will focus on the services of design, development, and implementation of EM programs.
Digital Observer Services (DOS)	Digital Observer Services is an EM service provider and partners with Satlink to do video review and data processing.
Ecotrust Canada	Ecotrust has EM programs in place in Washington State's Quinault crab fishery (~25 vessels) and the New England Groundfish fishery (~7 vessels).
Flywire	Based in Hawaii, Flywire is focused on low-cost systems that were designed to serve small-scale fisheries; it has systems in Mexico, Indonesia, Peru, and the US Gulf of Mexico.
Integrated Monitoring	A newcomer to EM, Integrated Monitoring's founder brings expertise from the telecom and satellite communication sector. A key focus of this company is downscaling data on-board vessels for real-time data transfer.
Marine Instruments	Marine Instruments is focused on the design and manufacture of electronic equipment for the fisheries sector. In 2017, the company entered into a partnership with Archipelago and will focus on hardware design and manufacturing in this arrangement.
Pelagic Data Systems	Although not making camera systems, this company is on track to install around 10 thousand cellular-based location tracking devices on small-scale vessels in the developing world in the next 1-2 years.
SatLink	Based in Spain, SatLink works primarily with tuna vessels. The company has about 140 EM systems in the field, mostly in the Western Central Pacific.
Saltwater, Inc.	Saltwater has EM systems in a variety of fisheries and is the vendor for the US Atlantic HMS fishery as well as the Alaska pot cod and Alaska small-boat fixed gear fisheries.
Shellcatch	Shellcatch produces low-cost cellular-based video systems for small-scale developing-world vessels. The company has about 300 systems in place throughout Latin America, which are used primarily for marketing purposes.
SnapIT	Based in New Zealand, SnapIT has a foothold primarily in its domestic market. The company is currently focused on software enhancements to help with data processing and transmission.

Source: Michelin et al., 2018

This study is the second research paper in a series of three, prepared for a PECH Committee Workshop. It provides a global overview of the latest developments, as well as potential benefits and risks of Electronic Monitoring (EM). Worldwide experiences with EM are discussed in light of the European context. During the period 2008 to 2019, altogether 26 EM trials were conducted within the EU. Despite promising results, none of the trials evolved into a fully integrated EM programme. Still, lessons learnt from these trials are valuable and show potential for implementing EM on larger scale in the EU.

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