2017
#GGSD
Forum

Greening the Ocean Economy

21 & 22 November
OECD, Paris

Part of OECD Ocean Economy Week

Issue Paper

An inventory of new technologies in fisheries

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OECD
BETTER POLICIES FOR BETTER LIVES

Challenges and opportunities in using new technologies to monitor Sustainable fisheries

OECD GREEN GROWTH AND SUSTAINABLE DEVELOPMENT FORUM

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Authorship & Acknowledgements

This issue note was prepared for the 2017 GGSD Forum to steer discussion around the theme "An inventory of new technologies in fisheries: challenges and opportunities in using new technologies to monitor sustainable fisheries"**.** This issue note was prepared by Pierre GIRARD, Consultant for Maritime Survey (France) and Thomas DU PAYRAT, Odyssée Development (France). This issue note benefited from comments of several OECD staff members including Antonia LEROY, Dulika RATHNAYAKE, Jaco TAVENIER, Franck JESUS, Roger MARTINI, Claire JOLLY, Ron STEENBLIK as well as Kumi KITAMORI. The authors are grateful to Antonia LEROY and Dulika RATHNAYAKE for their editorial guidance. The note was produced with financial support of Norway. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the OECD or of its member countries.

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List of Abbreviations & Glossary

AFMA	Australian Fisheries Management Authority
AIS	Automatic Identification System
CFP	Common Fisheries Policy
DG MARE	Directorate General for Maritime Affairs and Fisheries (EU)
EEZ	Exclusive Economic Zone
EMSA	European Maritime Safety Agency
ERS	Electronic recording and reporting system
FLUX	Fisheries Language for Universal eXchange
FMC	Fishery monitoring centre
FOCUS	Fisheries Open Source Community Software
GNSS	Global Navigation Satellites Systems (including via GPS)
GPRS	Global Packet Radio System (GSM data support)
GPS	Global Positioning System
GSM	Global System for Mobile communication
IMO	International Maritime Organization
IOT	Internet of Things
IUU	Illegal, unreported and unregulated (fishing)
JRC	Joint Research Centre
MCS	Monitoring, Control & Surveillance
MPA	Marine Protected Area
NM	Nautical mile
RFID	Radio-frequency identification Device
RFMO	Regional Fisheries Management Organisation
UN/CEFACT	United Nations Centre for Trade Facilitation and Electronic Business Union
UNCLOS	United Nations Convention on the Law of the Sea
VHF	very high frequency
VMS	Vessel Monitoring System
VTS	Vessel Traffic Services

Term	Definition
Hacking	gaining of access (wanted or unwanted) to a computer and viewing, copying, or creating data without the intention of destroying data or maliciously harming the computer
Spoofing	hacking that imitates another person software program, hardware device, or computer, with the intentions of bypassing security measures
Deception	Deception technology is a category of security tools and techniques that is designed to prevent an attacker who has already entered the network from doing damage.

Executive Summary

The 1982 UN Convention on the Law of the Sea (UNCLOS) sets out new responsibilities for coastal States regarding the use of resources in their exclusive economic zones (EEZs). Those responsibilities, in many cases, establish the need for both economic development and effective control of a country's marine resources, including fisheries. States are committed to the sustainable exploitation of fish stocks, through better management and conservation of fisheries, ecosystem-based approaches such as marine protected areas (MPA), and reducing illegal, unreported and unregulated (IUU) fishing.

New information and monitoring technologies are potential game-changers for fisheries management and can be of help in achieving green growth of the sector. Application of new technologies has allowed governments to collect more data on fish stocks, better monitor, enforce and evaluate the environmental impacts of fisheries activities and improve the effectiveness of policies to sustainably manage fisheries.

To this end, there are many recent technological developments. Such technologies can be collaborative, i.e. involving more than one stakeholder groups along the value chain or non-collaborative which are set up by governments to monitor the fisheries sector. These include the increased computing power of handheld devices; the proliferation of user-friendly Global Positioning System (GPS) and Global Navigation Satellites Systems (GNSS) applications; increased capacity for “big data” storage, sharing, and analysis; variety and improved durability of drones and low-maintenance radar stations; accessibility and accuracy of satellite imagery; continuous improvements in on-board digital cameras and recorders; expanded use of Automatic Identification Systems (AIS) and Vessel Monitoring Systems (VMS), and the internet at sea.

This paper examines some of these technologies used in maritime fisheries management, both current and emerging, so as to better understand how policies can influence their development and use and vice-versa. It will help governments to consider how they can adapt and improve their policies, regulations, their enforcement and compliances.

The future of fisheries management will not depend on any single technological innovation. A whole ecosystem of new technologies that complement and communicate with each other will help in shaping the toolbox used by policy makers for fish stock management, MPA implementation and fight against IUU fishing.

1. Setting the scene

SUMMARY

- Technological and digital advances now allow innovative monitoring equipment to better manage fish stocks, which are used in all stages of the value chain.
- New technologies, including Big Data, the internet of things (IoT), sensors, robotics, data storage and transmission will become more compact and cheaper thus encouraging their use.
- However, the wider use of these technologies is still limited by their cost, increasingly complex data requirements, challenges in sharing such data among fisheries management authorities and the limited numbers of individuals trained to use these tools.

Fisheries represent an important source of food and livelihood for millions of people around the world. However, based on Food and Agriculture Organization (FAO) analysis of assessed commercial fish stocks, the share of fish stocks within biologically sustainable levels has decreased since the 1970s and is only starting to recover now.[1] IUU fishing is estimated at 15% of total catches, representing a value of EUR 24 billion annually.[2]

Globalisation has provided opportunities for criminal networks to expand the scope and scale of IUU fishing operations, sometimes in combination with other crimes such as drug trafficking, forced labour, tax crimes and even financing of terrorist activities (UNODC, 2011; OECD, 2016).

International organisations support governments in their fight against IUU fishing (Figure 1) but this activity persists partly due to the difficulty in monitoring all seas in real time. As fish stocks become scarcer, fish quotas tend to decline further for law-abiding vessels thereby creating unfair competition from vessels fishing illegally.

[1] In its latest report of *The State of World Fisheries and Aquaculture 2016*, the FAO notes that "good progress is being made in reducing fishing rates and restoring overfished stocks and marine ecosystems through effective management actions in some areas". According to the FAO, 64% of the previously overfished stocks in United States waters had been rebuilt or were showing significant success by 2013. Government-managed Australian fisheries ended overfishing in 2014. Namibia rebuilt its iconic hake fishery, and Mexico restored abalone stocks.

[2] For a detailed definition, please see the United Nations Food and Agriculture Organization (FAO) International Plan of Action Against illegal, unreported and unregulated fishing.

Figure 1: International organisations involved in IUU and related fish crimes issues

Source: Leroy A. and R. Akam (2016)

Technological and digital advances these days allow innovative monitoring equipment to be attached to traditional sampling gear and collect more data such as ecosystem information, in order to better manage fish stocks and tackle IUU fishing. For instance, visual inspections in complex habitats using imaging systems installed on robotic and autonomous underwater vehicles (AUVs) can contribute to the advancement of marine science and better knowledge of fish stocks. In addition, advanced analytics, AIS and high-resolution imagery coming from satellite systems have made a significant change in how countries monitor vessel movements outside of their 12-nm territorial waters. Governments, businesses and individuals are increasingly moving towards these new tools.

As the diffusion and use of new technologies increase the cost of monitoring, surveillance and control at sea, data collection, storage and processing on activities and marine ecosystems continues to decline drastically. However, the wider use of these new technologies is still often limited by the cost of satellite imagery and equipment for smaller vessels, gaps in the interoperability of data-sharing software and hardware, and limited by the number of individuals adequately trained to use these tools. In addition, as fisheries management becomes more holistic, data requirements and analyses become increasingly complex.

This paper gives an overview of new and promising technologies while discussing the potential of innovative monitoring technologies to better manage fish stocks, MPA and IUU fishing. Then, the paper discusses public policy implications for their adoption for green growth.

2. Inventory of innovative monitoring technologies

SUMMARY

- Collaborative monitoring, control and surveillance (MCS) tools rely on the willingness of a given vessel's captain; non-collaborative tools rely on the decisions taken by the authorities in control (on when and where the vessel is monitored).
- Collaborative tools include Vessel Monitoring System (VMS) and Automatic Identification System (AIS).
- Non-collaborative tools include optical or radar satellites.
- New data processing technologies in fisheries include: big data, block chain, smart weighing at sea, Radio-frequency identification (RFID), smartphones for monitoring, artificial intelligence, drones, and on-board cameras.

New technologies can provide data that are reliable and useful to policy makers. This chapter provides an inventory of the current use and development of these technologies along with a description of how a fisheries monitoring centre (FMC) works in order to process and gather various data from all these new tools.

2.1 Current use of new technologies in fisheries

MCS is now a standard part of fishing operations and fisheries management.[3] To understand the incentives and actions motivated by MCS, a distinction will be drawn between **collaborative** and **non-collaborative** tools. The main difference is that collaborative tools rely on the willingness of the vessel's captain to participate in the system. For example, a captain can switch off their VMS or AIS devices, though they risk a penalty. Non-collaborative MCS tools rely on solutions like satellite imagery, where captains are not in control of reporting the time and place of fishing activities, as this is observed by satellites.

2.1.1. Collaborative tools

The main collaborative tools are VMS and AIS, which were first built on existing satellite and radio frequency technologies and electronic recording and reporting systems commonly referred to as E-Logbooks, in order to distinguish them from paper-based logbooks.[4]

a. Vessel Monitoring Systems (VMS)

VMS was originally a satellite-based system that provided data on the time-stamped location, course and speed of vessels to fisheries authorities at regular intervals (every two hours or 12 times per day). [5]

Prior to the 1980s, the only way to communicate with vessels beyond the horizon was by using satellites. In 1978, the members of the International Maritime Organization (IMO)

[3] As defined by [FAO 1981]: "Monitoring refers to the collection, measurement and analysis of fishing activity including, but not limited to, catch, species composition, fishing effort, bycatch, discards and area of operation. Control involves the specification of the terms and conditions under which resources can be harvested. Surveillance involves the regulation and supervision of fishing activity to ensure that national legislation and terms, conditions of access and management measures are observed."

[4] Operators of commercial fishing vessel and some recreational charter fishing vessel maintain on board the vessel an accurate and complete record of catch, effort, and other data on a form, called a logbook.

[5] https://ec.europa.eu/fisheries/cfp/control/technologies/vms_en.

created the International Mobile Satellite Organization (later re-named as Inmarsat) to improve safety at sea and provide the maritime community with satellite telecommunication services. It launched the first satellite constellation to provide VMS services, **Inmarsat**.[6] In the 1990s, the **Argos** constellation provided a solution to environmental monitoring and later for VMS. In 2000, **Iridium** entered the VMS market. Table 2 in Annex provides a comparison of these systems.

In the early 2000s, Eastern Adriatic riparian countries sought an alternative to satellite-based VMS required by the Common Fisheries Policy (CFP).[7] The Global Packet Radio System (GPRS)[8] network was identified as an alternative and adopted by other European countries such as Greece and the United Kingdom. A new generation of hybrid transceivers using both satellite modems (first Iridium, then Inmarsat) was introduced coupled with a GPRS modem. This enabled fishing vessels to communicate cheaply at a distance of six to eight nautical miles from the coastline, before switching to satellite coverage over this virtual limit. By doing so, fishing vessels could take advantage of cheaper global systems for mobile communication (GSM).

VMS are implemented nearly worldwide with various ranges of transceivers. Some countries (e.g. Algeria) only equipped tuna-seiner vessels or specific vessels for fishing in the high seas in order to comply with recommendations by regional fisheries management organisations (RFMO). Hybrid technology allowed some coastal states (e.g. Albania and Croatia) to install VMS transceivers at lower costs than satellite-only technology.

Collecting data on vessel movements can improve management and compliance with fisheries policies by allowing governments to collect near real-time observations of fishing vessel positions. VMS map the spatial distribution of fishing vessels and calculate fishing intensity. For instance, when fishing is prohibited in MPA, VMS information can help steer fishers away from the designated areas. In addition, VMS can be a cost-effective tool for establishing zoning for marine spatial planning (MSP). For instance, spatial fishing data can be incorporated in conservation planning processes to meet the conservation goals of MPAs while minimising loss of revenues for fishers.[9]

However, the scale of VMS remains a challenge as the data collection on vessel movements currently only applies to vessels over 15m in length or 300 Gt in weight. Some 80% of fishing vessels worldwide are currently not fitted with VMS. Since only small-scale vessels measuring less than 15m are allowed to fish in MPAs, they therefore remain unmonitored. In addition, as for all collaborative tools, vessel captains may decide to turn off their VMS transponder risking penalties if caught.

Open-source sharing may be the future of VMS. The United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT) Standards Framework and the Fisheries

[6] This used standard C VMS data in 56-bit (7 bytes) packets.
[7] The EU has accepted this policy with regard to some call of offer without any modification to the CFP. (cf. EuropAid/129568/C/Sup/AL).
[8] GPRS – Global Packet Radio Service is the GSM network counterpart for data transmission only (not voice).
[9] Gonzalez-Mirelis G, M. Lindegarth and M. Sköld (2014), "Using Vessel Monitoring System Data to Improve Systematic Conservation Planning of a Multiple-Use Marine Protected Area, the Kosterhavet National Park (Sweden)", *Ambio,* Vol.43/2, pp. 162-174, http://dx.doi.org/10.1007/s13280-013-0413-7.

Open Source Community Software (FOCUS) recently established a community whose purpose is to create and maintain free software for the management and preservation of fisheries resources.

In April 2015, the Union Vessel Monitoring System (Union VMS) was created as an open-source project funded by the Swedish Agency for Water Management and the European Commission's Directorate General for Maritime Affairs and Fisheries and Fisheries (DG MARE). The objective of Union VMS is to reduce the cost of developing, implementing and promoting collaboration among EU Member States.[10] Reports can be viewed, exported and printed in Union VMS to ensure responsible and legitimate fishing. A small number of EU member states such as Greece, Italy, Malta, and Sweden are currently testing this open-source software.

The Union VMS is currently an European initiative, but is anticipated to be more widely adopted. DG MARE expects that EU Member states, as well as third-party states, will not be reluctant to equip their fishing vessels with MCS collaborative tools (i.e. VMS transceivers, AI systems, FMCs and ERS).[11]

When it comes to lowering costs of VMS for small-scale fishing vessels, the dual or hybrid options should be considered, such as for GSM coastal coverage.

b. Automatic Identification System (AIS)

AIS is a ship-reporting system based on messages broadcasted by vessels carrying transponders. It was developed primarily as a tool for maritime safety to avoid vessel collision by Vessel Traffic Services (VTS) and as a means for coastal states to receive information on vessels operating near their coasts. AIS transponders send and receive signals, using a very high-frequency (VHF) transmitter, broadcast to receiver devices on other ships or to land-based systems. By sending and receiving regular communications about their identity and course, vessels can avoid collisions and navigate safely in low visibility.

AIS provide an opportunity for fisheries management and enforcement as many countries now require AIS for safety and to reduce costs. An AIS message primarily delivers security and safety data (e.g. a vessel's position relative to other vessels near or in relation to the nearest ground station) as well as information about the crew. Associated with a VMS and radar, these technologies can identity a vessel (if it is fishing in a forbidden zone) without giving away its position. VMS delivers 4 major data: latitude, longitude, Speed and direction as the AIS. Additionally, the AIS provides speed in relation to the bottom of the sea. When used together, they can detect whether the vessel is fishing (slowing down to 1 or 2 nautical miles per hour) in a specific area or in transit (moving at 7 to 8 nautical miles per hour). In addition, Radar-Sat monitoring can be used to retrace the trajectory of a ship and look for evidence of illegal trans-shipment, which may be confirmed by AIS or VMS data.

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[10] https://www.havochvatten.se/en/swam/eu--international/international-cooperation/union-vms/about-union-vms.html

[11] See https://ec.europa.eu/info/european-commissions-open-source-strategy_en#softwarestrategy Open-Source Software Strategy 2014-2017: "For the internal development of new information systems, in particular where deployment is foreseen by third parties outside the EC infrastructure, OSS shall be the preferred choice and used whenever possible".

AIS information is a critical tool for coast guards to enhance Maritime Domain Awareness (MDA) in support of all Coast Guard missions. Since May 2014, countries have authorised the use of AIS data and in the EU, AIS applies to all vessels above 15 metres in length.

The drawback of AIS is its limited range. AIS signal transmission is limited by the curvature of the Earth to approximately 40 nautical miles depending on the ground station height, approximately the visual horizon line. Beyond 40 nautical miles, AIS satellites take over, but these can be saturated depending on the area and the traffic intensity causing loss of messages. The European Space Agency (ESA) is promoting a European-based SAT-AIS system in partnership with the European Maritime Safety Agency (EMSA).[12] Two main stakeholders (exactEarth Ltd. and ORBCOMM) share this market today.

Since 2004, the IMO requires AIS transponders to be installed on-board most vessels, according to the SOLAS (Safety of Life at Sea) convention, but as for VMS this only applies to ships of 300 gross tonnes or more.

As AIS is a self-reporting system, the main drawbacks are its unreliability and vulnerability to manipulation. In this context, the main issues to be addressed are the following: *(i)* AIS messages can be erroneous, because a part of the information is entered manually by the crew, both at the initialisation of the system for permanent data (e.g. the name of the vessel) and with data related to each journey (e.g. vessel's destination); *(ii)* AIS reports can be falsified (or spoofed) as a deceptive behaviour since AIS is a broadcast system that sends information, it can be easily intercepted by anyone not only by coastal authorities; *(iii)* a vessel can turn off its AIS transponder so as to engage in illegal activities.

Despite its current weaknesses in term of data security, further consideration should be given to AIS (both satellite and terrestrial) functions in order to: (a) improve defences against spoofing[13] (hardware and software based); (b) grant major development to improve anomaly detection algorithms to identify AIS on-off switching; and (c) promote VHF Data Exchange System (VDES) for a secured future AIS.[14]

c. Electronic Logbook or ERS

Electronic Recording and Reporting System (ERS) is commonly referred to as E-Logbook, in comparison with former paper-based logbooks. E-logbook data (logs records) contribute to better management of fish stocks by keeping track of catches (origin and volume) and gear used. [15]

ERS collects information on species, volume and areas of catches, important data for fisheries. On-board logbooks are mandatory requirements for high sea fishing vessels in some RFMOs such as the Indian Ocean Tuna Commission. ERS can demonstrate when catches haven't been reported correctly and can revolutionise the entire process of data

[12] SAT-AIS bonus is that can be implemented without additional hardware upgrades – vessels and terrestrial stations are already outfitted with AIS technology.

[13] see Glossary.

[14] Major AIS-related threats are "spoofing" either due to software or RF (Radio Frequency) interference. See Trend Micro Research paper "A security evaluation of AIS" ©2014 by Marco Balduzzi, Kyle Wilhoit and Alessandro Pasta.

[15] NOAA (US National Oceanic and Atmospheric Administration) currently uses the term Record Keeping and Reporting (R&R).

collection and reporting during fishing operations. When properly deployed and used, ERS could transform the entire commercial fleet into a provider of good quality data and change the way fish resources are managed.

ERS will make it possible to trace catches back to the individual fishing operation, improve knowledge of fisheries and thus the efficiency of the sector as well as improving control of fishing operations and enforcement (MPA-regulated or otherwise).[16] Collecting data from VMS and AIS in addition to e-logbooks gives a more complete view of fishing activities that can help assess the impact of fishing activity on the ecosystem.

Australian fishers have been using an electronic logbook since 2011 to report catch and effort data to Australian Fisheries Management Authority (AFMA) and this is proving to have real benefits for both AFMA and the industry.[17] Canada is developing electronic logbook client applications (ELOGS), enabling fish harvesters to enter and transmit fishing catch and effort information to the Department of Fisheries and Oceans using electronic files. Phase 1 of this initiative is expected to start in summer 2018. E-Logbook development in China is in progress, relying on local systems, either on Chinese satellites constellation (i.e. Beidou, which also plans to begin serving global customers upon its completion in 2020) or coastal network coverage.

Remaining challenges lie in verifying and harmonising ERS data. The coupling of logbook and VMS data has already proven powerful for describing the spatial distribution of the marine biota habitat at a much finer spatial and temporal resolutions. The VMS and logbook data analysis involves extracting VMS pings from cruise track records that match fishing activities. More than 40% of logbook records were found with correct geographical locations with 0.3-degree precision in 2015. However, 9% of the log data were considered as "cannot be verified" under the data verification programme for catch certification for fish and fishery product export. Such cases of no-verification were mostly observed due to incorrect location data.[18] Diversity of ERS file formats can impede global sharing of pertinent data for fisheries management. DG MARE addressed this by calling for ways to harmonise data file formats. This resulted in the development of FLUX (Fisheries Language for Universal eXchange) format of data exchange designed in 2015.

d. Smartphone for monitoring VMS or AIS data

A fourth category of collaborative tools is using GSM smartphones with VMS transceivers to collect data from fishing vessels and transmit this data to satellite operator to feed customers' database. Such data is then available to be used for monitoring information. The owner of a fishing vessel can now monitor it without even being aboard (see Annex). Some satellite operators provide software which shows vessel location, Estimated Time of Arrival or the course over the last 24 hours. This is done without a direct connection to the satellite

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[16] Amos Barkai, Guy Meredith, Fatima Felaar, Zahrah Dantie, Dave de B (2012), "The Advent of Electronic Logbook Technology - Reducing Cost and Risk to Both Marine Resources and the Fishing Industry", *World Academy of Science, Engineering and Technology*, Vol:6, No:7, pp. ??.

[17] Australian Fisheries Management Authority Electronic Monitoring Program: Program Overview" September 2015 AFMA

[18] On the other hand, recording precise data in paper log book at sea is a challenging practice, especially onboard artisanal fishing vessels

network, using GSM (3G or 4G) with a specific subscription and transceiver with the satellite operator. Similarly, AIS data can be visualised on smartphones and tablets, along with weather data.

This tool provides economic benefit as most of people are already equipped with smartphones. This tool can be easily available and used by stakeholders. GSM smartphones are already used for search and rescue systems. However, the coverage of GSM networks can be very uncertain because this technology is land-based and not sea-based. This tool is therefore limited by its coverage at sea and cannot replace a VHF system at sea. Paradoxically, some countries have set up a distress call number to make calls at sea with cell phones.

2.1.2. Non-collaborative tools

Non-collaborative surveillance systems are increasingly used by national and regional fisheries management authorities to monitor fishing activities in their costal zones and wider EEZ. These non-collaborative tools to monitor fishing activities include a portfolio of systems: from improved coastal ocean radars that are often an integral component of national VTS systems (e.g. ground-based radar and aerial patrol), to new geospatial applications integrating complementary optical and radar satellite data (Annex, Table 2).

Spotting operators that do not play by the rules. IUU perpetrators regularly spoof or disable VMS or AIS messages to inhibit the identification and traffic of vessels operating illegally (in other words by terminating all communication links) they disappear from control screens. However, they can still be detected by coastal radars and satellites. The range available for ship detection varies greatly depending on types of coastal radar systems in place, from a few kilometres to more than 300 kilometres depending on weather conditions. In order to monitor large zones beyond coastal areas, a combination of both optical and radar satellite imagery allows improved detection and ship recognition. Satellite radar sensors allow day and night identification and small vessels down to 15 metres can be monitored, although the detection capabilities of ship targets are greatly influenced by the wind speed and direction (i.e. very small ships can be hidden by waves). Furthermore, although radar satellite surveillance provides wide area coverage, it is often limited by revisit times[19] and by the time necessary to process the imagery, analyse it and exploit it.

New technologies to fight IUU fishing have become more reliable but results tend to be hampered by financial and legal considerations. Satellite imagery technology provides evidence for a potential legal case, but the offended country often fails to make a complaint. Moreover, developing countries often do not have the means to fight IUU fishing.

2.2 Other technological development in fisheries

Section 2.1 showed how collaborative and non-collaborative tools can both greatly contribute to better manage fish stocks and tackle IUU fishing. Additionally, several new technologies, such as intelligent labelling or innovative equipment are increasingly used in

[19] The **satellite revisit** time is the time elapsed between observations of the same point on earth by a satellite, e.g. satellite imaging data with revisit time of 1.4 days. It depends on the satellite's orbit, target location, and swath of the sensor.

fisheries management or by marketing channels. Some new developments are presented below

2.2.1. Big data technologies for monitoring of fisheries

Facing tremendous increase of data for fisheries monitoring, control and surveillance, the Big Data can help in sorting out data coming from new technological tools. It offers an alternative to traditional database and requests tools. Today, data is created and processed on the cloud and displayed in near real-time on mobile devices. Big Data comprises customer transaction records, production databases, web traffic logs, automation, satellites, sensors and IoT.[20] One of the major problems with Big Data implementation is the lack of common language. For instance, there is no kind of "Big Data SQL" shared by various databases and comparisons between systems are far from simple.

Big data can help in sorting the information especially in case of vessel traffic intensity. For example, new web-based technology platform e.g. *Global Fishing Watch* was launched by Oceana, SkyTruth, Google in 2015 combining data from AIS sources (terrestrial and satellite) with powerful algorithms to isolate suspect vessel behaviours. In addition, *The Eyes on the Seas Project* was developed by Pew in partnership with Satellite Applications Catapult, which unites satellite monitoring and imagery data with fishing vessel databases and oceanographic data to help authorities detect suspect fishing activity in MPAs or globally. Other national initiatives are under way.

Box 1: An example of collaborative data analyses, the case of "hackathons"

A new and interesting concept, "hackathon", is proposed worldwide. Hackathons are time-bound design events in which people involved in software development such as computer programmers, graphic designers, interface designers, project managers and others often also including subject-matter-experts, collaborate intensively to develop new software for certain purposes.

This concept has recently been applied to fisheries management, MPAs and IUU fishing issues. Community of software developers propose together and for free new applications for the Ocean environment.

The French Ocean Hackathon relies on the presence in Brittany, France for many and varied digital data related to the ocean. These data are processed and made available for free during a week-end (last edition mid-October 2017), by well-known data providers and challenges offered by stakeholders including the national MPA agency. In 2016, FishHackathon winners used Internet-of-Things technology to help Fisheries and Oceans Canada solve Asian carps spawning problems in the Great Lake. In 2004, the WWF ran a Smart Gear Competition hackathon aimed at increasing selectivity for target fish species and reducing bycatch.

[20] The Internet of things (IoT) is the network of physical devices, vehicles, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data. Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure.

2.2.2. Blockchain technologies

A blockchain is a continuously growing list of records, called blocks, which are linked and secured using cryptography. Each block typically contains a hash pointer as a link to a previous block, a timestamp and transaction data.

By design blockchains are inherently resistant to modification of the data. The first distributed blockchain was conceptualised by Satoshi Nakamoto in 2008 and implemented the following year as a core component of the digital currency bitcoin, where it serves as the public ledger for all transactions.

The first implementation of blockchain technology for the seafood industry was initiated in 2017. Three companies partnered in order to create the first dedicated blockchain system for origin data and tracking for the international seafood industry –the Earth Twine-Stratis Platform. This platform combines collaborative technologies (Earth Twine, SPARKL, Stratis), and will provide the means to increase traceability for fish products, directly targeting IUU fishing products mixed within the value chain of legal products.

Nevertheless, this option is still hypothetical as a competitor will probably not freely share commercial data. Therefore, a critical mass of interest group needs to be fostered for further application and implementation.

2.2.3 Smart weighing system at sea

Large fishing vessels currently use motion-compensated weighing system at sea in order to directly measure and store raw weight of the catch. The boats' movement at sea does not allow determining the exact weight of the catch. Thus, the smart weighing system at sea calculates the weight of catches while taking into account boats' movement. Data is then regularly sent to fish market and ports by satellite support to update landing forecast.

Some of these weighing systems integrate RFID[21] tags stuck on fish boxes in order to add traceability features. New RFID tags allow reading and writing of information such as vessel ID, voyage, specie, weight, size, date of capture and presentation. This technology makes it possible to better respect quotas and control fishing bans for biological rest periods. Correlations can be drawn between fish catches and landing, limiting the risk of fraud.

However, again, the question of the cost of such technology limits the use of the smart weighing system, as it is 6 to 8 times more expensive than a weighing system on the ground. In addition, the "non-legal" aspect of the dynamic-weight is still present for some administrations, e.g. France, whereas Belgium, Norway or Denmark accept these measurements.

2.2.4 Drones (also named as Un-Manned Vehicle)

The growing use of fully or partly unmanned vehicles, or drones, is one of the prominent fields of application of new technology for sustainable fisheries.

[21] RFID (Radio Frequency Identification Device) uses two types of tags, readable by specific UHF reader and smartphone as well (NFC Near Field Contact technology). Use of RFID tags allow fish products to be fully traced, from net to fork, provided each stakeholder has the proper reading/writing device.

Three main type of drone may be distinguished:

- **UAV**: Unmanned Aerial Vehicle
- **USV:** Unmanned Surface Vehicle
- **UUV:** Unmanned Underwater Vehicle (where distinction is made between ROV (Remotely Operated Vehicle) & AUV (Autonomous Underwater Vehicle).

Drones can be used for fish stock assessments, therefore providing cheaper services than oceanographic vessels. MPAs can be monitored and controlled using drones, providing flexible and cheaper means to MPA authorities. Drone surveillance can assist in securing prosecution because it can provide sufficient information for a fishery officer to believe that an illegal act has taken place. As an example, the European Maritime Safety Agency (EMSA) associated with French private company CLS will launch a multi-purposes UAV mission in order to track Illegal Fishing vessels and smugglers (illegally transporting drugs and human). Paradoxically, drones have also been used by tuna fishing vessels for illegally locating tuna aggregations in the Pacific Ocean.

One challenge for the development of drones is that autonomous (unmanned) vehicles/vessels (flying or floating object) are not mentioned in maritime international codes and conventions (such as SOLAS, UNCLOS, COLREGS, STCW, ISM, IMO etc.). The topic is consequently subject to interpretations and uncertainties. For example, UNCLOS uses both the terms “ship” and “vessel” but neither is defined.

Efforts were made to present the concept and way forward for legislation/liability concerning autonomous vessels at the IMO meeting in May 2016. Even though IMO has not delivered a world-wide ratification, national initiatives allow drones on their domestic waters.

2.2.5 On-board survey camera and electronic monitoring

Electronic Monitoring loosely consists of a "closed" video or photographic system, integrated with a sensor system that can be used to view changes in fishing activity and to trigger or coordinate detailed viewing. Both (the recording and viewing) are "closed systems". The camera and sensor systems do not allow external or manual inputs or manipulation of data.

On-board survey cameras may identify interactions with bycatch species and are especially useful when recording bycatches of protected species. The viewed data can also provide a secondary source of data, for example, to validate catch and bycatch log sheets. Cameras can substitute for the observer’s requirements, largely where it may be impractical to deploy observers, or where there may be a threat to the security of on-board observers.

An EM can provide views of critical vessel areas, e.g. gear deployment and retrieval, catch on -board, sorting, processing, storage and can potentially be used to replace or complement the use of human observers (who are expensive, logistically complex and possibly open to bribery).Video records are also requested by the International Commission for the Conservation of Atlantic Tunas for Bluefin tuna catch and transfer from boat to farm.

This technology is not yet mandatory even if it starts to become so for some species in some regions such as Bluefin tuna. It limits the risk of corruption when observers are replaced by cameras.

2.3 Gathering and interpreting data from new technologies: the Fisheries Monitoring Centre

A full fishing vessel monitoring system relies on a well-functioning Fisheries Monitoring Centre (FMC), hosted locally or remotely. Manned by a few experts, the Centre collects fishing vessels' data, validates and stores them, and makes the information available for analysis, either for monitoring in real time of for historical analyses.

1) It relies on four main pillars to collect data:

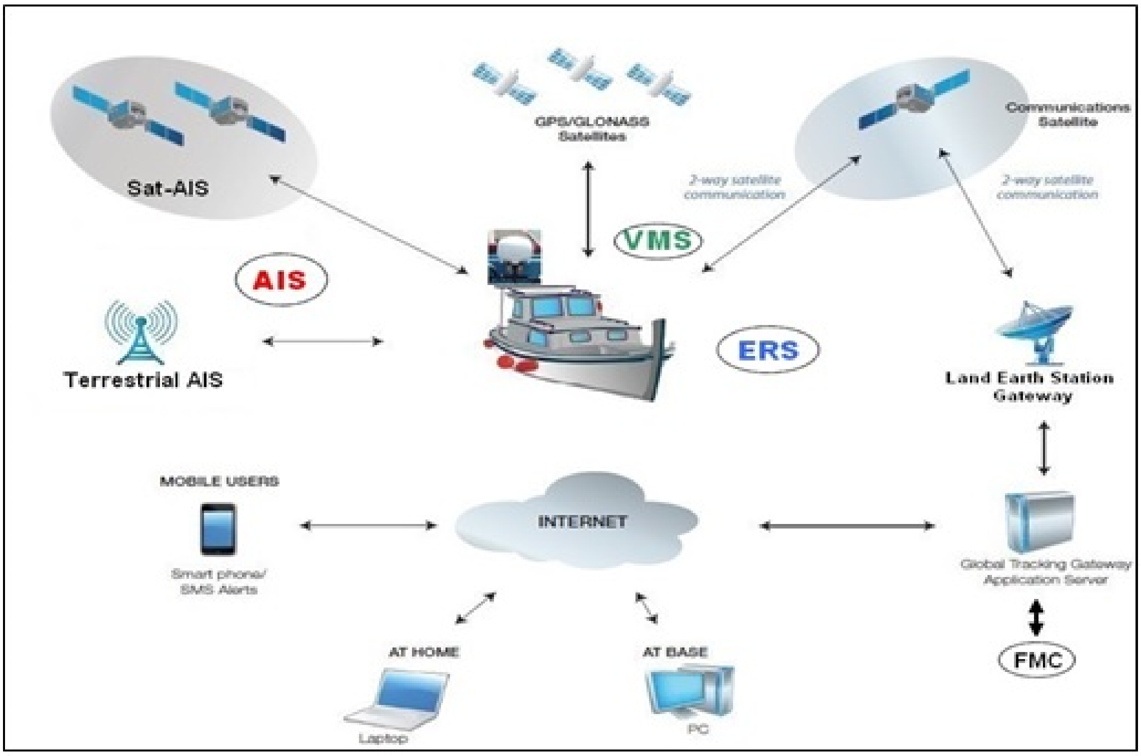
- Database (a collection of data items organised as a set of formally described tables from which data can be accessed),
- Application software (to manage data),
- GIS (Geographic Information System) mapping,
- Communication software (to send and receive various data from various sources).

2) Various data sources can be parsed and merged (figure 2), including;

- VMS (Argos, Iridium, Inmarsat),
- AIS (satellite or terrestrial),
- Satellite optical or Radar data (imaging),

Oceanographic/meteorological data,

Figure 2: Fisheries Monitoring Centre and monitoring tools



Source: Maritime Survey

Figure 2 illustrates a central ship, receiving data from various sources: AIS data, either from terrestrial and satellite; VMS data, from satellite and GPRS (mobile) and ERS data, from satellite and GPRS (mobile). All data are received (via Land Earth Station and Gateway), analysed, saved and monitored in FMC. Access is granted to internet or mobile users.

3) The main functions of FMS are to:

- Provide alerts features on configurable criteria (areas, reports on the vessel's positions, speed, etc.) when spotting suspicious vessels. This allows inspection or interception of a vessel to ordered.
- Display electronic marine charts with options of different layers (i.e. combine several data sources to get a more accurate information),
- Be scalable to integrate any other relevant source of marine data,
- Provide secure remote access (Web).

New technology offers cheaper new assets, e.g. by offering Web-based systems and open-source development features, rather than investing in expensive servers and hosting structures locally. Private owners are renting hosting capacity and highly skilled human resources on a monthly basis. Cost of doing so is reasonable compared to large investment budgets for owing a national FMC. New Zealand and Papua New Guinea use web-based FMCs.

A specific issue in this field is AIS where European consortium JRC (Joint Research Center) is trying to determine whether or not a shortage of AIS message represents an alerting situation. In other words, whether it is due to cheating or accidental technical events. In this context, artificial intelligence could be used by a FMC system trying to learn from multiple past examples to draw a pattern, technically backed on Received Signal Strength available at the AIS Base Station. Some FMCs already use artificial intelligence for cross-checking data received on the vessels' course and their coherence seen with respect to the declared activity.

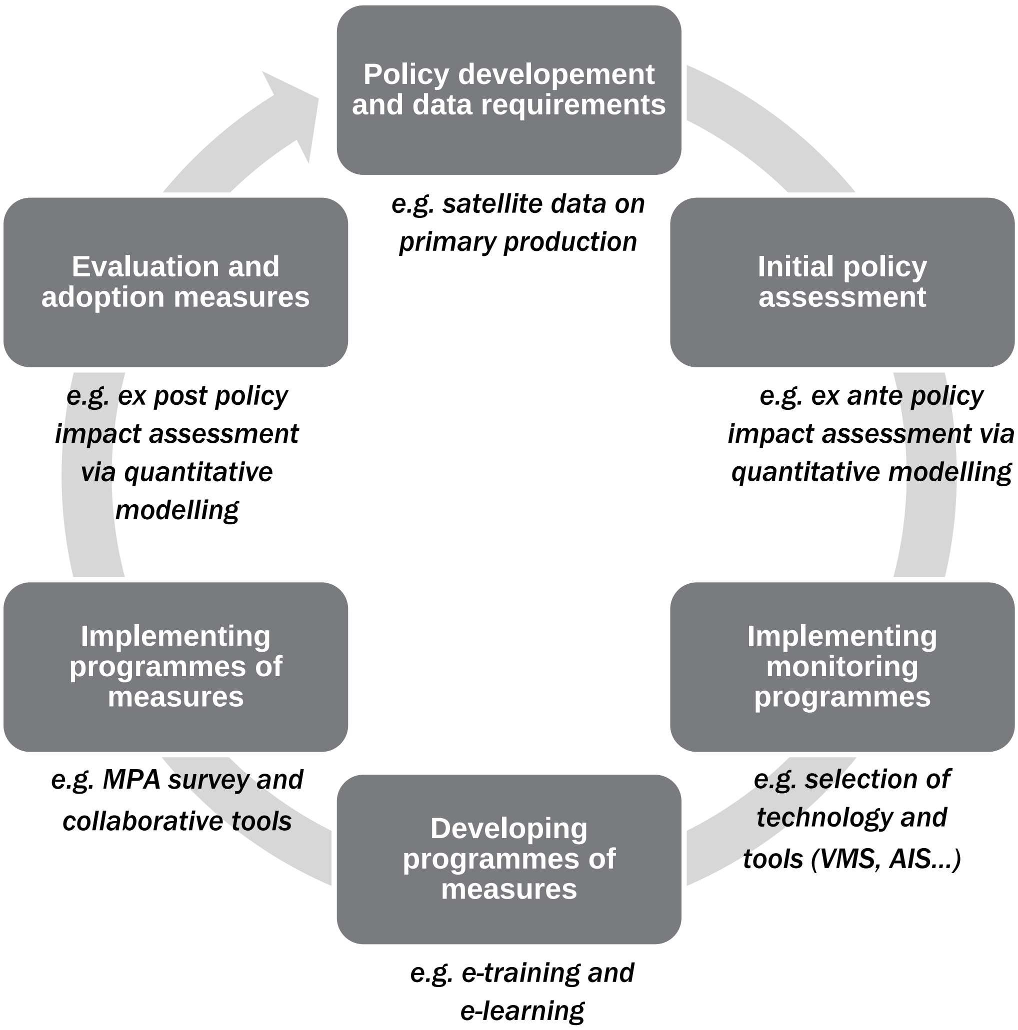
3. Implications for government policies: The pros and cons

SUMMARY

- Promising future technologies and their link to policy instruments are categorised in eight key policy concerns.
- Innovative monitoring technologies are used at the various stages of fisheries policies. They enhance the design, implementation and evaluation of fisheries policy instruments.
- The use of many innovative monitoring technologies carries more advantages for the policy makers and the industry alike – in terms of proper stock management, MPA implementation and fighting IUU fishing – than drawbacks when these tools are used adversely, or when their positive market outcome can yield a negative impact on fish stocks.

New monitoring technologies are commonly used at all stages of fisheries management policy (Figure 3), from development, assessment, implementation, to evaluation.

Figure 3 Use of innovative monitoring technologies at various policy stages



Source: Author compilation

Management tools have more often been successful when used in combination, particularly pairing tools that controlled fishing mortality or efforts with the use of marine spatial management. Examples of successful combinations were the use of catch limits with quotas and limited entry and MPA with effort restrictions.[22]

Fisheries policy instruments are based on the OECD green growth policy toolkit.[23] Examples of specific use of innovative monitoring technologies are suggested for each category, for promoting sound fisheries management, MPA implementation and the fight against IUU fishing.

3.1 Encouraging use of product certification, e.g. eco-labelling

Today, around 13% of fish products are marketed in association with some type of environmental claim (OECD, 2015). Labels that address consumers' concerns regarding sustainability are an effective means to transfer market signals from the consumer backwards through the production chain (OECD, 2016). In this context, a first step in using new technologies would be to better assess fish stock status in general and for certification purposes. This can be done by using satellite, big data and computing power to collect and cross-check data on the ecosystem and thus stock status. The second step, along the chain of custody could be to use smart tags (RFID on boxes or individual fish), or block chain technology available to all stakeholders.

Lastly, social networks can be given an easier and faster access to existing ecolabels information for professional buyers and end-consumers, using smart tags from vessels to markets (via RFID). Social networks will also increase public awareness for more sustainable patterns of consumption via eco-labelling and certification. However, social networks are not always a reliable source of information. Misinformation or "alternative facts" are sometimes broadcast on purpose by stakeholders, acting on public emotion. Another remaining challenge is the willingness of stakeholders to cooperate as they may want to protect their commercial and trade interest. .

3.2 Strengthening fishing gear standards for selectivity and ecosystem preservation

Nowadays, selectivity is an important component of fisheries policies in order to sustainably manage fish stocks. As an illustration, the new CFP regulation, started in 2016, seeks to make fishing fleets more selective in what they catch. By 1st January 2019, all catches of species which are subjected to catch limits will be covered by the landing obligation, prohibiting the practice of discarding unwanted catches back into the sea, unless specific exemptions are in place.

Connected remote cameras provide live feed on on-board practices to fisheries authorities (experimental measures are carried out in some Latin American countries). A risk remains in spoofed or tampered video feeds, deceiving fisheries authorities.

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[22] Elizabeth R Selig, Kristin M Kleisner, Oren Ahoobim, Freddy Arocha, Annabelle Cruz-Trinidad, Rod Fujita, Mafaniso Hara, Laure Katz, Patrick McConney, Blake D Ratner, Lina M Saavedra-Díaz, Anne-Maree Schwarz, Djiga Thiao, Elin Torell, Sebastian Troëng, and Sebastian Villasante (2017) "A typology of fisheries management tools: using experience to catalyse greater success" *Fish and Fisheries*. 18 (3): 543–570

[23] OECD (2015) *Green Growth in Fisheries and Aquaculture*, OECD Green Growth Studies. OECD Publishing, Paris

Quantitative modelling can contribute to adjusting mesh size and light emitting trawls (*SafetyNet Technology)* also increase the selectivity of commercial fishing practices. Internet of things could be used to monitor fishing gears, e.g. net and trap locations or status (empty or full), hence increasing efficiency and reducing fuel consumption. Simultaneously, with the increased use of fish aggregation devices[24] outside regulations, drones and information communication technologies can be used to monitor such technology.

Raising awareness on best practices related to fishing gears can be done more easily and cost effectively through social media to help speed the adoption of environmental innovations in fishing gear, e.g. trawl panels' innovations for fuel consumption and reduced environmental impact (less bottom dragging). In addition, collaborative funding is made available for green technologies applied to fisheries, with public financing, e.g. there are several regional sustainable fishing funds in France. However, some technical "innovations" are subject to discussion, e.g. electric fishing by Dutch fishing vessels is condemned by NGOs and other neighbouring countries of having a strong negative impact. However, commercial (short-term reduced revenues for fishers) and financial (cost of equipment) considerations can postpone or cancel implementation of stricter standards.

3.3 Monitoring Marine Protected Areas

While global coverage of MPAs has been increasing over the past two decades (reaching 11 million square kilometres worldwide), further efforts are required to meet the target under the Sustainable Development Goals and to ensure they are effectively monitored.

AIS and VMS allow for the implementation of strict sailing areas inside MPAs and artificial intelligence can help track suspicious behaviour in sailing patterns, as discussed above. Operating costs of surveillance is often an issue when monitoring MPA. Operating costs can be reduced by using drone surveillance in some selected marine areas.

All these data can be centralised throughout the FMC that connects and analyses data collected via the above technologies. The use of new technologies to monitor MPAs has been considered in correlation to traditional use of vessels like in Mauritania for the Arguin Bank. Nevertheless, the error or the spoofing of AIS messages can have a negative impact on the implementation and lead to false signals to fisheries management authorities when monitoring MPA.

3.4 Modelling the environmental impact of the fishing activity

Intense exploitation of our oceans and seas is degrading marine biodiversity and ecosystems at an alarming rate. Targeting environmental outcomes, when feasible, or operations of fishing activities could help to reduce the environment footprint.

The analysis of sonar and video data can enhance the capacity for modelling environmental impacts. AIS and VMS could help implement and monitor "ecological footprint freeze"[25] or agreements not to develop new fishing zones, e.g. the agreement reached between NGOs,

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[24] Fish aggregating devices (FAD) are rafts used in tuna fisheries, whose shadow attracts fish like artificial reefs. Their use (number per vessel) is strictly regulated.

[25] As fishing activities have already been under way, for decades in some cases, fishers agree not to develop new fishing zones

industry and government in Western Canada trawl fishery. However AIS or VMS messages can also be spoofed (see Glossary) or erroneous, misleading fisheries authorities

3.5 Improving market based instruments for fisheries

Established secure and tradable property rights in the fishery could benefit from new technologies, e.g. Individual Transferable Quota in the Canadian halibut fishery. Monitoring technology allows for real time management of individual or collective transferable quota. For several species and landing points, AIS and VMS system help preserving the stock levels through property rights-based management. FMC connects and analyse the above technologies, and helps policy implementation. However, ITQ databases can be hacked and AIS or VMS messages can be spoofed or erroneous.

3.6 Support traceability in a well-functioning markets

Electronic auctions and real time security deposit follow-up, e.g. in Belgian, French and Dutch fish auctions markets allow remote web-based access to electronic auctions (2/3 of sales at French auctions are web-based).

RFID-based smart boxes/crates allow for complete traceability. For example, French fishing ports are fitting such devices along the value chain from boat to market. Following landings, blockchain technology could secure remote payments in the future and better connect stakeholders along the value chain. USAID Oceans promotes a transparent and financially sustainable electronic Catch Documentation and Traceability system to help ensure that fisheries resources from Southeast Asia are legally caught and properly labelled. The risks remain in illegal transactions, i.e. marketing of IUU products.

Having a better overview of what is happening in the value chain could also contribute to monitor subsidies in fisheries with the contribution of electronic data interchange for international trade operations. This facilitates exports by directly obtaining information on legislation and import restrictions imposed by a third State.

3.7 Enhance capacity to make the best use of new technologies

There is a growing need to contribute to technological capacity building of developing economies that do not have the tools to monitor their EEZ properly. Initiatives for small scale fisheries have been made possible with new technologies by reducing the cost of a new tracking system. For instance smart vessel identification plates in small scale fisheries have been developed, e.g. Western Africa. In addition, new technologies allow for community-based management and co-management. For instance, in remote areas such as in Madagascar, shrimp fishery industry/government co-management relies on new monitoring technologies.

New technologies also raise profile of fisheries in poverty reduction strategies especially in remote fishing communities. It can provide information and communication technologies infrastructures and services such as mobile phone payment. Donor agency could have a better access to market information and target the allocation of funding for fisheries in Aid for Trade projects. Nevertheless, there is also a risk of further impoverishment of poorest individuals or communities, which cannot afford the new technology. They find themselves subject to more efficient harvest strategies on the one hand (declining catch), and greater pressures with higher demand for sea products (higher prices) on the other hand.

Further R&D in developed economies could contribute to using ever-more heterogeneous systems to provide cheaper solutions to fisheries managers. Technologies provide opportunities for a broader and cheaper learning process, e.g. incorporating best practices in training, education and advice programmes throughout the entire value chain. This include E-Learning, collaborative training program using ICT and the use of social networks. For instance, E-learning developments are already undertaken e.g. maritime Massive Open Online Courses on environmental best practices.

Lastly, collaborative data analyses on shared datasets improve public-private partnerships for research, e.g. the use of hackathons in various parts of the world. Such collaborative efforts contribute to increasing transparency especially when E-reputation of fishers, lenders, insurers, marketers can be made and un-done on the internet, prompting them to follow best practices from fear of consumer boycott. However, one has to bear in mind that IUU fishers can use shared data to plan illegal activities, or escape monitoring, if data sharing is done without proper control.

As stated in the beginning of the section, one innovative monitoring technology cannot be singled out as the policy instrument. Rather the combination of technologies, complementing and communicating with each other, offers policy makers an effective toolbox for fish stock management, MPA implementation and fight against IUU fishing.

4. Recommendations for future research

Based on the description of new technological developments and their potential contribution to better manage fisheries, including the organisation of the food chain, this paper considers new technologies as important tools to realise green growth in the fisheries sector. However, there are also many open questions related to policy implications. Potential fields for future investigation encompass technical, legal, economic, financial, human, organisational and awareness aspects. The following is a list of issues for policy discussions and future research:

- How to overcome the barriers arising from commercial and trade interests for the broader use of new technologies internationally along the value chain?
- Numerous initiatives are launched by institutional agencies, RFMOs and NGOs with regards to best fisheries management practices. Nevertheless, lack of coordination and sharing of databases prevents compiling, integrating data and results, leading to a system vulnerable to fraud such as with the current paper-based catch certificate. How to overcome the limited cross-checking of databases? Could a solution be a central data sharing matrix that fishers and NGOs could feed? Hackathons are a good example of best-practice and data-sharing to be encouraged, as it allows for the development of new concepts in MPA implementation and proper stock management.
- New jobs are created with the developments of new technologies. They require training to usefully operate new tools and use and interpret data from new sources. Crowdfunding for fostering new innovations could usefully be complemented by matching public funds. Additionally, fisheries authorities could help innovators pilot test new technologies in quasi-real situations, by providing more flexible legal and administrative framework for pilot testing.
- From a technical point of view, the portfolio of tools to help the fight against IUU fishing is mature and becoming cheaper every year, thanks to the availability of new technologies (in analogy to Moore's Law).[26] The question now is, how can quality control relating to the receipt, verification and tasking of information for monitoring and control systems be improved? Countries need to set up and maintain regional information systems or similar facilities. Greater use of multilateral inspections, and providing consistency in management and enforcement measures including co-operation with RFMOs, should be fostered in order to optimise harmonisation, improve global effectiveness and avoid duplication of work. Better allocation and deployment of inspection resources between neighbouring countries is needed.
- Small-scale fisheries make an important contribution to nutrition, food security, sustainable livelihoods and poverty alleviation – especially in developing countries. Despite this significant contribution, the issues constraining the adoption of new

[26] Moore's law is the observation that the number of transistors in a dense integrated circuit doubles approximately every two years, making technology faster, cheaper and more reliable.

technologies for small-scale fisheries remain poorly understood.[27] Dual or hybrid aspect of new technologies could be considered to lower costs, such as for GSM coastal coverage.

- Stakeholders along the value chain should be included in the decision–making process and the implementation of new technologies to be more adaptable to such changes especially in the case of fishermen working on small-scale vessels under 12 metre where monitoring can become difficult. Prior consultation seems essential in order to present new tools and their use in practice.
- Finally, how can new technologies be better taken into account as evidence in legal cases in court? Do national and international legal frameworks need adjusting, including for areas beyond national jurisdiction?

[27] See SSF guidelines 27 and the Code of Conduct for Responsible Fisheries, which, alongside the fishing provisions of UNCLOS, is the most widely recognized and implemented international fisheries instrument.

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Appendix

Table 1. Optical Vs Radar satellite imagery

Optical satellite imagery	Radar satellite imagery (SAR)
✓ Adapted to the human eye (user-friendly) ✓ Can be analysed at a glance ✓ Gives colour images ✓ Does not require powerful development to obtain a picture	✓ Not dependent on the weather (cloudy, rainy ✓ Adapted to EEZ area down to vessel size ✓ Allows for multi-sources data merging (e.g. VMS & AIS) ✓ Gives cheaper results ✓ Makes forecasting easier ✓ Fisheries monitoring is conventionally based on VMS data. However IUU perpetrators habitually spoof/disable VMS/AIS messages to inhibit the identification and traffic of vessels operating illegally. The use of detection by satellite radar images enables to detect the location of vessels not transmitting ✓ Makes multi-constellations and sensors available on board according to the type of data requested. New generation satellites have a very frequent revisiting time, a very high resolution/ precision and a more reliable and versatile system. (e.g. RADARSAT-2, Sentinel-1A, COSMO SkyMed, TerraSAR-X)
× Severely affected by weather conditions (cloud, fog or night) × More expensive (according to accuracy expected, can be twice) × Hard to predict because it depends on the weather forecast	× Complementary analysis and interpretation are needed for a “non-expert” reading × Black and white image

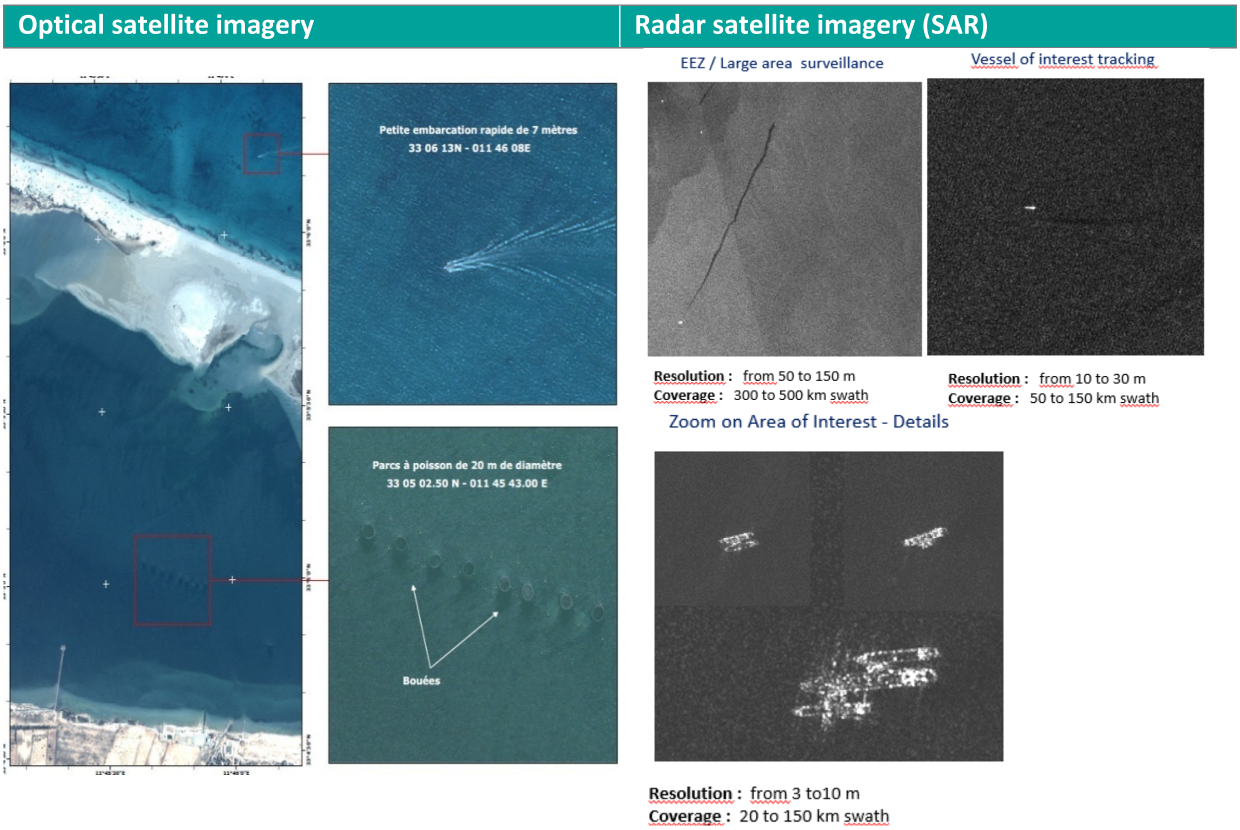

Table 2 Satellite constellations used for vessel monitoring systems (VMS) purposes

Name	Orbiting Altitude	Number of satellites	Assets	Weakness
Inmarsat C (1980)	Geosynchronous orbit above Equator line. Currently I-5 satellite generation.	4 +1 (back-up) standing at 36,000 km altitude. Four oceans coverage	✓ Two way communication ✓ Native *Global Maritime Distress and Safety System* (GMDSS) ✓ Cheap	× Limited coverage on the poles × Lack of anti-spoofing
Argos (1990)	Initially dedicated to environmental monitoring, then offering VMS services. Low polar orbit. Currently Argos 3 and Argos 4 beta.	7 satellites flying at 850 km high	✓ Using both GPS and Doppler effect to get accurate and non-spoofed location	× One way communication × Not e-logbook ready
Iridium (2000)	66 active satellites + backup. Roaming system between satellites	780 km altitude	✓ Two way communication ✓ Cheap ✓ E-logbook ready	× (GMDSS) expected by 2018

Figure 2. VMS data on smartphone (credit: CLS)

Similarly, AIS data can be visualized on smartphones and tablets, along with weather data. Vessels are displayed by categories (fishing, pleasure, commercial…).

Figure 3. AIS mobile application (Source: Marine Traffic)

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