STUDY
Requested by the PECH Committee

Workshop on electronic technologies for fisheries

Part III: Systems adapted for small-scale vessels

Fisheries

Policy Department for Structural and Cohesion Policies
Directorate-General for Internal Policies
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RESEARCH FOR PECH COMMITTEE

Workshop on electronic technologies for fisheries

Part III: Systems adapted for small-scale vessels

Abstract

This study is the third research paper in a series of three, prepared for a PECH Committee Workshop. It examines and presents possibilities of electronic technologies (ET) that can be used to report, document and monitor fishery activities of the small-scale vessel fleet. The national fishing fleets in the EU are large where most of the vessels are less than 12 metres in length. The information on this fleet segment's fishing activities is limited and insufficient for documentation of the fleet's impact on the environment and for fisheries management and governance in general. The present research contains four case studies with current usages of such technologies developed for small-scale vessels.

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

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AIS	Automatic Identification System
BB R2	Black box R2 system (Anchor Lab. EM sensor system)
BLE	Federal Office for Agriculture and Food (of Germany) *(Bundesanstalt für Landwirtschaft und Ernährung)*
CCTV	Closed-circuit television
CFP	Common Fisheries Policy
DCF	Data Collection Framework
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DTU Aqua	National Institute of Aquatic Resources, Technical University of Denmark
EM	Electronic monitoring
ET	Electronic technolog(ies)
EU	European Union
FDI	Fisheries Dependent Information
GDPR	EU General Data Protection Regulation
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICES	International Council for the Exploration of the Sea
Mofi	Mobile fisheries log
MSFD	Marine Strategy Framework Directive
NGO	Non-governmental organisation
PET	Protected, endangered and threatened (species)
REM	Remote Electronic Monitoring

RFID	Radio-frequency identification
RFMO	Regional Fisheries Management Organizations
SSF	Small-scale fisheries
TAC	Total allowable catch
UI	User Interface
VMS	Vessel Monitoring System
3G	Third generation of broadband cellular network
4G	Fourth generation of broadband cellular network

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EXECUTIVE SUMMARY

KEY FINDINGS

- **Electronic Monitoring (EM)** systems using **closed-circuit television (CCTV) cameras** and various sensors can also be used on vessels below **12 metres**.
- **EM sensor systems** can record detailed information on **all length classes** fishing vessels.
- The **use of tablets and smartphones** as a tool for recording fishing operations and as logbook and report tool can **prevent data deficiencies**.
- The **use of EM** can improve possibilities for **monitoring compliance** with *e.g.*, the landing obligation (LO).
- **Electronic technologies** (ET) are cost-effective to **monitor compliance** in small-scale fisheries (SSF).

Background

The **small-scale vessel fisheries (SSF)** are playing an **important** socio-economic and cultural **role** in European waters and coastal communities, but in terms of **monitoring and control** they have generally been **neglected** in Europe by fisheries scientists and fisheries managers at national and European Union (EU) level. In general, the SSF segment can be characterised as a fisheries fleet segment providing **insufficient information** on its fishing activities for **sustainable management** of the EU fisheries and the marine ecosystem.

In the EU fisheries, only vessels above the length of **10 metres** are obliged to fill in a **logbook** and only vessels above the length of **12 metres** are obliged to use **VMS** (Vessel Monitoring System). Furthermore, for both obligations there are possibilities for **exemptions**. The management and the development of the small-scale EU fishing fleet – where **no or limited information** on fishing **effort**, use of fishing **gear**, **location** of the fishery and on what has been **caught and landed** exist – is not optimal.

Usages of electronic technologies for fisheries control and monitoring

Worldwide, ET are increasingly being deployed to improve fisheries **monitoring** in **all types of fisheries**. The use of camera-based Electronic Monitoring (EM) systems including CCTV (closed-circuit television) cameras, gear sensors and advanced data analysis can provide **full documentation** and accountability for **fishing activities**. The use of EM and other electronic devices generates several benefits, such as **high levels of compliance** and documentation of **fishing practices**. For the SSF fleet, the **use of tablets and cell phones** for electronic reporting and monitoring has **developed significantly** over the latest years in many parts of the world.

Fixed **video-based EM systems** installed on fishing vessels offer a cost effective and 24/7 monitoring **alternative to independent fisheries observers** to collect data in SSF. Video-based high-resolution data makes it possible to **estimate accurately** *e.g.*, **compliance** with the LO, discard activities and incidental bycatch of protected, endangered or threatened (PET) species.

Observer coverage in the SSF is traditionally **low**, and there is often a **lack of information** on the spatiotemporal distribution and intensity of fishing effort. Implementation of video-based EM systems in the SSF can become an important tool to assess the **impact of SSF on marine ecosystems** in the EU.

Non-camera **EM sensor systems** provide high-resolution fishing data by **recording vessels' fishing activities**, which result in better control and surveillance of the fisheries. The implementation of EM sensor systems on **bivalve fishing vessels in Denmark** has **increased accuracy and transparency** of fishing activities. Combining the **EM sensor data** with **logbook information** provides the possibility of **fine-scale mapping** and assessment of actual area impacted by each individual fishing activity with a **very high** temporal (10 seconds) and spatial (below 10 meters) **resolution**.

EM systems have, within the **EU, mainly** been installed on **larger vessels**. However, **EM systems for SSF** have been developed and are implemented for large scale use in **Latin America** with more than **600 vessels** being **monitored in 2021**. The systems are fitted specifically for the small vessels in terms of power use, mounting and data upload.

Most Europeans own a smartphone or a tablet nowadays, and these **portable devices** offer an ideal platform to **develop monitoring solutions** for SSF for which space and power onboard are often limited. The ease of use and versatility of **apps can speed up and facilitate tasks** like reporting the fishing activity to the authorities. Replacing **logbooks** and **landing declarations** using **data recorded semi-automatically** on a smartphone/tablet can be a **strong incentive** for fishers.

When available, **apps can enhance fishing procedures**, without the need of dedicated computer software to run on the vessel. This is of **particular interest** on small-scale **artisanal fishing vessels,** which cannot accommodate such equipment onboard for a lack of space or power, or simply because it would be too expensive. A major **advantage of apps** compared to, e.g., fixed or mobile EM systems is that they can be used on literally **any vessel**, regardless of size, provided the fisher carries a smartphone or tablet. The **costs of implementing** such systems on a large number of vessels, be it for management, scientific monitoring or control purposes, is therefore **below the one of all the other ET solutions** presented in this report, without necessarily losing much in resolution and accuracy. For **very small vessels** operating in European waters, the **generalisation of apps** combining fishing activity monitoring, logbook and landings declarations could conveniently **replace pen and paper** in the future, thereby enhancing considerably the **quality of fishery-dependent data.**

Policy recommendations

Small-scale vessel fisheries play an **important socio-economic and cultural role** in European coastal communities. In terms of **monitoring and control**, SSF have generally been relatively **neglected in Europe** by fisheries managers and fisheries scientists both at national and EU level. In European waters, SSF often provide **insufficient information** with regards to fishing activities for ensuring a sustainable management of this fleet segment and of the marine ecosystem. Based on the present review, we have come up with a short list of global **policy recommendations**:

- For **monitoring** compliance with the LO, fishing vessels in SSF could be equipped with **video-based EM systems**, as those described in **case studies I** and **III**. It is recommended that video-based EM systems are installed on all the vessels using **mobile gears**, as this is the **fleet segment** with the **highest risk** of non-compliance with the LO. To limit the workload for EM analysts and reduce the cost, it is advised that **national competent fisheries authorities** analyse a subset of the entire EM data that are collected. For instance, only a **random selection** of 10 % of the entire **fishing activity** could be reviewed for any **discard** of species with a **total allowable catch** (TAC) as portrayed in **case study I**

- In fisheries with low discard or bycatch risk, such as **dredge fisheries** for bivalves or low impact fisheries using *e.g.*, **pots** or **handlines**, video-based EM is likely unnecessary, but it is recommended to **monitor the spatiotemporal** distribution at a fine-scale for control but also for **documentation** of important **fishing grounds**, using for instance an **EM sensor systems** – or a similar technology – as is described in **case study II**.
- In fisheries where there is a suspicion of **high-risk of incidental captures** of **PET species**, including marine mammals, birds, chelonians, as well as **non-commercial fish** and elasmobranchs, it is recommended that at least a **representative sample** of the fishing vessels in the fleet carry a **video-based EM system**, such as the ones described in **case study I** or, *e.g.*, for small open boats, the technology described in **case study III**.
- The current requirements for documenting fishing activities in EU fisheries using traditional **paper logbooks** for vessels below 12 meters (10 metres in the Baltic Sea) have been **outdated** for several years. It is recommended to gradually generalise the utilisation of **tablet or cell phone apps** specifically designed to fulfil the EU reporting requirements. These apps, such as some of the apps listed in **case study IV**, should be available in the fishers' **native language**.
- Finally, it is recommended that, for all length classes, individual vessels **identity** and fishing **activity** are accessible at the **finer possible spatiotemporal scale** to the competent authorities and to the national scientific bodies responsible for the scientific advice.

Data alone will not result in more sustainable fisheries, and data themselves will not lead to better decision-making, but they are a key component of an **effective ecosystem-based management** in EU waters. It is of course a **challenge for fishers** and especially for small-scale vessel fishers to adopt and afford new technologies for monitoring and reporting fishery-dependent data. Therefore, **financial support** will be necessary when implementing electronic technologies in the SFF, for instance through the **European Maritime Fisheries and Aquaculture Fund (EMFAF).**

1. INTRODUCTION

KEY FINDINGS

- The European Union **small-scale fishing fleet** (vessels below 12 metres) consists of approximately **70,000** vessels representing about **85 %** of the total EU fishing fleet.
  - The small-scale fishing fleets **total annual landing** of fish and shellfish amounts to approximately **0.4 million tonnes** (out of a total 5.4 million tonnes for the entire EU fishing fleet). *or give a percentage like in the bullet point above.*
- In general, the **small-scale fleet** segment is characterised as a fleet segment not providing sufficient information on its **fishing activities** for sustainable management of the fisheries and the **marine ecosystem**.

The EU fishing fleet is large and scattered along the littorals of 22 Member States. The EU fishing fleet operates in the Baltic Sea, the North Sea, the Arctic, North Western Waters, South Western Waters, the Mediterranean and Black Sea, Outermost regions, third country waters and areas under purview of Regional Fisheries Management Organizations (RFMO's).

The EU fishing fleet consisted in 2019 in total (UK included) of 81,253 fishing vessels that landed (UK included) in total 5.4 million tonnes (European Commission, Directorate-General for Maritime Affairs and Fisheries, 2020). The small-scale fleet (vessels below 12 metres in total length) amounted to 69,480 of the vessels and they landed 0.4 million tonnes (FDI database[1]). The majority of these vessels are operating in the Mediterranean.

The small-scale vessel fisheries play an important socio-economic and cultural role in European waters and coastal communities. However, they have generally been neglected in terms of monitoring and control in the EU by fisheries scientists and fisheries managers at national and EU level. This is probably because of their relatively small share of the total landings despite the fact that this fishing fleet segment is playing an important socio-economic and cultural role.

It is a challenge for the management of EU fisheries, that only vessels above the length of 10 metres are obliged to fill in a logbook and that only vessels above the length of 12 metres are obliged to have and use VMS. Furthermore, for both obligations there are possibilities for exemptions. The management and the development of the small-scale EU fishing fleet – where no or limited information on fishing effort, use of fishing gear, location of the fishery and on what has been caught and landed exist – is not optimal. In general, the small-scale fleet segment can be characterised as a segment providing insufficient information on its fishing activities for sustainable management of the fisheries and the marine ecosystem.

In some EU Member States, vessels below 10 metres are required to register and report their fishing activity in modified logbooks *e.g.*, in Sweden and France. Regardless, of which alternative logbooks are used, or whether recordings are made weekly or monthly, these logbooks are filled in after landing and sale. Moreover, the small-scale fleet segment is the fleet segment where it is common that catches are sold directly to private consumers without having a third-party verification of the weight of the landings. Even though all vessels should report landings by submitting landing declarations to the national competent authorities, some uncertainty on total landings exists.

1 See: Fisheries Dependent Information https://stecf.jrc.ec.europa.eu/dd/fdi.

Spatial restrictions (i.e., restrictions on where fishing can take place) are often put into place with the intent of protecting spawning aggregations, fragile habitats, and marine biodiversity. Securing compliance to such restrictions can be controlled when fishing vessels are equipped with position recording devices such as VMS. Many vessels including smaller vessels also use Automatic Identification System (AIS) for security reasons but only fishing vessels above 15 metres in length are obliged to use AIS. As vessels below 15 metres can shut off the AIS, which they do from time to time to protect information of their fishing grounds, there is no or limited information on where the small-scale fleet is operating.

Limitation in logbook information, as well as in VMS or AIS information for the small-scale fleet, results in insufficient information on *e.g.*, fishing effort, temporal and spatial distribution of the fishery and limited possibilities for securing compliance of the fisheries.

Electronic technologies are increasingly being deployed to improve fisheries monitoring in all types of fisheries. The use of EM systems with cameras in industrialised fisheries is described by Michelin *et al*. (2018) and van Helmond *et al*. (2020). EM systems use cameras, gear sensors and advanced data analysis to provide full documentation and accountability for fishing activities. The use of EM and other electronic devices generates several benefits, such as high levels of compliance and documentation of sustainable fishing practices. Especially the use of tablets and cell phones for electronic reporting and monitoring for small-scale vessel fisheries has developed significantly over the latest years (Bradley *et al*., 2019).

The purpose of this report is to describe examples of electronic reporting and monitoring technologies that can be used specifically in fisheries carried out by the small-scale fishing fleet, and to show how surveillance and monitoring programmes using state of the art electronic technologies can be designed for any fishery.

The report focuses on technologies that can be used for documentation of the fishery and that are useful for monitoring compliance with fishery regulations such as catch limits, the landing obligation, fishing effort limits, compliance with closed areas limitations and to improve fishery yields, profits, and conservation performance.

To provide an overview of examples of exciting technologies that can be used to monitor or document fishing activities carried out by the SFF, four different technologies are presented in four case studies. The four case studies included in this report are selected because they all describe technologies that can be used by the small-scale fishing fleet in the EU for monitoring or can be used for documentation or reporting of fishing activities. Case study I describes one of the most advanced EM camera systems, optimal for medium-large sized SFF vessels (9 to 12 metres) for monitoring *e.g.* compliance with the landings obligation and to ensure full documentation of fishing activities including monitoring of all catches, discards and landings. Case study II describes a sensor-based EM system that can be used for detailed monitoring of fishing activities, *e.g.* where and when any fishing activity takes place. Case study III describes a simple and cheap mobile EM camera system that can be used for monitoring fishing activities of small open boats. This system can also be used for documenting catches. Case study IV describes the use of tablets and cell phones for electronic recording and reporting of catches including recording spatial distribution of fishing activities.

2. CASE STUDY I - ELECTRONIC MONITORING VIDEO SYSTEM

KEY FINDINGS

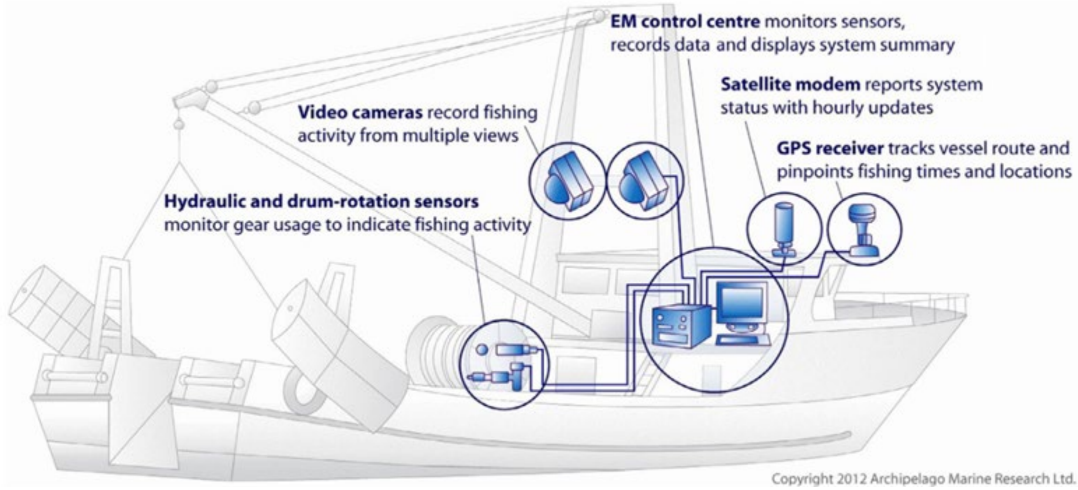
- Video-based EM systems **provide** high-resolution **fishing data** and allow documenting rare or **inconspicuous events**, including bycatch of PET species or discards.
- Video-based EM is a **cost-effective method** for fisheries **management** and **monitoring** that can complement fisheries observers and self-reported data in SSF.
- Video-based EM can enhance **surveillance of compliance** with *e.g.*, the landing obligation and make control and monitoring of SSF **more effective**.
- Evidence from video-based EM provides essential information to understand and assess the **impact of SSF on marine ecosystems**, *e.g.* bycatch of threatened taxa.

2.1. Aim of usage

For most of its long history, fishing has been a self-regulating industry. Since the second half of the twentieth century, the captures of wild fish and other target species have more than quadrupled globally (FAO, 2020), and the understanding of the natural processes at play in the ocean, as well as the impact of fishing on stocks, have made the monitoring of fisheries – what the fishing vessels catch, where, when and how – an essential task to regulate the potential negative impacts of fishing and ensure the sustainability of marine ecosystems.

In the EU, fisheries monitoring relies for a large part on fishers self-reported data, for instance through the use of official logbook and landings data. The reliability of these fisheries-dependent data has often been questioned and it is generally admitted that they must be completed with independent data collection programmes, *e.g.*, using fisheries observers. When monitoring for compliance with *e.g.* landing obligation other types of monitoring such as self-sampling is not regarded as reliable as it not an independent monitoring. However, for economic reasons and for sea safety reasons, in fisheries characterised by small vessels, the fraction of the fleet (or the fishing effort) that observers are able to monitor is generally low. The development of EM with cameras, which started more than 20 years ago in Canada, was originally seen as a solution to complete the work of observers. Electronic monitoring with video can record the details of the fishing activity of sampled vessels for prolonged periods. The cameras allow in theory to record every catch event and to link the fisher's declarations to the reality of their activity at sea (Figure 1). Besides, the recordings can be stored on dedicated data servers to be viewed as many times as necessary. This technology was gradually adapted to the specificities of small vessels, by reducing the size and power consumptions of the central units. A number of companies in North America, the Pacific region and in Europe have specialised in the development and commercialization of EM systems for fisheries, including solutions adapted to small fishing vessels. Electronic monitoring programmes for compliance purposes are well established in several countries, including the United States of America, Canada and Australia, and to a lower extent New Zealand, Chile, Peru or the United Kingdom (Michelin and Zimring, 2020) In the EU however, there has both from Member States and from the fishing industry been a reluctance to implementing the use of EM for full documentation and for compliance of EU fisheries. Denmark has played a leading role in demonstrating the interest of EM for European fisheries, *e.g.*, for monitoring discards in demersal fisheries and with the aim of testing whether EM could be a tool to ensure full accountability of all catches (Bergsson *et al.*, 2017; Dalskov *et al.*, 2012; Mortensen *et al.*, 2017; Plet-Hansen *et al.*, 2019, 2017, 2015) or for collecting information on the fishing activity of smaller vessels (Nielsen *et al.*, 2021).

Figure 1: General principle of an electronic monitoring system, showing the placement of cameras, GPS and sensors on a fishing vessel



Source: Archipelago Marine Research Ltd

In 2008, the National Institute of Aquatic Resources (DTU Aqua) started using a Canadian developed EM system[2] with videos as a tool to obtain exhaustive catch and discard data from fishing vessels, also known as "*fully documented fishery*" where catches of all species should be accounted for. (Dalskov and Kindt-Larsen, 2009). The success of this initial pilot study gave rise to several research projects, among which monitoring of incidental catches of PET in the Danish gillnet fishery, mostly comprising of small vessels below 12 metres in overall length.

In 2013, a Danish tech company[3], was selected to equip the vessels in the different EM programmes in Denmark. The Danish company had developed a full monitoring system for capturing video and sensor data onboard fishing vessels, the Black Box Video EM system, coupled with a powerful EM data analysing software (Figure 2). All sensor data and video footage is stored at the system onboard and can be pulled to a server on land when the vessels is in cell phone range. As of 2021, a total of 14 Danish gillnet vessels have been equipped with the Black Box Video system. Covering on average 2.3% of the yearly national fishing effort (in number of days at sea) of the commercial gillnet fleet, EM with video proved indispensable to assess the scale and distribution of incidental catches of marine mammals and seabirds in gillnets in Denmark (Glemarec *et al*., 2020; Kindt-Larsen *et al.*, 2012a). Since 2020, EM data collection with video aboard small commercial gillnet vessels has been integrated to the national DCF (Data Collection Framework) programme for Denmark, which allows to document the national gillnet fishery with respect to time, fishing locations, net lengths, soak times and number of bycatches.

2 See: Archipelago Marine Research Ltd

3 See: www.anchorlab.dk

Figure 2: Black Box Video Electronic Monitoring System

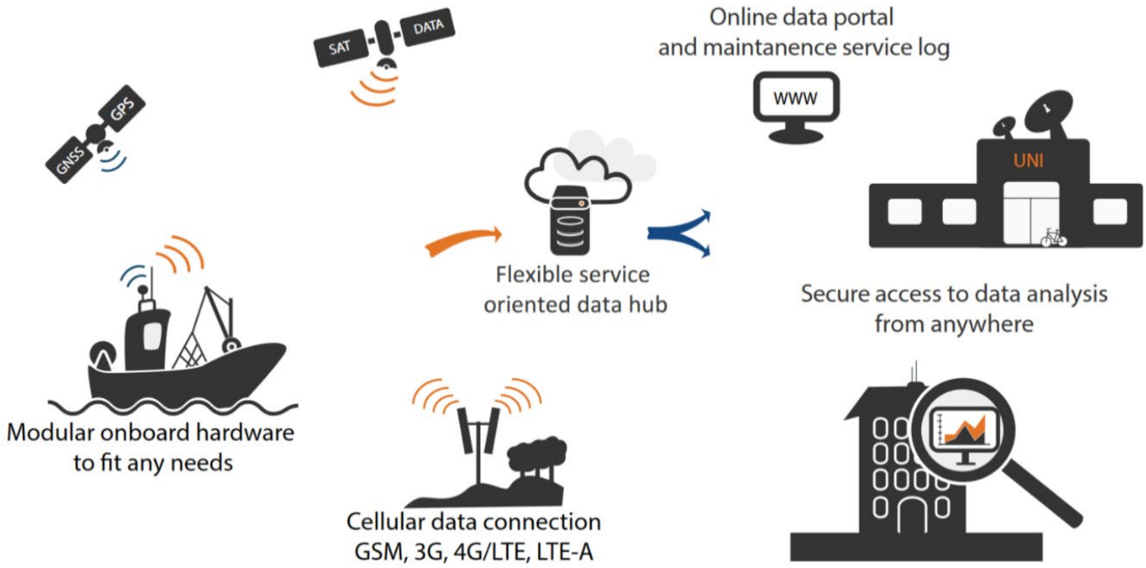
Source: Anchorlab

2.2. Description of the system

The Black Box video system[4] consists of a durable and flexible EM platform that integrates Global Positioning System (GPS) data, video data from up to 16 cameras and data from optional rotation and hydraulic sensors (Figure 2). The hardware, both the central unit and the associated sensors/cameras, are designed to ensure an "*always on*" capacity. Video and sensor data are stored internally and are transmitted automatically to a storage server over the air (Wi-Fi or cellular network) when the vessel is in a covered zone, *e.g.* a harbour (Figure 3). Video recordings start and end automatically whilst the fishing vessel is outside a harbour area to reduce the amount of data collected.

[4] See Anchorlab: http://www.anchorlab.dk/

Figure 3: Illustration of the principle of an electronic monitoring programme using the Black Box Video system



Source: Anchorlab

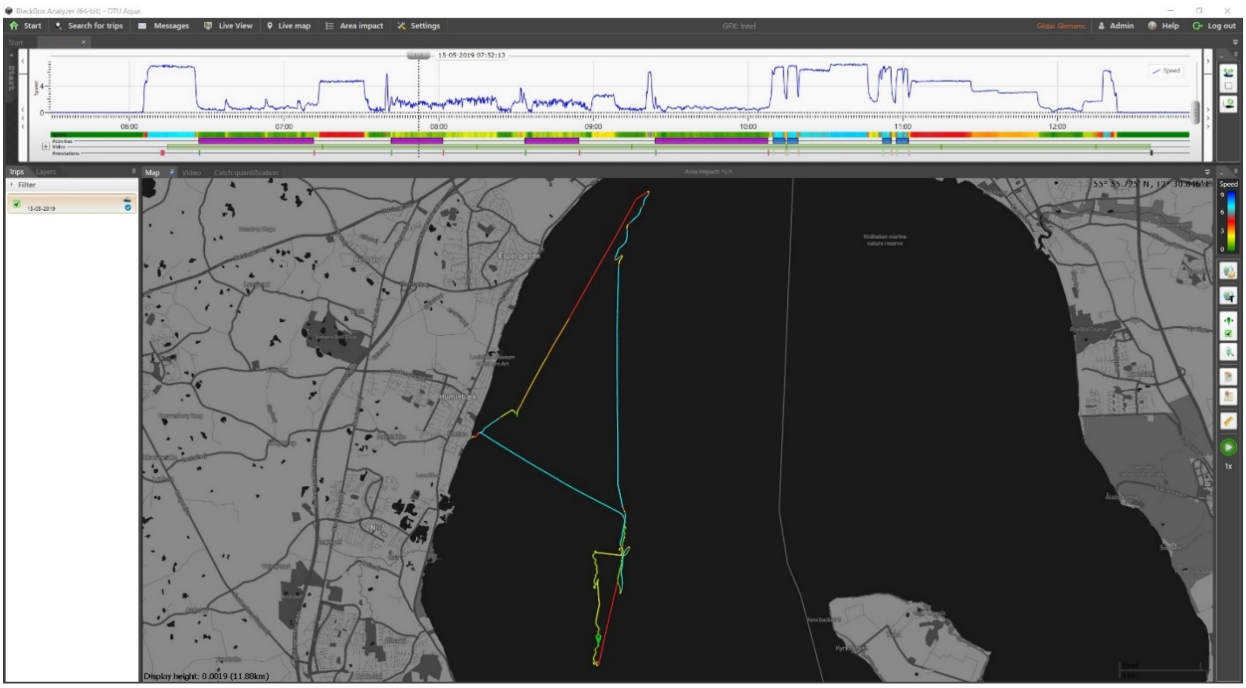
Anchorlab developed a powerful analysing environment for EM data with videos called Black Box Analyzer (Figures 4-6). Although it was designed to work in conjunction with Black Box EM systems, Analyzer is compatible with EM data from hardware designed by other companies. The software ensures efficient visualisation of the fishing trips, by permitting to review concomitantly videos from all cameras, GPS trace and a timeline on to which one can push in annotations. These annotations correspond to entries in a database and associate the time, position and speed of the vessel to user-defined numerical and categorical parameters. For instance, a fishing operation can be defined as a point in time or a state event. In the latter, the time and distance between the start and end point can be retrieved to estimate the duration and length of a fishing haul. The analysis of the video files can be done at various playback speeds, allowing to identify target and non-target species captured during the fishing process. The software permits to overlay a measuring grid on top of the picture and to estimate and store the length of the catches. If the user identifies the species, Analyzer automatically applies a length-weight algorithm to the specimen to estimate its weight. By the end of a fishing operation, the total weight of the catch per species can be easily retrieved from the dataset. Anchorlab is currently working on automatizing the analysing process by using different deep-learning techniques, including estimating commercial species automatically and flagging abnormal events, *e.g.*, bycatch of PET species.

Figure 4: Snapshot of an electronic monitoring analyser software

Source: DTU Aqua

Note: The on-screen information that could allow identifying the fishing vessel was removed from this picture. A) timeline indicating the instantaneous speed of the vessel; B) Annotations used for identifying fishing operations and bycatch events; C) Map with the trace of the fishing trip and the current position of the vessel; D) video footage (the arrow points to a common guillemot *Uria aalge* captured in the net).

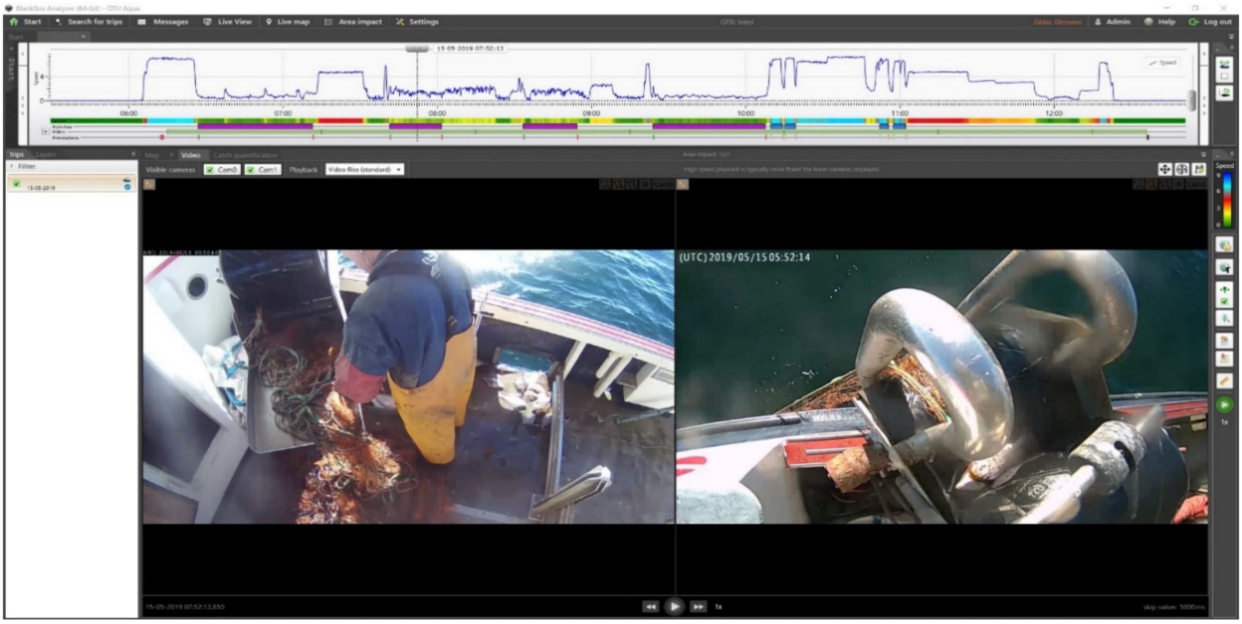
Figure 5: Map view in an electronic monitoring analyser software



Source: DTU Aqua

Note: Snapshot showing the GPS trace of a single fishing vessel during one day at sea. The colour gradient on the map indicates the speed of the vessel.

Figure 6: Video view in an electronic monitoring analyser software



Source: DTU Aqua
Note: Snapshot showing the video feed from two digital cameras during the hauling of a bottom-set gillnet

2.3. Evaluation of the system

Electronic monitoring with video is generally considered a cost-effective method for collecting accurate fine-scale fisheries-dependent data over extended durations. Unlike data from logbooks and landings registrations, EM with video can provide data at haul level on catch composition, possible discards, or bycatch of non-target species, among others (van Helmond *et al*., 2020). The comparative costs to collect the same data using human observers is in favour of EM, even in countries where wages are high (James *et al*., 2019). Furthermore, fisher-reported data, including self-sampling, are usually much cheaper to implement, but also often less reliable than EM (Mangi *et al*., 2015). The global cost of an EM with video monitoring programme is difficult to assess, as it is very case-specific: number and type of vessels to monitor, goals of the monitoring programme (*e.g.*, fully documented fishery, PET bycatch assessment), auditor's salaries, etc.

The possibility offered by EM with video to review the fishing activity of one vessel or an entire fleet in near real-time makes it a valuable tool to fisheries managers. For instance, spatially restricted temporal fishing closures can be enacted based on evidence from fishing vessels, or the fleet fishing effort can be displaced to avoid the bycatch of unwanted species (O'Keefe *et al*., 2014). Additionally, there is an evident interest for control authorities to use data from vessels equipped with EM. Using real-time EM data or historical records of the fishing activity, control authorities can readily check compliance to the local fishing rules or enforce their application. Conversely, EM systems can be used by fishers to demonstrate that they conform to regulations like spatiotemporal fishing closures (Nielsen *et al*., 2021). For fisheries with a paucity of information on the distribution and intensity of the fishing effort, as is the case for many SSF in Europe, EM with video offers a window of opportunities for assessing the impact of fishing on the ecosystems. For instance, the contribution of SFF to the bycatch of PET species is known to be high in Europe, yet many bycatch estimates are based on indirect evidence. The long-term monitoring of vessels in areas where the risk of bycatch is elevated with video-based EM provides data that are difficult if not impossible to acquire with traditional methods (Glemarec *et al*., 2020). Such data from SSF are essential to increase our understanding of the interaction between SSF and species, and to move toward an ecosystem-based management of SSF (Bartholomew *et al*., 2018).

2.4. Evaluation of the technology, timeliness, lack of policy and standards, data integrity and data integration

The benefits and risk when using EM video system for monitoring SFF are evaluated in relation to the following five overall categories: (1) technology, (2) timeliness, (3) lack of policy and standards, (4) data integrity and (5) data integration.

Table 1: Benefit-risk assessment of video-based electronic monitoring systems in SSF with regards to fisheries control authorities, fisheries/aquaculture professional sector and fisheries science

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(1) Technology (1st part)				
Proprietary vs. open-source software	Yearly costs for Anchorlab Analyzer software license to access the stored data. Data storage costs.	N/A	Yearly costs for Anchorlab Analyzer software license to access the stored data. Data storage costs.	Anchorlab permits downloading the data from the storage server to analyse them using alternative software.
Data transmission and interference	Automatic daily data transmission via Wi-Fi or cellular network to the authorities.	N/A	Automatic daily data transmission via Wi-Fi or cellular network to the authorities (if allowed in the project scheme).	
Power supply and system reliability	Dirt on camera lenses or other obstructions in the field of view can reduce video data quality. Power failure or hardware defect will often result in missing fishing activity. Real-time monitoring only possible in areas covered with GSM/3G/4G/Wi-Fi.	System uses the internal power of the vessel.	Dirt on camera lenses or other obstructions in the field of view can reduce video data quality. No data transfer if no GSM/3G/4G/Wi-Fi network is available.	Data are stored locally on the local high-capacity hard drive until transfer via GSM/3G/4G/Wi-Fi. Frequent contact with fishers is necessary to ensure they remember to keep camera lenses clean and unobstructed. Typically, cameras record at 5 frames per second at a resolution of 1360x768 pixels, but both framerate and resolution can be increased.

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(1) Technology (2nd part)				
Sensor integration	Documentation of actual fishing activities.		Documentation of actual fishing activities.	
Camera species identification	Possible during footage analyses.	In case of rare or vulnerable species captures, fishers can show the catch to the camera to ease up identification by EM analysts.	Routinely done in the bycatch monitoring programme.	Automatic identification is not implemented yet but is under development.
Weight accuracy/precision	Possible in industrial fisheries, but not adapted to SSF.	N/A	Possible in industrial fisheries, but not adapted to SSF.	Semi-automatic weight estimation from on-screen length measurements through a species-specific weight-length relationship. This only applies for vessels where the camera-fish distance is known and remains constant, *e.g.*, with the camera above the sorting belt on a trawler (van Helmond *et al.*, 2020).
(2) Timeliness				
Time to review/ process data	Hours to weeks depending on how many vessels and fishing activities need to be reviewed/processed.	N/A	Hours to weeks depending on how many vessels and fishing activities need to be reviewed/processed.	The time to review/process data depends on the project goals. If only the spatiotemporal distribution of the fishing effort is needed, the review process can largely be automated.
Delay in data availability	Data transferred at the end of each fishing trip (often daily in artisanal fisheries).	N/A	Data transferred at the end of each fishing trip (often daily in artisanal fisheries).	-

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(3) Lack of policy and standards				
Protocol design/ vessel adherence	EM system is "*always-on*". Video recordings starts/ends when the vessel leaves/returns to the harbour.	Participating vessels are often volunteering and can obtain a compensation in terms of *e.g.*, additional quota. In the bycatch monitoring programme, participants are asked to maintain the equipment clean, and present drown animals to the camera to facilitate identification. Turning off the EM system is forbidden by contract.	EM system is "*always-on*". Video recordings starts/ends when the vessel leaves/return to the harbour.	In the bycatch monitoring programme, anonymity is guaranteed by contract and collected data are not used for control enforcement.
Chain of custody	N/A	N/A	N/A	-
Multiple service providers	N/A	N/A	N/A	-
Fast technology development	Automation of the data analysing processes with machine learning techniques or other ad-hoc algorithms.		Automation of the data analysing processes with machine learning techniques or other ad-hoc algorithms.	Cloud-based machine learning process to identify vulnerable species bycatch is under development.

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(4) Data integrity				
Data format	Cloud-based storage: data stored in a MS SQL Server database.	Local storage: encrypted flat files.	Cloud-based storage: data stored in a MS SQL Server database.	
Data access/use	All or part of the data are accessible to authorised staff, with different levels of permissions. Data access and analysis typically done through the Anchorlab Analyzer software interface.	The interface shows a live view of the cameras, with status information of the EM system.	All or part of the data are accessible to authorised staff, with different levels of permissions. Data access and analysis typically done through the Anchorlab Analyzer software interface.	
Data loss	Back-up systems of all data-servers.	Possible for local data if not already uploaded.	Back-up systems of all data-servers.	
Data tampering	Possible if access to the storage server is granted.	EM system turned off or unplugged. Data tampering is not possible from the software.	Possible if access to the storage server is granted.	Automatic notification system of authorities for vessels with no data logged/transferred within a certain time range would improve the reliably of the system.
Data ownership and confidentiality	Unless explicit permission from the fisher is granted, the data can only be published if fishers' anonymity can be guaranteed.	Fisher keeps a viewing right on collected data. If the data are collected for monitoring, the data cannot be transferred to a control authority to check and enforce regulations (unless permission is granted by the fisher).	Unless explicit permission from the fisher is granted, the data can only be published if fishers' anonymity can be guaranteed.	To respect the current regulations, access to fishery-dependent data should only be granted to a data analyst provided a confidentiality disclosure is signed beforehand.

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(5) Data integration				
Data compatibility with legacy systems	Data are stored as an exportable dataset, associating unique tags (*e.g.*, picture within haul, within trip) to a vessel/user. The tags include time (duration) and position (area).		Data are stored as an exportable dataset, associating unique tags (*e.g.*, picture within haul, within trip) to a vessel/user. The tags include time (duration) and position (area).	Data can be queried from the storage server using SQL, allowing analyses using alternative software.
Link fishery-dependent and independent data	Data input to stock assessment and national Data Collection Framework (DCF) programmes.	N/A	Data input to stock assessment and national DCF programmes.	
Data integration into management/science	Document fishing areas, *e.g.*, in relation to time-area closures. Calculation of fishing effort and intensity, in particular for fleets using passive gears.		Bycatch estimates of protected, endangered, and threatened species (Glemarec *et al*., 2020). Document fishing areas, *e.g.*, in relation to time-area closures (Beest *et al*., 2017; Kindt-Larsen *et al*., 2016). Input in stock assessment (Plet-Hansen *et al*., 2019). Calculation of fishing effort and intensity, in particular for fleets using passive gears (Kindt-Larsen *et al*., 2012b).	

Source: Authors

2.5. Conclusions on the use of this technology

Fixed video-based EM systems installed on fishing vessels offer an interesting alternative to fisheries observers to collect data in SSF. In Denmark, although the initial costs of Blackbox Video are high in comparison to other monitoring methods, the long-term costs remain lower if the data should be collected over extended periods. By ensuring a long-term monitoring of the fishing activity using high-resolution data, video-based EM systems make it possible to estimate accurately *e.g.*, discard rates and PET species bycatch per unit effort that would otherwise be difficult to evaluate.

In European SSF, where fisheries observer coverage is traditionally low, there is often a lack of information on the spatiotemporal distribution and intensity of fishing effort. In this regard, the generalisation of video-based EM systems in SSF can become an important tool to assess the impact of SFF on marine ecosystems in the EU. Nevertheless, camera systems remain unpopular in the fishing community due to their perceived intrusiveness and privacy issues (Plet-Hansen *et al*., 2017). Therefore, data collected for science-based advice and monitoring purpose, *e.g.*, to assess PET species bycatch in fisheries will have to be treated as confidential. Moreover, the processing, management and use of data has to comply with GDPR rules. If implementing EM on a voluntary basis, the aims of monitoring programmes need to be clearly defined and explained to participating fishers to maximise cooperation and minimise inappropriateness behaviour.

Analysing EM with video data manually is labour-intensive and can therefore become prohibitively expensive. Video-based EM will become more attractive to fisheries managers and fisheries scientists if at least some of the most tedious tasks can be automated. All the major actors in the field are currently developing their own methods, usually based on machine-learning, to facilitate the process of reviewing video monitoring data, including the automatic determination of the fishing effort distribution and intensity and the identification of commercial and unwanted species directly from the video feed. These processes require large quantities of data to become operational, especially in SSF where camera angles and light conditions can differ significantly between vessels (Glemarec *et al*., 2020). A public data bank, pooling together videos and still images from anonymised fishing vessels could facilitate the implementation of automated species identification in existing and future monitoring programmes in the EU.

2.6. Examples of other video-based Electronic Monitoring Systems

Other European technology providers have also developed video-based EM systems. Examples of these systems are shown in Figure 7 for "*Marine Instruments*" (Spain), associated with "*Archipelago Marine Research*" (Canada), and in Figure 8 for "*Satlink*" (Spain). These EM systems are similar to the Anchorlab Black Box Video EM system and are used mainly by larger vessels fishing for tuna, but they can be adapted for other fisheries and fleet segments.

Figure 7: "*EM Observe*" Electronic Monitoring System

Source: Marine Instruments and Archipelago Marine Research Ltd.

Figure 8: "*Satlink SeaTube*" Electronic Monitoring System

Source: Satlink

3. CASE STUDY II - EM SENSOR SYSTEM

KEY FINDINGS

- The EM sensor system provides high-resolution fishing data by **recording** the vessel's fishing **activities** in **10 second intervals**.
- Better **control and surveillance** of the fisheries.
- Increased **accuracy and transparency** by documentation of fishing activities benefits both fisheries control authorities and fishers.
- Combined with **logbook information**, the EM sensor system data can be used to assess the area impacted by fisheries at a **high spatial** and **temporal resolution**.

3.1. Aim of usage

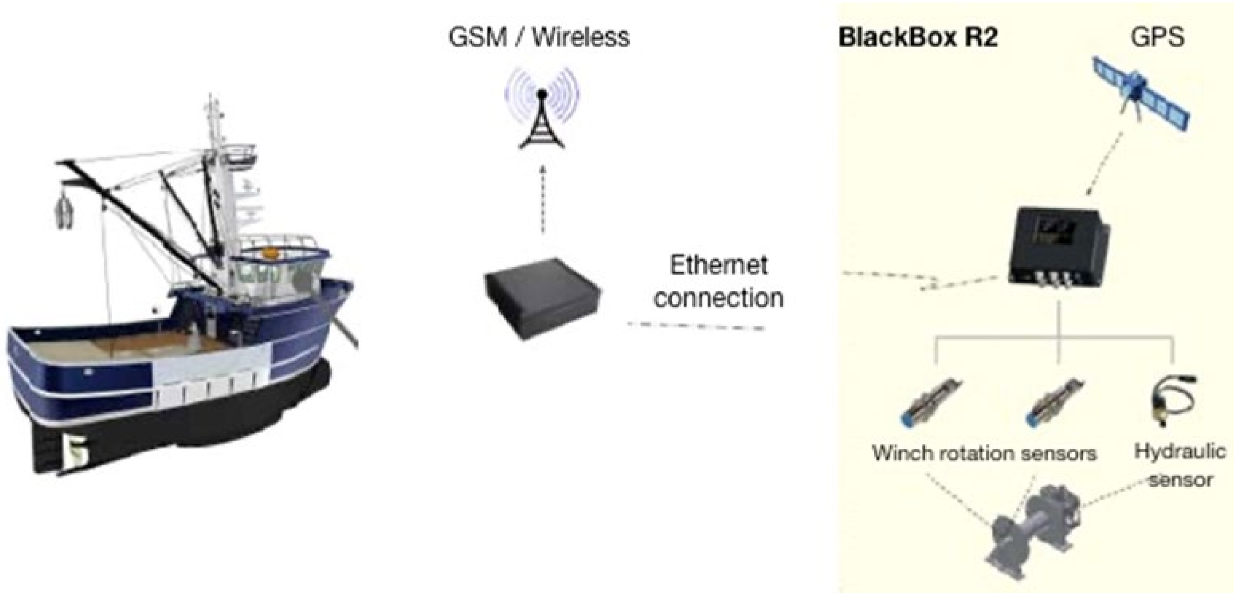
In 2008, the Danish environmental non-governmental organisations (NGOs) were concerned whether sufficient effort was made to protect the designated habitats and species within the Natura2000 sites, where bivalve fisheries are allowed and complained to the EU Commission. The EU Commission accepted a national consensus agreement, where implementation of a high-resolution EM sensor system to monitor and document fishing activities became a fundamental premise for allowing bivalve fisheries in Natura2000 sites.

The "*Black Box R2 system*" (BB R2) is used as a general control measure by the authorities but also to assess the area impacted by the bivalve fishery within the Natura2000 sites and is the fundamental data input in the environmental impact assessments carried out for each Natura2000 site before each new fishing season. The *BB R2* system has provided a very high transparency of fishing activities, which has resulted in maintained quotas by implementing fishing boxes and allowed opening of fishing areas previously closed due to nature conservation targets (Nielsen *et al*., 2021).

3.2. Usage of the system

The *BB R2* (Anchor Lab, Denmark) consists of a GPS to record vessel location (accuracy of 2 to 10 metres depending on the conditions), winch rotation sensors to record fishing activities and onboard hard drives to record data (Figure 9). Data are recorded once every 10 seconds and with spatial resolution of less than 10 metres. The data are automatically transferred wireless to a centralised data storage at the Danish Fisheries Agency via the cellular network (3G or 4G) or Wi-Fi network when the vessel approaches harbour.

Figure 9: **Schematic overview of the BlackBox R2 system mounted on all Danish bivalve fishing vessels**

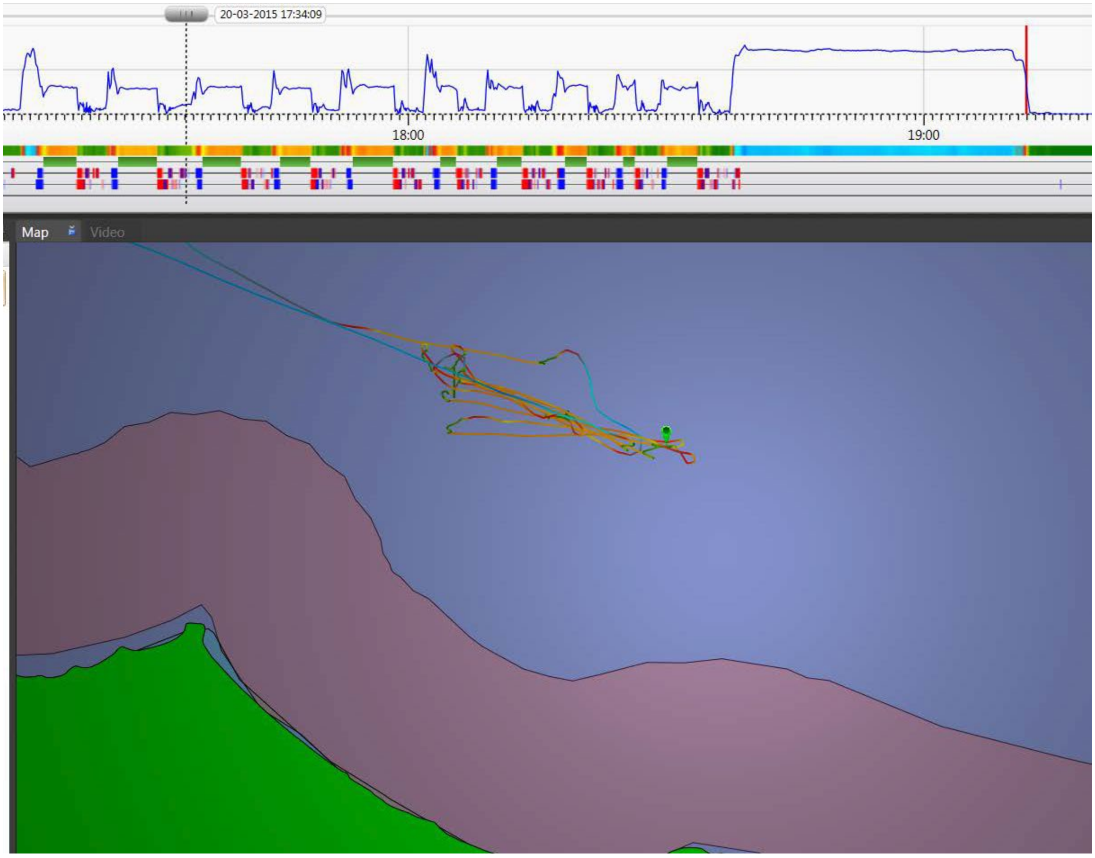


Source: Danish Fishery Agency

There is a high frequency of data recording (10 seconds logging) as the *BB R2* also logs while sailing to and from the fishing grounds and while the vessels are in the harbour. The transferred *BB R2* data is analysed by the Danish Fisheries Agency to assess, which data points are covered by actual fishing. The Black Box Analyzer[5] is used to assess fishing activities through a set of criteria, where the first requirement is rotation recorded in the winch sensors. If data for the winch register movement in the same direction (clockwise or counter clockwise) for a predefined time *e.g.* 30 seconds, it indicates if a fishing activity has just begun or has been completed. Found fishing activities are filtered based on two criteria: 1) sailing speed within a predefined range and 2) fishing time with a minimum length greater than a predefined value. This procedure results in a list of fishing activities that include start and stop times for each dredge track (Figure 10) and are associated with an ID. Each track is then checked manually by the Danish Fishery Agency before the quality assured *BB R2* data subsequently is transferred to DTU Aqua, where further analysis can be carried out.

[5] Anchor Lab, Denmark

Figure 10: Snapshot from Black Box Analyzer



Source: Danish Fishery Agency

Note: Snapshot showing the dredge tracks (yellow lines on the map), and the instant speed (blue line on the timeline) of a Danish bivalve fishing vessel.

A similar EM onboard Scottish scallop vessels has been implemented in 2017 to ensure that the fishing practises comply with the restrictions on number of dredges. The system consists of a control box/storage box for data and software storage, a minimum of two digital cameras, winch sensors linked to the digital cameras and a GPS device (for further information, see www.anchorlab.dk).

3.3. Evaluation of the system

The fixed costs of EM can generally be broken down into two main categories: up-front fixed costs and annual costs, which can either be paid by the fishers/industry, authorities or the two combined. With the implementation of the *BB R2* system in the bivalve fishery in Denmark, the costs are divided, so that the fixed costs and annual costs for the installed *BB R2* onboard the vessels are paid by the fishers, whereas the annual costs for control are paid by the authorities (Table 2).

Table 2: Estimated costs for Black Box R2 system on Danish bivalve fishing vessels, 2018 prices

	Costs in EUR
Per vessel equipment costs – paid by fishers Black Box R2, two winch sensors, GPS-antenna, GSM-antenna and an isolated DC/DC converter (exclusive installation)	2 350
Per vessel annual estimated running costs – paid by fishers Black Box R2 license fee (inclusive updates) data transfer: 20 EUR/month Online access to own data: 14 EUR/year	254
Annual estimated running costs – paid by Danish authorities 1 server license (10 users) per year Each additional user 535 EUR/year Server license for 99+ users 27 000 EUR/year *(NB: Exclusive 7 months of salary for 1 person for control and quality assurance of data for area impact assessments)*	7 500

Source: Authors.
Note: Own calculations based on input from Anchor Lab, Denmark, and the Danish Fishery Agency.

From a fishery managers point of view, EM can increase monitoring coverage and improve data robustness and compliance and can relatively easily be scaled to cover 100 percent of fishing activity, which overall results in more efficient regulations and increase transparency of the fisheries (Michelin *et al*., 2018). The *BB R2* data provides fisheries managers with a precise data-based documentation of the discrete impacts of bivalve fisheries, which has resulted in better control and surveillance but also increased transparency of the bivalve fishery. Furthermore, combining the *BB R2* data with vessel logbook information of gear type and configuration, provides a strong data-based documentation of area actually affected by bivalve fisheries, which have been a key tool for the mangers to allow bivalve fisheries within Natura2000 sites in Denmark; for further details see Nielsen *et al*. (2021). As the use of the system was a prerequisite for allowing the fishery, the fishing industry took the system onboard and has since the implementation in general accepted the conditions and been cooperative.

In 2012, when the *BB R2* was implemented, it was perceived as an extra cost and a control measure limiting the fishery, but it is now positively recognised by the fishery/industry as a useful tool used to maintain quotas in Natura2000 sites and display transparency of their fishing practices. The *BB R2* has been used actively by the fishery organisations to respond to accusations of bad practice by the public. Besides, in 2016, the fishers initiated further development of the *BB R2*, so individual vessels now have access to their own data. The information is not only used actively by the industry to keep track of the total area impacted within a fishing season but can also be used by the individual fisher to optimise their own fishery.

The high-resolution *BB R2* data in combination with logbook information provide detailed information for researchers that can be used to assess *e.g.*, actual area impacted (Nielsen *et al*., 2021) and fishing effort, which are not possible when using data from other available electronic monitoring sensor systems, such as VMS and AIS (Pedersen *et al*., 2009; Rowlands *et al*., 2019). Furthermore, the *BB R2* data has been used together with targeted sampling and suitable reference areas to detect fishery effects in coastal areas that are highly stressed by eutrophication (McLaverty *et al*., 2020). The *BB R2* can also be further integrated into science-based advice, regarding *e.g.*, fisheries practices, quota regulations and fisheries impact of objectives under the EU Water Framework Directive and Marine Strategy Framework Directive; for more details, see Nielsen *et al*. (2021).

The costs of EM sensor systems and who will pay for the up-front fixed costs and the annual costs were a most-talked-about concern when the system was implemented in the Danish bivalve fishery. The fishers wanted insurance that their fisheries would continue to cover the up-front fixed costs and to keep the fishers' expenses low. In addition, incorporating EM sensor systems into a monitoring, control, and surveillance program required a significant investment of time, energy, and resources by fishery regulators to develop an EM program and EM data protocol (Table 2), especially for data quality assurance if the data is used in assessments of fishery impacted area. An inclusive and dialogue-based process between the Danish government, involved nature conservation NGOs, and the mussel industry was the foundation to identify and agree on key objectives and regulatory drivers to develop an EM program and the national consensus agreement, known as the Danish Mussel and Oyster Policy of management of the bivalve fisheries in Denmark[6]. Furthermore, a clear agreement of data standards, data ownerships and confidentiality were of importance for the fishers to ensure that their data would not be used without their permission.

In Table 3, an overview of the main benefits and risks by implementation of *BB R2* in the Danish bivalve fishery have been listed for fisheries control authorities, the fisheries/aquaculture and fisheries science, respectively. The benefits and risks are evaluated in relation to five overall categories: technology, timeliness, lack of policy and standards, data integrity and data integration.

[6] https://fiskeristyrelsen.dk/erhvervsfiskeri/saerlige-fiskerier/muslinger-og-oesters/muslinge-og-oesterspolitikken/#c83289

3.4. Evaluation of the technology, timeliness, lack of policy and standards, data integrity and data integration

The benefits and risk of using an EM sensor system are evaluated in relation to the following five overall categories: (1) technology, (2) timeliness, (3) lack of policy and standards, (4) data integrity and (5) data integration.

Table 3: Benefit-risk assessment of sensor electronic monitoring systems in SSF with regards to fisheries control authorities, fisheries/aquaculture professional sector and fisheries science

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(1) Technology				
Proprietary vs. open-source software	Yearly costs for software license.	Yearly costs for software license to have access to own data.	None	
Data transmission and interference	Automatic daily data transmission via GSM/3G/4G/Wi-Fi to the authorities.		Data transfer to DTU Aqua needs manual initiation by authorities	
Power supply and system reliability	Risk of failure of *BB R2*. Real-time monitoring only possible in areas covered with GSM/3G/4G/Wi-Fi.	Lack of indicator of failure/no data transfer.	Failure in *BB R2* will often result in missed fishing activities.	Data are stored on the local hard drive until transfer via GSM/3G/4G/Wi-Fi
Sensor integration	Winch sensors to document fishing activities.		Documentation of actual fishing activities.	Another sensor or camera could be added.
Environmental impediments	N/A	N/A	N/A	
Camera species identification	N/A	N/A	N/A	Cameras are currently not implemented.
Camera weight accuracy/precision	N/A	N/A	N/A	Cameras are currently not implemented.

(2) Timeliness				
Time to review/ process data	Hours to weeks depending on how many vessels and fishing activities that need to be reviewed/processed.	N/A	Days to weeks after quality assured data have been transferred from the authorities	
Delay in data availability	Daily transfer expected unless no access to GSM/ Wi-Fi	Daily transfer expected unless no access to GSM/Wi-Fi	Days, since authorities need to quality assured the data before transfer	
(3) Lack of policy and standards				
Protocol design/ vessel adherence	Since 2012 mandatory enforcement of *BB R2* on all Danish bivalve fishing vessels	Only authority approved systems are accepted (*BB R2* or updates)	A standard protocol for data storage and assessment of total area impacted by fisheries in Natura2000 sites has been developed by DTU Aqua[1]	[1] DTU Aqua unpublished data
Chain of custody	All fishing activities within Natura2000 sites are quality assured before any further analysis.	N/A		
Multiple service providers	N/A	N/A	N/A	
Fast technology development	Systematic data quality assurance protocols have been implemented later	A notification system of the fishers if no data has been transferred		Automatic notification system of the fishers if no data has been logged/transferred within the last 24 hours would improve reliably of the system

(4) Data integrity				
Data format	Cloud-based storage in a SQL server database	Local storage until upload.	Data are transferred as compressed SAS-files to DTU Aqua, where the data are processed by statistical programming software.	
Data access/use	All data are accessible to authorised staff.	Fee for online accesses to their own data (Table 2).		
Data loss	Back-up systems of all data-servers	Failure in *BB R2*	Back-up systems of all data-servers	
Data tampering	N/A	Turn off the *BB R2*.	N/A	Automatic notification system of authorities for vessels with no data logged/transferred within the last 24 hours would improve reliably of the system
Data ownership and confidentiality	The data are owned by the fishers/Danish Fishery Agency and are strictly confidential.	All *BB R2* data are considered under the GDPR-regulations and any transfer and use of the data must be approved by the fishers.	All data are anonymised before publishing /shared internally at DTU Aqua.	
(5) Data integration				
Data compatibility with legacy systems	N/A	N/A	N/A	Older versions might have a tendency to have a higher rate of malfunction/failures
Link fishery-dependent and independent data			Data input to stock assessment.	

Data integration into management/science	Assessment of area impacted by fishery with fine-scale resolution data[1]. Ensure fisheries comply with general nature conservation objectives *e.g.*, in marine protected areas or the EU Water Framework Directive[2].	Data input for Marine Stewardship Council (MSC) certification	Calculation of fishing effort and intensity (Nielsen *et al*., 2021). Input in stock assessment[1].	[1] DTU Aqua unpublished data

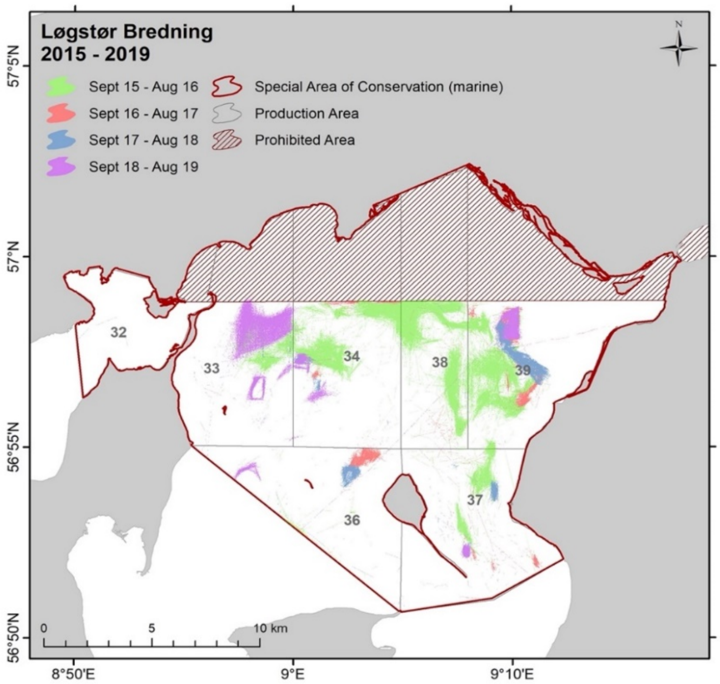
Source: Authors

3.5. Conclusions on the usage of this technology

The EM sensor system is easy to install, can be scaled to cover 100 percent of fishing activity and the up-front fixed costs are relatively low as well as low annual running costs for maintenance of the system and access to own data (Table 2). The annual running costs for control and surveillance are higher and especially the time spend on data quality assurance are a major contributor to the total annual salary costs (Table 2). However, the need for data quality assurance can be reduced if the data are not used to estimate actual area impacted by bivalve fisheries, as in the Danish bivalve fisheries within Natura2000 sites. The EM sensor system can provide the same high accuracy as the EM camera system but with lower up-front cost, which can be a cheaper solution for fisheries with limited bycatches and discard.

The EM sensor system are well suited to monitor coastal fisheries where the areas often are covered with Global System for Mobile Communications (GSM), 3G or 4G. The EM sensor system onboard fishing vessels with bottom contacting gear, can provide high-resolution data of actual fishing activities beneficial for both fishery control and surveillance in relation to *e.g.*, marine protected areas or areas closed for fishing but also for data input in Marine Stewardship Council (MSC)-certification of fisheries. Furthermore, the EM sensor system data can be integrated into science-based advice of *e.g.*, fisheries practices, quota regulations, fishery impact of sensitive habitats or objectives under the EU Water Framework Directive and EU Marine Strategy Framework Directive. Additionally, the EM sensor system can in combination with logbook information provide documentation of the actual fishing impact in a given area and can be assessed by *e.g.*, each vessel, total fishing fleet, day, month or the entire fishing season (Figure 11).

Figure 11: Impacted area by bivalve fisheries within the Natura2000 site Løgstør Broad, DK



Source: Nielsen *et al.*, 2021
Note: The impacted area is assessed for four different fishing seasons from 2015-2019

4. CASE STUDY III – MINI VIDEO SYSTEMS

KEY FINDINGS

- **Camera system** fitted for small scale vessels.
- **Smart-phone applications** for the setup and configurations of the mini video system.
- This technology is used by "*FrescaPesca*" to secure full **traceability** of fishing products.
- It serves as monitoring technology of over 600 vessels in **Latin America**.

4.1. The aim of the use of the system

Small scale coastal fisheries around the world have increasing needs to meet the growing global demand for quality, control, and ecosystems preservation. A high proportion of these small-scale fisheries, particularly those in developing countries, use gillnets. Gillnets are known to be associated with high levels of bycatch of non-target species with high conservation needs, such as marine mammals, sea birds, sea turtles and elasmobranchs. While onboard observers and CCTV monitoring platforms have played an important role in monitoring large fleets, small scale fisheries present a greater challenge for observation and monitoring. They often have limited space onboard and thus cannot accommodate observers. On SSF vessels, CCTV monitoring has been difficult to implement as many of these vessels have no deck cover, fish in remote areas with low power supply access, if any at all.

To our knowledge only one company, Shellcatch[7] produces a video-based EM system specifically fitted for small vessels. The system has been used to monitor over 600 vessels by governments, NGOs and private companies. The system is used in Chile (gillnet and hook and line fisheries), Mexico (beam trawlers, fish pots, seine), Thailand (large fish nets), Peru (gillnets), Hawaii (hooks), California (bottom and pelagic trawl, pots and traps, hooks), Ecuador (gillnets), Turkey (gillnets), Costa Rica (longlines), Brazil (longlines), Pakistan (gillnets), Galapagos (longlines, handlines) and Belize (spear guns, hook sticks, beach traps, handlines, gillnets).

4.2. Description of the system

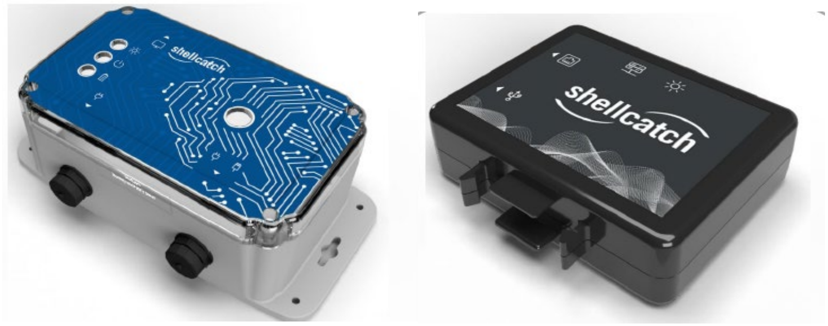
4.2.1. VirtualObserver

Shellcatch has developed an all-in-one camera system called VirtualObserver[8] (Figure 12). It is a robust and waterproof monitoring system with video and GPS sensors. It can be mounted on all sizes of vessels but is especially designed for small vessels where only one or few cameras are needed. It is solar powered or powered by an internal battery which can record for one full fishing day. Its function therefore depends upon the power supply onboard. The camera is very easy to mount, as it is delivered with different mounting brackets and a very explanatory user manual. The fisher can thus install it himself, and the system is provided with a mobile application that can verify that all functions are working correctly. After instalment of the VirtualObserver, the fisher can go to sea and carry out their fishing activity using normal procedures. When the fisher returns to the port, she/he detaches the camera from the mounting brackets and brings the VirtualObserver home to upload the data. The

[7] https://shellcatch.com/
[8] https://shellcatch.com/welcome/emonitoring/

video footage is uploaded through the device uploader device to the Shellcatch cloud platform by Wi-Fi connection. The communication between the camera and the uploader is high speed, but the speed of the data upload depends on the internet connection (generally a few hours). After the upload, the camera is set to charge to be ready for observation the next day.

Figure 12: VirtualObserver - video camera (left) and uploader device (right)



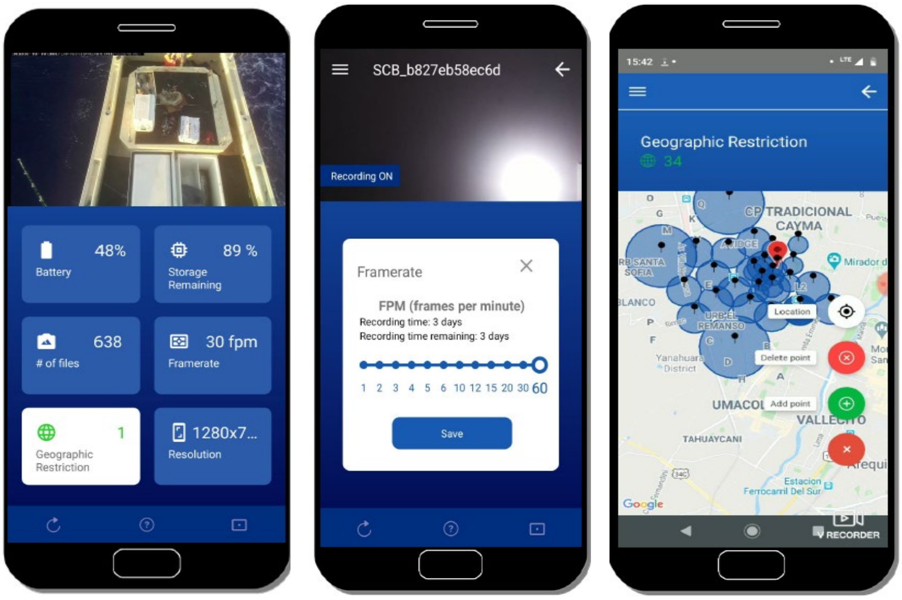
Source: Shellcatch

A cloud platform enables monitoring and collection of statistics on bycatch by Shellcatch or other end user. An AI-algorithm is under development to detect non-target species of high conservation value to reduce the time spent on reviewing the data.

4.2.2. Mobile App

The mobile app is an additional tool to facilitate the work and is used for customization of the system. With the mobile App, one can check the status of the camera, as well as set up areas where they do not want images to be collected. This is done by a geographical restriction functionality, where points can be marked on a map for restricting recording of images.

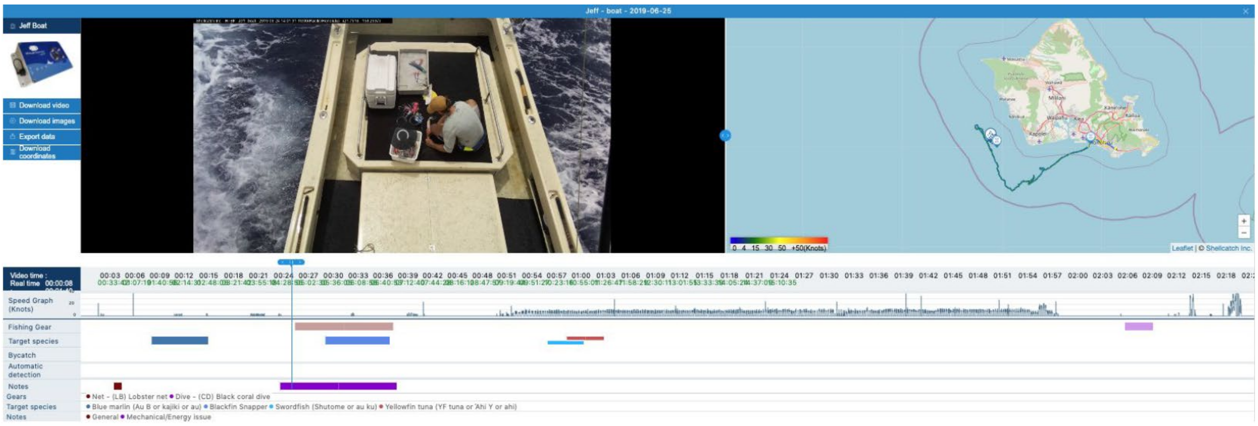
Figure 13: Screenshots of the Shellcatch mobile app



Source: Shellcatch
Note: the Shellcatch app controls the VirtualObserver device setup, where battery, storage, framerates, resolution, and geographic restrictions can be parametrised.

In the review and registration area, the system allows the review and annotations of events, fishing gear, target species and bycatch. The GPS and video footage lowers the review time as only footage of interest can be selected. The graphics contain the results of the information generated from the video reviews, and reports can be generated. Furthermore, all videos and coordinates are downloadable. When more support in the revision is required, the system allows for inviting more users. AI are in the next step for development: The automatic detection of certain events relevant to the fishing in question can be implemented *e.g.* detection of marine mammals.

Figure 14: Snapshot of the cloud-based review platform for the Shellcatch system

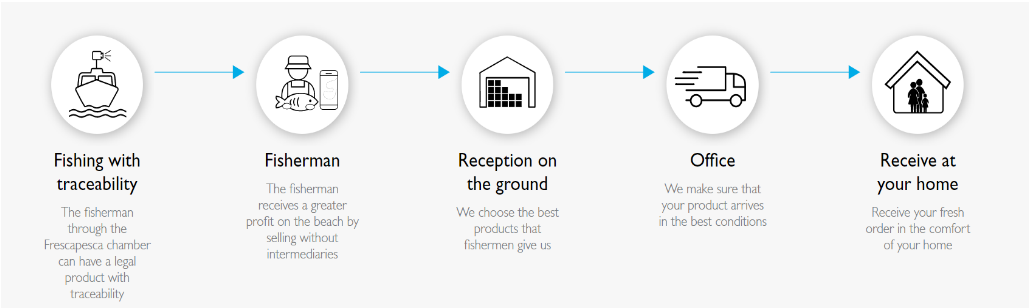


Source: Shellcatch
Note: video footage (top left), position of the vessel and GPS trace of the current fishing trip (top right) and timeline to enter review annotations (bottom)

4.2.3. FrescaPesca

The system *FrescaPesca*[9] is being used as a tool to solve the problems inherent in the supply chain of fresh seafood in Latin America, by connecting fishers to consumers directly, through the use of traceability technology (Figure 12). Shellcatch systems are installed on vessels that are members of FrescaPesca and all video footage are verified in terms of legality. Fishing area and all video footage are reviewed for bycatch of protected species (including *e.g.* marine mammals). The fish are freshly delivered to the consumer and the consumer can scan QR-codes to get access to the name and picture of the fisher, fishing area, legality of the fishery and a clip of 15 seconds video footage from the trip where the fish was caught. The main driver for the fishers to join FrescaPesca is that they get higher prices for the fish.

Figure 15: FrescaPesca traceability chain and information available to the consumer through the app



Source: Shellcatch

4.3. Evaluation of the system

The costs of equipment can be seen in Table 4. The only costs of installation are the mounting brackets and the fisher must have an android or iOS mobile phone available for setup and data collection. User training and ongoing support are included in the different options. In terms of scalability the systems have been used from pilot programmes with single camera setup to large implementations with up to 300 boats participating.

Table 4: Up-front costs of equipment and installation tools of Shellcatch

Camera (video monitoring and GPS tracking)	EUR 1.25
Uploader (data upload system)	EUR 167
Switch- optional (on/off recording)	EUR 206
Mounting pole/cabin mounting (adaptable to multiple/ high structures)	EUR 251 – 334
Total	**EUR 1 881 – 1 964**

Source: Authors, own calculations

The Shellcatch system comes with different opportunities for payment or subscriptions (Table 5). The subscription includes the costs of the camera, uploader and 1 Terabytes (TB) of cloud storage. Mounting brackets and switch (optional) are not included. The standard option includes 1 TB of cloud

[9] https:f//frescapesca.com

storage but requires separate purchase of the camera, uploader, mounting brackets and switch (optional). If necessary, additional 1 TB storage packages can be added for 26 EUR/month per camera.

Table 5: Running annual costs of equipment and installation tools of Shellcatch

With subscription	**Costs**
12 months	197 EUR/month
24 months	149 EUR/month
36 months	119 EUR/month
Standard	
Monthly payment	149 EUR/month
Annual payment (contract for 1 year is agreed)	1 530 EUR

Source: Authors, own calculations

4.4. Evaluation of the technology, timeliness, lack of policy and standards, data integrity and data integration

The benefits and risks when using hand-held devices in fisheries (tablets and cell phones) are evaluated in relation to five overall categories; (1) technology, (2) timeliness, (3) lack of policy and standards, (4) data integrity and data integration.

Table 6: Benefit-risk assessment of mini video systems in SSF with regards to fisheries control authorities, fisheries/aquaculture professional sector and fisheries science

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(1) Technology				
Proprietary vs. open-source software	None	Cost for software license to have access to own data (Table 5)	None	The data have mainly been verified by Shellcatch. The software is not open access so the costs can be assigned to all depending on the terms of agreement
Data transmission and interference	Data are uploaded daily by fishers and is available to authorities through Shellcatch	Camera needs to be in range of uploader which sends data by Wi-Fi to Shellcatch cloud	Data can be reached through the Shellcatch cloud	
Power supply and system reliability	Very high reliability (95%) in new version. No data transfer if no GSM/3G/4G/Wi-Fi network is available	3-36 volt and can be solar powered. Indicators in app for failure/data transfer	Dirt on camera lenses or other obstructions in the field of view can reduce video data quality	Data are stored at local hard drive until transfer via GSM/3G/4G/Wi-Fi
Sensor integration	Video, GPS and switch to document fishing activities	Temperature to secure system functionality	Video, GPS and switch to document fishing activities	Other sensors can be added
Environmental impediments	N/A	N/A	N/A	
Camera species identification	Identification of species manually	Identification of species manually	Identification of species manually	Automatic identification is not implemented yet, but is under development

Camera weight accuracy/precision	N/A	N/A	N/A	In progress
(2) Timeliness				
Time to review/ process data	1 day of fishing takes approximately 2.5 hours to review	N/A	At this stage, all data are analysed by authorities or Shellcatch. However, data can be made available for science when processed or when uploaded by fishers	Time to review data depends on the amount of effort, type of fishery, video quality and skills of the viewer
Delay in data availability	Daily transfer expected unless the fisher does not bring the camera to the uploader device	Daily transfer unless there is no access to GSM/3G/4G/Wi-Fi network	Can be made available as soon as the data is uploaded by fisher	
(3) Lack of policy and standards				
Protocol design/ vessel adherence	The system needs to be turned on by the fishers themselves on a daily basis when returning from charging and data upload	In many cases until now the fishers have wanted the cameras on themselves, thus they have been responsible for data upload	The system needs to be turned on by the fishers themselves on a daily basis when returning from charging and data upload	
Chain of custody	N/A	N/A	N/A	
Multiple service providers	N/A	N/A	N/A	
Fast technology development	Automation of the data analysing processes with machine learning techniques or other ad-hoc algorithms	A notification system of the fishers if no data has been transferred	Automation of the data analysing processes with machine learning techniques or other ad-hoc algorithms.	

(4) Data integrity				
Data format	SQL database	SQL database	SQL database	
Data access/use	Cloud-based, depends on the contract agreed by Shellcatch and fishers	Cloud-based, fee for online accesses to their own data	Cloud-based, depends on the contract agreed by Shellcatch and fishers	
Data loss	Back-up systems of all data-servers	Failure of VirtualObserver or uploader device	Back-up systems of all data-servers	
Data tampering	N/A	Not uploading data	N/A	
Data ownership and confidentiality	The data are owned by the fishers are strictly confidential and only shared if agreed with other parties.	Any transfer and use of the data must be approved by the fishers.		
(5) Data integration				
Data compatibility with legacy systems	Fishing rights are linked to government data bases	Fishers are reminded about fishing rights by using the app. *E.g.*, entering closed areas	N/A	
Link fishery-dependent and independent data	N/A	N/A	N/A	Data are not yet liked to stock assessment
Data integration into management/science	Not yet but can easily be done	Data input for Marine Mammal Protection Act	Has not been done yet	

Source: Authors

4.5. Conclusion on the use of this technology

As is the case for the larger fixed video-based systems, mini video systems fitted for small vessels offer an alternative to having observers onboard fishing vessels. Mini video systems allow monitoring SSF vessels over extended periods and estimate accurately *e.g.*, the spatiotemporal distribution of the fishing effort, discard rates or PET species bycatch per unit effort in this fleet segment. The main system on the market has proved to be robust and very easy to install, securing more than 600 users in Latin America at the time of writing. Multiple factors explain this success. It is a relatively cheap system that can be implemented anywhere due to its simple installation method and its internal power source, while data upload is easily done through the uploader device. It can easily be swapped between vessels, which is one of the main critiques of the fixed electronic monitoring systems. The data are thus comparable to observers as they also swap between vessels and influence from single fisher habits can be eliminated.

Furthermore, in a world where sustainability is becoming a selling argument in many industries, there have been increasing demands from consumers to document bycatches of PET species in the fisheries from where their fish originate, to guarantee the legality of the fish they consume. This has created a market opportunity for initiatives such as the FrescaPesca, which both secures high fish prices for the fishers but also ensures traceability, legality, and transparency for consumers, notably with regards to bycatch levels of PET species. Other forces are likewise pushing for monitoring of bycatch like the Marine Mammal Protection Act, which secures that the US only imports fish from fisheries (including SSF) where bycatch levels are properly documented. Video-based EM like the Shellcatch will thus become more attractive to SSF as it can give them the opportunity to document their fishery and hereby export.

4.6. Examples of other "*mini*" (still picture) systems

Another example of an EM technology is the LIME™ (Lite Integrated Monitoring Equipment) that has been developed by Archipelago Marine Research Ltd, Canada (Figure 16). The LIME™ is not a video system but a low-cost data collection platform that allows fleet managers, fisheries managers, and enforcement managers to monitor and access critical fisheries-related activity in real-time[10]. LIME™ is designed to fit on a variety of vessels, and has features such as: GPS, integrated sensor inputs, still imagery, Radio Frequency Identification (RFID), global cellular coverage and real-time data transfer. Its minimal footprint makes it ideal for smaller boats without the space for a full-scale EM system, or in less active fisheries.

Figure 16: Mini electronic monitoring system LIME TM

Source: Archipelago Marine Research Ltd

[10] https://www.archipelago.ca/wp-content/uploads/2021/03/Archipelago-EM.LIME_.pdf

5. CASE STUDY IV - TABLETS AS E-LOG AND OTHER ELECTRONIC TECHNOLOGIES

KEY FINDINGS

- Portable devices like **tablets and smartphones** can be used to **record and report** the **fishing activity** of vessels in SSF, via specially designed apps.
- Smartphone/tablet apps are **cost-effective** tools for fisheries managers, fisheries scientists and control authorities to **monitor** fishing effort, and/or enforce regulation **compliance**.
- Fishers can **benefit** from the **flexibility** of portable devices for **registering or reporting** fishing activity, or for **demonstrating compliance** to fishing regulations like time/area closures.
- The use of tablets or smartphones can **improve the data quality**.
- There is a **rapid development** of smartphone apps to **enhance or replace paper logbooks** and **landings declarations** in many SSF worldwide.

5.1. The aim of the use of the system

One of the prerequisites for management of sustainable fisheries is a transparent and reliable fishery dependent data collection process, *e.g.*, data reported in logbooks, landings data, sales notes data, or VMS data. Within the EU, fishery-dependent data for vessels below the length of 12 metres are insufficient for ensuring sustainable management of the marine living resources and for the management of the ecosystem in general.

One solution for improving the capture of fisheries-dependent data from the small-scale fleet is to use portable electronic devices such as tablets and cell phones as tools to record and report fishing activities.

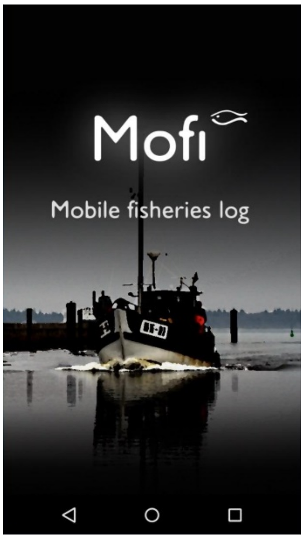
The global development of mobile technologies has enhanced possibilities in fishery-dependent data system advancements and opportunities. The portability of smartphones and tablets has led to a growing recognition of their potential for the collection of data for all fisheries sectors (Bradley *et al.*, 2019; Gutowsky *et al.*, 2013; Lorenzen *et al.*, 2016; Papenfuss *et al.*, 2015; Venturelli *et al.*, 2017). Modern smart devices integrate a set of instruments useful to collect information on the fishing activity of a vessel, in one handy device and for a fraction of the price of the same instruments bought separately. Specialised apps running on smartphones and tablets can be used to replace or enhance catch registration on paper (electronic logbook), track and record the spatiotemporal distribution of the fishing effort of a vessel using GPS data, and report these data in real-time to the competent authorities while in range of a mobile phone or Wi-Fi network. In the situations where real-time two-way communications between harvesters and law enforcement authorities are allowed, the fishers – who know their activity might be observed – are more likely to respect established regulations, than if non-compliance to rules cannot be registered and would result in no consequence for them (Bradley *et al.*, 2019).

Small-scale fishing fleets are generally under-monitored in comparison to large-scale and industrial fishing fleets. Adapting mobile technologies to SSF could then become a crucial element to cast a light on data-poor small-scale vessel fisheries and improve the management of this fleet segment, but also to bring analysing tools into the hands of the fishers themselves, allowing them to enhance their own fishing habits (Bradley *et al*., 2019). For instance, Saville *et al*. (2015) facilitated the management of a small-scale dredge fishery in Japan by equipping the vessels with a tablet on which to enter their daily catches. The data were linked to location tracking data from a GPS and shared in near-real time via email to a storage server. A computer programme was set up to run automatic analyses on the incoming data and calculate the so-called catchable stock index – an indicator of the maximum total allowable catch at a fine spatiotemporal scale, given the area swept by the gear. The results of the computations were transmitted back to the fishers instantly, so they could enhance catch efficiency while reducing the risk of overfishing the resource. Moreover, integrated online databases registering information on gear type, fishing locations, catches of target species and bycatches of PET species would participate in improving seafood products' traceability, ensuring that the fishing vessels that are sharing their data are fishing the resource sustainably and eventually securing a better market value for their catch (Bradley *et al*., 2019).

5.2. Description of the system

An example of such an app is *Mofi* (short for "*Mobile fisheries log*"). *Mofi* is a smartphone app developed by Anchor Lab, with the collaboration of the Thünen Institute in Germany that runs on Android and iOS (ICES, 2018; 2019). The *Mofi* app collects fisheries-dependent data from participating users, by registering automatically and continuously a vessel track and the fishing operations. Other information that can be registered include the registration of bycatch of protected species (*e.g.*, marine birds or mammals), and the catch composition at haul level. As such, *Mofi* is being developed to become a modern alternative to paper logbooks, ensuring a higher level of reliability offered by new technologies, i.e., a higher precision of the positions of the fishing operations, a real-time or near real-time reporting of the fishing activity, the possibility to take pictures of the interesting captures (rare species, bycatch of protected species) for later identification, among some of the advantages offered by smartphones.

Figure 17: Mofi App front-page design



Source: Anchor Lab

Mofi is a flexible platform in terms of what should be present in the app User Interface (UI), depending on the specific needs of the end users and of the requirements of the project administrator (Source: Anchor Lab, n.d.). The app is built upon a scheme structure, where each project defines its own scheme, i.e., which fields are present in the app UI. These fields include for instance whether the fisher is required to start/stop a trip, the frequency the GPS should be logged at, the list of available species to report (both commercial and bycatch species), images for each species to facilitate direct identification by the end user, as well as additional extra fields required when starting/ending a fishing operation, registering a catch, or starting/ending a trip.

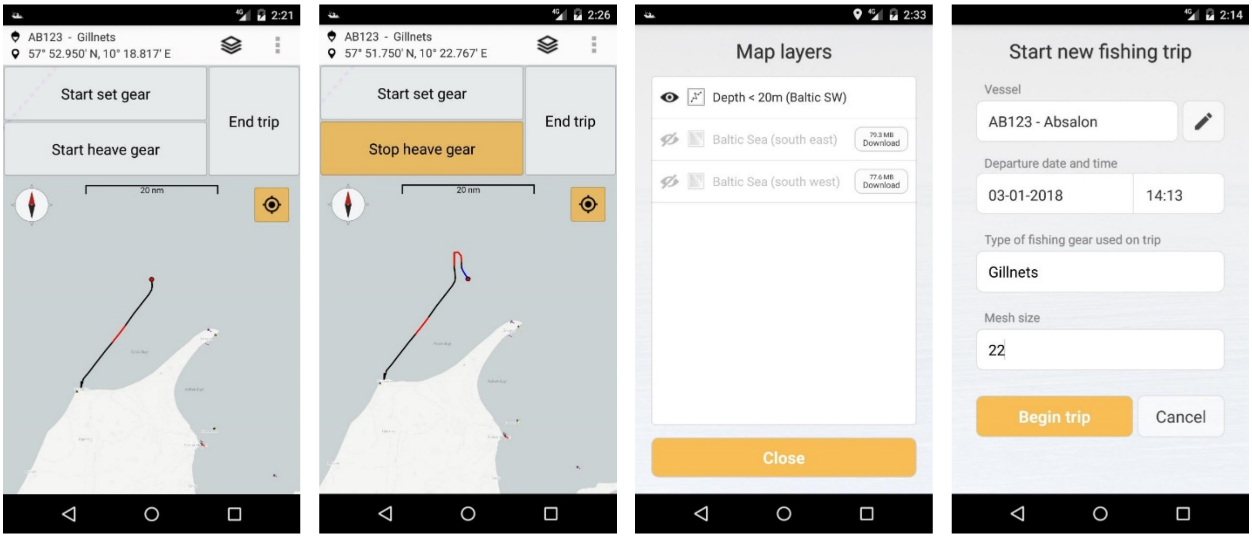
A *Mofi* project administrator can log in on a secured management website to define the mandatory data fishers must push in, depending on the project requirements. Therefore, a project can be tailored specifically to a local fishery or be adapted to fit the needs of an entire fleet. Provided fishers engagement, the flexibility offered by an app like *Mofi* can therefore enhance most already existing monitoring strategies.

Before starting using the app, the fisher first needs to create a *Mofi* user and add one or several vessel(s). Each *Mofi* project scheme has its own privacy policy, to ensure notably that the app complies with the GDPR (General Data Protection Regulation[11]). Therefore, the new user must also accept the policy rules before any data can be registered. An administrator then approves the user and assigns the user to a scheme. This way, only approved users can report data. Once the fisher is approved for one or more vessels, he/she can start using the app. Logging in is required when the app is started (using a PIN code, password, or any other approved identification method), to avoid unintended access and potential false reporting. Collected data are transmitted over the mobile phone network or Wi-Fi using an encrypted connection.

From the end-user viewpoint, interacting with the app is easy. The fisher just needs to select a vessel and a scheme from a drop-down list before departing the harbour, and the user Interface changes according to the selected scheme. Position and speed data are registered continuously while the app is running, and the fisher is invited to register various information on the fishing activity throughout the fishing trip. Once a trip is finished, the data are uploaded to a secure data server. The resulting database can be reviewed and analysed by authorised users. The *Mofi* app being developed by Anchorlab, the company recommends its own software for running data analyses (Anchorlab Analyzer is presented in Chapter 2), however, the data can also be reviewed using alternative software. The *Mofi* app includes Bluetooth support, so it is possible to use external hardware (*e.g.*, GPS position sensor) to indicate when and where fishing operations take place.

[11] See: Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC, https://eur-lex.europa.eu/eli/reg/2016/679/oj

Figure 18: Screenshots of the Mofi app (running on Android)



Source: Anchorlab

5.3. Case study: 2018 Baltic cod spawning fishing closure

During the 2-months mandatory cod spawning closure in February to March 2018 in the western Baltic Sea, the German control authority decided to impose the usage of the *Mofi* app to small commercial vessels (below 12 metres) to ensure the vessels' compliance to fishing in waters shallower than 20 metres (ICES, 2019). The intensity and the spatio-temporal distribution of the fishing effort were collected for small scale fishing vessels using the *Mofi* app. Ninety vessels, mostly gillnetters, but also vessels using active gears, participated in the data collection programme.

A scheme was created in *Mofi*, which required the participating fishers to start a trip, register their gear type and mesh size, and to stop the trip once they were back in harbour. Once the trip started, the App logged one position per minute and revealed buttons in the UI for the fishers to specify when the fishing gear was set and when it was hauled. For gillnet vessels, the scheme defined buttons for start and stop of setting and hauling the gear, respectively. For active gears, only buttons for setting and hauling the gear were visible. The scheme also defined a shape file that was visible on the map in *Mofi*, showing the whole fishing area within 20 metres depth as a green polygon. This indicated the areas where fishing was allowed, so skippers could easily ensure that they avoided waters deeper than 20 metres, where fishing was prohibited. When a trip was ended by the user, the scheme dictated the data to be sent to a dedicated secured storage server based in Germany. Data analysts from the Federal Office for Agriculture and Food (BLE) of Germany could access these data and control whether fishers were following regulations and take proper actions if not. Additionally, the project administrator included the possibility for specific users to remotely access the position of a vessel in real-time. This function was implemented to allow the authorities to control potential infringement without delay if they suspected a vessel to violate the fishing closure. Thanks to the involvement of the German government in the financing of the *Mofi* app scheme, the app was provided for free to all participating fishers.

Beyond this single case study, the *Mofi* app is currently being expanded with additional functions, including logbook capabilities, in collaboration with MSC and different partners from Germany, Sweden, Denmark, and the Netherlands[12]. The apps full release, scheduled in 2021, aims at proposing a modern, credible alternative to pen and paper to register bycatches of endangered species in selected MSC fisheries. Among others, the new *Mofi* app offers the possibility to register and report automatically incidental captures of protected species, as well as record total catches and discards. The app will provide MSC with data on the spatiotemporal distribution of the fleet, while fishers are encouraged to document the catches of vulnerable species, like sturgeons, sharks, rays, and other interesting captures using photography uploads. This picture dataset will be used to enhance the knowledge of the distribution of vulnerable species bycatch in the participating fleets and will be shared with partnering environmental NGOs to support conservation goals.

5.4. Evaluation of the system

Unlike fixed electronic monitoring systems, which need to combine additional hardware (computer, GPS, sensors, cameras, and cables), an app only requires a smartphone/tablet, generally already owned by the end-user. This equipment integrates all the technologies necessary for the app to function (position sensor, camera, storage capacity, and network communication through Wi-Fi or cellular network). Because of its inherent flexibility, the costs of the *Mofi* app can vary widely depending on the chosen project scheme. The development, implementation and data storage costs can be reported onto the end-user through a one-time fee or a subscription. These can be entirely covered by the project administrator, or a combination of both. Regardless of the preferred option, the costs can be broken down into two main categories: up-front fixed costs and annual costs. The fixed and running costs for the *Mofi* app in the cod spawning closure study case were entirely paid by the authorities, making the app "*free*" for the fishers.

[12] https://www.msc.org/what-we-are-doing/our-collective-impact/ocean-stewardship-fund/impact-projects/smartphone-apps-helping-species

5.5. Evaluation of the technology, timeliness, lack of policy and standards, data integrity and data integration

The benefits and risk when using hand-held devises in fisheries (tablets and cell phones) are evaluated in relation to five overall categories: (1) technology, (2) timeliness, (3) lack of policy and standards, (4) data integrity and (5) data integration.

Table 7: Benefit-risk assessment of hand-held devices (tablets and cell phones) in SSF with regards to fisheries control authorities, fisheries/aquaculture professional sector and fisheries science

Criteria	Fishing control authorities	Fisheries/aquaculture	Fisheries science	Comments
(1) Technology				
Proprietary vs. open-source software	One-time development costs per project scheme. Yearly costs for Anchorlab Analyzer software license to access the stored data. Data storage costs.	Depending on the project scheme, the app may be provided for free to the end user or through a subscription.	Yearly costs for Anchorlab Analyzer software license to access the stored data. Data storage costs.	Anchorlab permits downloading the data from the storage server to analyse them using alternative software.
Data transmission and interference	Automatic daily data transmission via Wi-Fi or cellular network to the authorities.	Local data stored on the hand-held device can be reviewed by the user and used as a fishing diary.	Automatic daily data transmission via Wi-Fi or cellular network to the authorities (if allowed in the project scheme).	
Power supply and system reliability	Risk of incompatibilities on devices running older versions of Android or iOS. Real-time monitoring only possible in areas covered with GSM/3G/4G/Wi-Fi.	Risk of incompatibilities on devices running older versions of Android or iOS. Location-based apps like *Mofi* are power-hungry and can rapidly drain the device's battery.	Failure in the *Mofi* app will often result in missed fishing activities if no other monitoring system is in place. No data transfer if no GSM/3G/4G/Wi-Fi network is available.	Data are stored locally on the hand-held device until transfer via GSM/3G/4G/Wi-Fi.
Sensor integration	Documentation of actual fishing activities	Possible through Bluetooth, depending on the project scheme.	Documentation of actual fishing activities.	Sensors to add can include position sensor (GPS), winch sensor, or external camera.

Camera species identification	Possible depending on the project scheme.	Automatic identification not possible yet.	Possible depending on the project scheme.	
(2) Timeliness				
Time to review/ process data	Hours to weeks depending on how many vessels and fishing activities need to be reviewed/processed.	N/A	Hours to weeks depending on how many vessels and fishing activities need to be reviewed/processed.	The time to review/process data depends on the project scheme and the goals of the project administrator. If only the spatiotemporal distribution of the fishing effort is needed, the review process can largely be automated.
Delay in data availability	Data transferred at the end of each fishing trip (often daily in artisanal fisheries).	Immediately visible on the hand-held device screen.	Data transferred at the end of each fishing trip (often daily in artisanal fisheries).	
(3) Lack of policy and standards				
Protocol design/ vessel adherence	Dependent on the project scheme. In the Baltic cod spawning area closure, the German control authorities made the use of *Mofi* mandatory to prove that the vessels fishing near the cod spawning closure area were effectively fishing only in waters shallower than 20 metres.	Dependent on the project scheme. In the Baltic cod spawning area closure, 90 vessels between Feb. 1st and March 31st 2018.	In the Baltic cod spawning area closure, the Thünen Institute was originally refused access to the collected data, slowing down scientific conclusions of the trial.	In 2018 in the Baltic cod spawning area closure, the forced usage of the *Mofi* app by the control authorities antagonised German Baltic coastal fishers and slowed down its generalisation in the region.
Chain of custody	N/A	N/A	N/A	
Multiple service providers	N/A	N/A	N/A	

Fast technology development	Automation of the data analysing processes with machine learning techniques or other ad-hoc algorithms.	Integration of an electronic logbook to replace pen and paper.	Automation of the data analysing processes with machine learning techniques or other ad-hoc algorithms.	For very small vessels, with limited space and manpower, integration of a Bluetooth waterproof buzzer to start/stop fishing activity. Cloud-based machine learning process to identify vulnerable species bycatch.
(4) Data integrity				
Data format	SQL database.	N/A	SQL database.	
Data access/use	All or part of the data are accessible to authorised staff. Data access and analysis typically done through the Anchorlab Analyzer software interface.	Directly on the app.	All or part of the data are accessible to authorised staff. Data access and analysis typically done through the Anchorlab Analyzer software interface.	
Data loss	Back-up systems of all data-servers.	Possible for local data if not already uploaded.	Back-up systems of all data-servers.	
Data tampering	Possible if access to the storage server is granted.	App turned off. Data tampering is not possible from the app.	N/A	Automatic notification system of authorities for vessels with no data logged/transferred within a certain time range would improve the reliably of the system.
Data ownership and confidentiality	Depending on the project scheme, access to the stored data needs to be granted by the project administrator.	The data stored on the hand-held device belongs to the user. Depending on the project scheme, the data may be transferred to a control	Depending on the project scheme, access to the stored data needs to be granted by the project administrator. Unless explicit permission from the fisher is granted, the	To respect the current regulations, access to fishery-dependent data should only be granted to a data analyst provided a confidentiality

		authority to check and enforce regulations. In that case, the data can provide proof in a manner that can stand up at court.	data can only be published if fishers' anonymity can be guaranteed.	disclosure is signed beforehand.
(5) Data integration				
Data compatibility with legacy systems	Data are stored as an exportable dataset, associating unique tags (*e.g.*, picture within haul, within trip) to a vessel/user. The tags include time (duration) and position (area).	Encrypted data are stored locally in the hand-held device and can be reviewed in the *Mofi* app.	Data are stored as an exportable dataset, associating unique tags (*e.g.*, picture within haul, within trip) to a vessel/user. The tags include time (duration) and position (area).	Data can be queried from the storage server using SQL, allowing analyses using alternative software.
Link fishery-dependent and independent data	N/A	N/A	Data input to stock assessment and national DCF programmes.	
Data integration into management/science	Document fishing areas, *e.g.*, in relation to time-area closures. Calculation of fishing effort and intensity, in particular for fleets using passive gears.	Fishers can demonstrate that they respect fishery closures.	Document fishing areas, *e.g.*, in relation to time-area closures. Input in stock assessment. Calculation of fishing effort and intensity, in particular for fleets using passive gears.	

Source: Authors

5.6. Conclusion of the use of this technology

Most European citizens own a smartphone or a tablet nowadays, and these portable devices offer an ideal platform to develop monitoring solutions for small-scale vessels for which space and power onboard are often limited. The *Mofi* app has shown the interest of such apps to monitor the fishing activity of vessels below 12 metres in coastal German waters in relation to spatiotemporal fishing closures. In the case of the cod spawning closure in the Western Baltic, the app was mandatory for small vessels to enforce the compliance to the regulations. This may have limited long-term fishers' engagement, and few continued using it after the fishing closure was ended. On the contrary, the ease of use and versatility of apps are appreciated in other fisheries, as they can speed up and facilitate tasks like reporting the fishing activity to the authorities. Replacing logbooks and landing declarations using data recorded semi-automatically on a smartphone/tablet can be a strong incentive for fishers.

When available, apps can enhance fishing procedures, without the need of dedicated computer software to run on the vessel. This is of particular interest on small-scale artisanal fishing vessels, which cannot accommodate such equipment onboard for a lack of space or power, or simply because it would be too expensive. As with other monitoring systems adapted to SSF, apps allow collecting fisheries data in fleet segments that remain otherwise largely under monitored. A major advantage of apps compared to, *e.g.*, fixed, or mobile EM systems (Chapters 2, 3 and 4) is that they can be used on literally any vessel, regardless of size, provided the fisher carries a smartphone/tablet. The costs of implementing such system on a large number of vessels, be it for management, scientific monitoring or control purposes, is therefore below the one of all the other electronic technologies presented in this report, without necessarily losing much in resolution and accuracy. For very small vessels operating in European waters, the generalisation of apps like *Mofi*, combining fishing activity monitoring, logbook and landings declarations could conveniently replace pen and paper in the future, thereby enhancing considerably the quality of fishery-dependent data.

5.7. Examples of other smartphone and tablet apps

As smartphones and feature phones worldwide are widespread among fishers including in the small-scale vessel fleets, a number of mobile apps have been developed for catch monitoring and reporting. Within the EU several digital tools for SSF have also been developed. In December 2018, a workshop organised in the context of the Expert Group on Fisheries Control was held where solutions, current trends and best practices on digital monitoring and catch reporting tools for small-scale vessels were presented[13]. Furthermore, in several countries outside the EU, national competent authorities and/or software development companies have developed apps that can be used for catch reporting notably. Below is a non-exhaustive list of some interesting ET solutions using smart devices apps currently available on the market; some examples were retrieved from Fujita *et al*. (2018).

Abalobi, South Africa

Abalobi[14] is a suite of tools developed for the Android operating system only. It stands out as being one of the few apps on the market initiated by and for small-scale fishers. It integrates an electronic logbook, which the skipper can share with others – including fisheries authorities – or keep private to run analytical tools from. The development team behind *Abalobi* is also working on enhancing the current system to permit fisheries managers to collect real-time data from the users' apps for

[13] https://ec.europa.eu/fisheries/press/outcomes-workshop-digital-tools-small-scale-fisheries-brussels-4-5-december-2018_en

[14] http://abalobi.info/

monitoring purposes and to create a market platform to guarantee the traceability of the fish product between the harvester and all the way to the final consumer, logbook, and port monitoring. *Abalobi* also includes analytics for fisheries management.

AST iCatch and AST Guardian, United Kingdom

AST, a UK-based company, developed an electronic logbook app, *iCatch*[15], specifically for designed for inshore fishing vessels, in order to reduce the bycatch of some PET species commonly captured in these coastal UK fisheries. The app is branded as a "*fish catch reporting app for smartphones*" and consists of a user-friendly electronic logbook that the fisher can fill in with information on gear type, catches of target species, and eventual bycatches of PET species. For the latter, the fisher can also take a photograph of the incidentally captured animals. The logbook data complement the tracking data collected during the entire duration of each fishing trip by another app developed by *AST*, the *Guardian*[16] app. Both sources of data are stored on the smart device and uploaded to a storage server when in an area covered with a mobile phone network. A summary of the information collected by the app and relevant to the fisher is accessible on a map view, showing for instance the areas/periods where catches are maximised or where bycatch of PET species are minimised.

Deckhand™ Pro, Australia

Deckhand™ Pro[17] is an electronic logbook designed for commercial fishers and used mostly in Australia and New Zealand. The company behind the app recently received the approval to operate in US fisheries. The app is available on iOS only and is customised to specific fisheries needs. It is designed to facilitate the reporting of catches, fishing effort and potential other valuable information (*e.g.,* bycatch of PET species) to the relevant fisheries authorities. *Deckhand™ Pro* complements the information entered manually by the end-user, by utilising the GPS of the device to collect data on the position and speed of the vessel continuously. The collected data can be transmitted automatically to a secured storage server, when the smart device is in range of a cellular or Wi-Fi network.

FACTS™, Canada

FACTS™[18] (Fishing Activity and Catch Tracking System) is a multiplatform Software as a Service (SaaS) solution that is able to run on various hardware, depending on the end-users needs. The "*app*" is in fact a suite of fishery data collection and management software modules acting as an electronic logbook for those accountable for collecting and/or reporting fishing activity and catch data in a fishery. *FACTS™* provides real-time multi-stakeholder data from at-sea and onshore sources, delivering timely, complete, and accurate fishing activity and catch information across a fishery.

FisherMobile, Australia

FisherMobile[19] is a secure mobile App that has been developed to enable the reporting of commercial fishing activity information by authorised fishers using mobile devices such as smartphones and tablets/iPads. *FisherMobile* currently allows authorised fishers to submit and manage real time fishing activity reports such as pre-fish, pre-land and/or post-land reports access quota balance information (consumable and non-consumable).

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15 https://www.theastgroup.com/uk/case-studies/ast-icatch-fish-catch-reporting-app-smartphones/
16 https://www.theastgroup.com/uk/solutions/remote-asset-tracking-monitoring-control/guardian/
17 http://deckhandapp.com/
18 https://www.fisheryfacts.com/
19 https://www.dpi.nsw.gov.au/fishing/commercial/fishonline/fishermobile

mFish, USA

The cloud-based "app" *mFish*[20], available in many different languages regroups a simple logbook to enter catch data and relevant information on weather, price and fishing best practices, while limiting bandwidth usage and corresponding data costs to a minimum[21].

Shellcatch eReporting, USA

Shellcatch eReporting[22] is a smartphone/tablet app available for iOS and Android aiming at facilitating the reporting of fishing operations, captures, landings and fishing effort distribution. The app can conveniently replace pen and paper logbooks in target fisheries. The near real-time reporting speeds up and strengthen fisheries management decision process and allows fishers to declare their fishing activity without needing to travel to the fisheries department. The app can also serve as a fishing diary for fishers to register area and time of the year with best catches per species. The app can be used independently or in conjunction with the rest of the Shellcatch ecosystem. The eReporting app is used daily by several hundreds of small vessels in Central and South America, including Ecuador, Belize, Brazil, Costa Rica, or in the US State of Porto Rico.

VeriCatch, Canada

Similarly, *VeriCatch*[23] has developed an ecosystem of customisable apps to fit the specific needs of their client fisheries. Next to a single customisable electronic logbook app, the company provides two integrated apps: *FisheriesApp*, and *KnowYour.Fish*. The former allows fishers to register and report automatically to the relevant fisheries authorities the details of their catches, fishing effort and potential other valuable information (*e.g.,* bycatch of PET species). The latter takes the data from the electronic logbook (*FisheriesApp*) as an input to help create a chain of traceability between the harvester and all the way to the final consumer. That way, catches can be sold to otherwise non-accessible markets, by guaranteeing the sustainability of a fish product, and the respect of the specifications of ecolabels as *Monterey Bay Aquarium*, *Seafood Watch* and *Ocean Wise*.

[20] https://mfish.co/
[21] https://eachmile.co/state-department
[22] https://shellcatch.com/welcome/ereporting/
[23] https://vericatch.com/about/

6. DISCUSSION AND CONCLUSIONS

In EU fisheries, vessels below 10 metres (below 8 metres in the Baltic Sea) are not required to carry a logbook and record their catches and vessels below 12 metres are not required to use a VMS system. In addition, several Member States have allowed derogations from these requirements. This situation partly explains the lack of information from SSF vessels, which represent more than 85% of the EU fishing vessels, and has a negative impact on the assessment of several fish stocks status, as well as on the efficiency of the management of fisheries and on the assessment of the impact of fishing on EU marine ecosystems.

Since the Control Regulation (1244/2009)[24] and its respective Implementation Regulation (404/2011)[25] were adopted, there has been a significant development of **new electronic technologies** for monitoring all types of fisheries, no matter the vessel size or gear type. Fisheries management processes can take advantage of the recent developments of **electronic technologies to collect fishery-dependent data** across multiple fisheries sectors (Bradley *et al*., 2019). Nevertheless, in EU fisheries, these technologies have not been widely integrated into **fisheries management schemes** yet.

Although the **cost of the hardware and software** for data collection technologies may be a **barrier for small-scale fisheries vessels** and slow down their adoption, this could be overcome by using **adequate financial incentives**. The adoption of the proposal for the European Maritime, Fisheries and Aquaculture Fund 2021-2027 offers possibilities of financial support to implement ET in SSF for monitoring all commercial fishing activities. Especially, **smartphones or tablets may be an adequate solution** in SSF for improving the monitoring of fisheries-dependent data, while the investment in the technology and associated apps is limited.

A reason for not having implemented optimal monitoring solutions using high-tech fishery-dependent data systems most likely pertains to the legal and bureaucratic barriers present in the EU. For SSF fishers, data **confidentiality concerns**, including the identity and near real-time location of their vessels, and potentially even the personal identification of individual fishers, are often seen as a major problem in countries where EM programmes have been implemented. A resistance to change by design is to be expected in institutional systems characterised by an established top-down management structure, such as what exists currently in the EU. In addition, with regards to SSF, a formal **common management structure is lacking** in the Union. Individual fishers or entire fishing communities can be strongly attached to their traditions and thus consider the adoption of new regulatory measures, and in particular the introduction of new electronic technologies, as an inconvenience affecting their normal fishing practices, or even as a threat to their way of life or even to their own food security (Eayrs *et al*., 2015). Such barriers represent a significant challenge to their adoption by fishers, and **specifically designed legal frameworks** adapted to new fisheries data collection technologies might be needed to surmount them.

For fishing vessels above 12 metres, rules for reporting in logbooks, landing declarations and the use of VMS are in place. The requirements imply that fishers are self-reporting catch, effort, and other

[24] COUNCIL REGULATION (EC) No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy, amending Regulations (EC) No 847/96, (EC) No 2371/2002, (EC) No 811/2004, (EC) No 768/2005, (EC) No 2115/2005, (EC) No 2166/2005, (EC) No 388/2006, (EC) No 509/2007, (EC) No 676/2007, (EC) No 1098/2007, (EC) No 1300/2008, (EC) No 1342/2008 and repealing Regulations (EEC) No 2847/93, (EC) No 1627/94 and (EC) No 1966/2006

[25] COMMISSION IMPLEMENTING REGULATION (EU) No 404/2011 of 8 April 2011 laying down detailed rules for the implementation of Council Regulation (EC) No 1224/2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy

fisheries-dependent data, resulting in a data stream that may or may not be reliable. Therefore, a **data quality ensuring system**, such as the use of at-sea observers or onboard cameras, **might be needed**. Monitoring goals vary considerably from fishery to fishery; hence the technologies used to achieve them will also vary. For example, if monitoring compliance with the landing obligation is the goal or if data are to be used to prosecute illegal fishing activities, technologies must be chosen that can generate data capable of meeting standards of evidence in court.

The **management of fisheries** and the preservation of marine ecosystems in the EU would greatly **benefit from the generalisation of ET** adapted for small-scale vessels. Tools allowing fishers and managers to record, review and analyse fine-scale spatiotemporal fisheries-dependant data already exist, but remain largely underused in the Union. **Expanding the usage of these ET** to more vessels would provide fisheries stakeholders with information on SSF that are otherwise largely ignored in the EU. This would help achieving a **more sustainable resource management system**, based on sound and reliable data. Nonetheless, it should be stressed here that a more sustainable fisheries management framework depends not only on the enhancing of the incoming data from the fisheries, although this is arguably a **keystone in achieving an effective ecosystem-based management system** in the EU. To that end, it is essential for fishers – and especially for small-scale vessel fishers – to adhere to the adoption of new technology for monitoring and reporting of fishery-dependent data that management authorities **support financially the uptake of new ET**. For instance, subsidies or other incentives could be made available through the European Maritime Fisheries and Aquaculture Fund (EMFAF). The enhanced and more transparent data streams resulting from the adoption of new ET to collect and report fisheries-dependant data in SSF fleets could offer additional valuable benefits to fishers. For instance, the generalisation of **real-time monitoring** using a smart device connected to the mobile phone network would **greatly improve the safety at-sea** of single-crewed fishing vessels fishers operating inshore, while the **traceability tools** available with several software suites could **increase the market value** of fish captured in SSF, by flagging them as more sustainable then their non-traceable counterparts.

In addition to the above, the use of **electronic technologies** for **scientific purposes** for monitoring fisheries has developed significantly over the last 6-8 years. Most fisheries research institutes now use tablets instead of pen and paper for recordings of biological data. By direct electronic recordings, errors can be minimised, and the overall quality of data recording can improve.

7. POLICY RECOMMENDATIONS

Small-scale vessel fisheries play an **important socio-economic and cultural role** in European coastal communities. In terms of **monitoring and control**, SSF have generally been relatively **neglected in Europe** by fisheries managers and fisheries scientists both at national and EU level. In European waters, SSF often provide **insufficient information** with regards to fishing activities for ensuring a sustainable management of this fleet segment and of the marine ecosystem. Based on the present review, we have come up with a short list of global **policy recommendations**:

- For **monitoring** compliance with the landing obligation, fishing vessels in SSF could be equipped with **video-based EM systems**, as those described in **case studies I** and **III**. It is recommended that video-based EM systems are installed on all the vessels using **mobile gears**, as this is the **fleet segment** with the **highest risk** of non-compliance with the landing obligation. To limit the workload for EM analysts, as well as resulting in a prohibitive cost of such a large monitoring scheme, it is advised that **national fisheries competent authorities** analyse a subset of the entire EM data that are collected. For instance, only a **random selection** of 10% of the entire **fishing activity** could be reviewed, as is a standard in several countries using EM for monitoring compliance with fisheries regulations, and/or **discard** monitoring could be restricted to species with a **total allowable catch** (TAC).
- In fisheries with low discard or bycatch risk, such as **dredge fisheries** for bivalves or low impact fisheries using *e.g.* **pots** or **handlines**, video-based EM is likely unnecessary, but it is recommended to **monitor the spatiotemporal** distribution at a fine-scale for control but also for **documentation** of important **fishing grounds**, using for instance an **EM sensor systems** – or a similar technology – as is described in case study II.
- In fisheries where there is a suspicion of high-risk of incidental captures of **PET species**, including marine mammals, birds, chelonians, as well as **non-commercial fish** and elasmobranchs, it is recommended that at least a representative sample of the fishing vessels in the fleet carry a video-based EM system, such as the ones described in case study I or, *e.g.* for small open boats, the technology described in **case study III**.
- The current requirements for documenting fishing activities in EU fisheries using traditional **paper logbooks** for vessels below 12 meters (10 metres in the Baltic Sea) have been **outdated** for several years. It is recommended to gradually generalise the utilisation of **tablet or cell phone apps** specifically designed to fulfil the EU reporting requirements. These apps, such as some of the apps listed in **case study IV**, should be available in the fishers' **native language**.
- Finally, it is recommended that, for **all length classes**, individual vessels **identity** and fishing **activity** are accessible at the **finer possible spatiotemporal scale** to the competent authorities and to the national scientific bodies responsible for the scientific advice.

Data alone will not result in more sustainable fisheries, and data themselves will not lead to better decision-making, but they are a key component of an **effective ecosystem-based management** in EU waters. It is of course a **challenge for fishers** and especially for small-scale vessel fishers to adopt and afford new technologies for monitoring and reporting fishery-dependent data. Therefore, **financial support** will be necessary when implementing electronic technologies in SFF, for instance through the **European Maritime, Fisheries and Aquaculture Fund (EMFAF).**

A reason for having implemented sub-optimal solutions for monitoring SSF vessels in the EU thus far likely pertains to cultural, as well as legal and bureaucratic barriers. For the fishers' viewpoint, data **confidentiality concerns**, including the identity and near real-time location of their own vessels, and potentially the personal identification of individual fishers, are often seen as major issues in countries where monitoring programmes using ET allowing such identification have been implemented.

Overcoming trust barriers represents a significant challenge for regulatory authorities and fisheries scientists alike, and **specifically designed legal frameworks** that are designed with the use of specific ET adapted to monitoring SSF vessels in mind are needed to guarantee the collection of best fisheries-dependant data possible, while maintaining a high level of confidentiality for individual fishers. Nevertheless, it is recommended that fine-scale fisheries-dependant data, including the identification of individual vessels, are collected and made available to the competent authorities and to the national scientific bodies responsible for the scientific advice. Of course, the usage of these sensitive data, including access and publication, should comply with the current and future European regulations on data handling and storage – notably GDPR – to safeguard their misuse.

It is a challenge for the fishers and especially for the small-scale vessel fishers to adopt new technologies for monitoring and reporting of fishery-dependent data. A better data-input will not by itself result in more sustainable fisheries, nor will it lead to better decision-making, but collecting fishing effort and distribution at a much finer spatiotemporal scale in SSF is a key component to effective ecosystem-based management.

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This study is the third research paper in a series of three, prepared for a PECH Committee Workshop. It examines and presents possibilities of electronic technologies (ET) that can be used to report, document and monitor fishery activities of the small-scale vessel fleet. The national fishing fleets in the EU are large where most of the vessels are less than 12 metres in length. The information on this fleet segment's fishing activities is limited and insufficient for documentation of the fleet's impact on the environment and for fisheries management and governance in general. The present research contains four case studies with current usages of such technologies developed for the small-scale vessels.

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