Agenda Item 5	Review of approaches to bycatch monitoring and mitigation measures
Information Document 5	**What's in the Net? Using camera technology to monitor, and support mitigation of, wildlife bycatch in fisheries**
Action Requested	Take note
Submitted by	WWF

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WHAT'S IN THE NET?

Using camera technology to monitor, and support mitigation of, wildlife bycatch in fisheries

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Report delivered by
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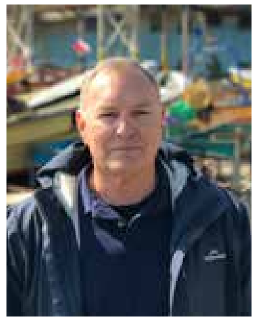


A healthy ocean is essential to all life on our blue planet. But today, the ocean's health is precarious, which is why WWF is working around the world with partners from community groups to UN agencies, businesses to watchdog groups, to secure ocean recovery.

The UN Intergovernmental Report on Biodiversity highlighted that commercial fishing has been the biggest cause of marine biodiversity loss in the last 50 years. As well as the impacts of fishing on target species, fishing vessels often – either unintentionally, or on purpose and illegally – catch species they are not interested in, or are prohibited from taking and selling. It's called "bycatch."

These non-target bycatch species can be almost anything that lives in or near the ocean: fish, seabirds, marine mammals, turtles, sharks – including many endangered, threatened or protected species. Sadly, bycatch is the main driver of decline and threat of extinction in a number of endangered or critically endangered marine species, and staggering statistics estimate that every year fisheries bycatch kills: 720,000 seabirds, 300,000 whales and dolphins, 345,000 seals and sealions, over 250,000 turtles, and more than 1.1 million tonnes of sharks and rays.

While these bycatch estimates show the need for urgent action to bring the death toll down, action is too often hampered by significant scientific uncertainty around the true impact of fishing on our ocean, due to very low levels of independent monitoring. This is why WWF is advocating for greater accountability and transparency from fishing fleets and calling on governments, managers and industry to adopt the most effective, value-for-money tools for monitoring fishing activities at sea, collecting data and assuring best practice and compliance.

A number of fisheries around the world are recognised as being high risk for bycatch and, ideally, these should have 100% observer coverage. However, fishery observers work in some of the harshest and most dangerous work environments known.

As well as heavy machinery and overhead moving equipment, there is the issue of a working on an unpredictable moving platform, often in dangerous seas. Crews can be hostile if there are perceived or real conflicts of interest between observer data and fisher livelihoods. If vessels are at sea for long periods, observers may feel isolated and unsupported. Accidents, injury, intimidation, abuse and unexplained deaths have been reported in some monitoring programmes around the world.

REM presents a cost effective and low risk solution to support the work of human observers, and significantly expand independent monitoring across fleets where there is no monitoring. This report looks at the many benefits REM with cameras has to offer fisheries management, which include cost savings, ability to scale up and improved accuracy of science used to manage and mitigate wildlife bycatch. It also highlights staff welfare as a benefit, whereby REM can improve transparency and safety for human observers on vessels and in doing so, reduce the risk of injury, abuse or even fatality witnessed in human observer programmes.

The COVID-19 pandemic has highlighted the critical importance of building sustainable, healthy natural systems and resilient supply chains, and we feel confident that REM with cameras can contribute to these efforts. REM with cameras and sensors represents a transparent, cost-effective, proportionate and risk-based approach to improving monitoring of fisheries. The comprehensive and verifiable data provided by REM can facilitate the transformation of fisheries across our oceans by unlocking the multiple benefits that flow from sustainable and transparent fisheries management, while also potentially saving lives at sea.

EXECUTIVE SUMMARY

Sustainable fisheries management is vital for the livelihoods and wellbeing of people all around the world, and for the health and survival of marine ecosystems and species.

Remote Electronic Monitoring with cameras (REM) of fisheries is a powerful tool to underpin sustainable fisheries management. This report explores how REM can be used to address the particular issue of unintentional killing of Endangered, Threatened and Protected (ETP) species in commercial fishing, which we term "ETP bycatch."

It outlines the benefits of REM for bycatch monitoring and mitigation and provides an overview of where REM has been used in relation to ETP bycatch around the world to date. It provides five case studies and identifies best practice elements of implementation, and applies these to two hypothetical fisheries of different scale and scope. Finally, it offers advice on accelerating the adoption of REM and recommendations for the adoption of REM as a key element of sustainable fisheries management.

EXECUTIVE SUMMARY

The value of REM for ETP bycatch monitoring

ETP bycatch is a significant issue globally. Every year, it is estimated that fisheries bycatch kills: 720,000 Seabirds, 300,000 whales and dolphins, 345,000 seals and sealions, over 250,000 turtles, 120,000 sea snakes (in one fishery alone), 1,135,000 tonnes of sharks and rays, as well as many thousands of tonnes of protected coral.

Effective management and mitigation of ETP bycatch requires first identifying and quantifying the problem through monitoring fisheries. REM is helping to overcome the significant challenges of monitoring ETP bycatch and is providing the data needed to inform effective management and bycatch mitigation. It can also help meet the needs of an increasingly concerned and environmentally aware public and businesses who want food supply chain transparency and assurance.

Independent monitoring of bycatch at sea is often a choice between using human observers or REM with cameras or a blend of both. Significant advantages of REM over traditional human observer programmes include:

- **cost savings** – independent monitoring coverage can be vastly expanded at a fraction of the cost of a human observer programme
- **efficiencies for data and science analysis** - including producing bycatch estimates, and spatially explicit fisheries risk assessments
- **enables innovative bycatch management** - including targeted risk-based prioritisation of management effort, and the potential for tracking fisheries bycatch impact on populations in real-time
- **addresses observer bias** - thereby improving the accuracy of the science used to manage and mitigate bycatch
- **improves the accuracy** of fisher self-reporting and compliance
- **improves staff welfare** – where observers are supported by, or replaced with, REM systems, reducing risk of injury, abuse or fatality witnessed in human observer programmes
- **enables monitoring on smaller vessels with limited space** - REM can be used effectively on small sized vessels, where placing human observers has been challenging or impractical. New REM 'lite' systems are being developed for use on small-scale and artisanal fisheries

The costs of REM are reducing the more the technology is used, and particularly with the advancement of machine learning. Artificially intelligent software is driving cost and time efficiencies in some industries and these could be applied to REM data, particularly in the review of camera footage and the automatic identification of fishing events from sensors. REM computer systems could automatically detect bycatch events, identify bycatch species, and mark sections of the footage that require the attention of human reviewers.

EVERY YEAR, IT IS ESTIMATED THAT FISHERIES BYCATCH KILLS: 720,000 Seabirds, 300,000 whales and dolphins, 345,000 seals and sealions, over 250,000 turtles, 120,000 sea snakes (in one fishery alone), 1,135,000 tonnes of sharks and rays

Best practice elements of REM implementation

In-depth analysis of case studies of REM implementation in a range of fisheries around the world reveals certain steps and processes that significantly improve the chance of REM project success.

These include:

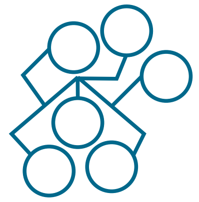
- Feasibility / pilot study conducted that tests specific objectives
- REM in place operationally to address clear objectives
- Roles, responsibilities, and operational requirements, systems and processes are documented (in writing)
- Timeframe for retention of REM information is stated
- Programme review and evaluation undertaken regularly (annually)
- Creating incentives for fishers (e.g. allows vessels with high ETP bycatch to be targeted for management, while vessels performing well continue their normal operations; allows vessels access to markets; could be used to prioritise access to new fisheries/quota; evidence removes inaccurate allegations and builds trust)
- Vessel-specific monitoring data is regularly provided to fishers and there is an identified channel for follow-up when there are differences of opinion about findings
- REM integrated within the broader management framework for management of ETP interactions

While there are clear processes and aspects of REM implementation that encourage success, effective implementation of REM projects and programmes is highly context specific. To illustrate this, best practice is explored in two hypothetical fisheries – an industrial scale trawl fishery with a relatively small number of vessels, and a coastal gillnet fishery with many smaller scale operators. These examples highlight the various stages of successful REM programme rollout.

Accelerating the adoption of REM

The benefits of REM for monitoring and managing ETP species fisheries interactions are clear. The essential question then becomes – *how do we encourage and accelerate the adoption of REM across fisheries globally*? The report identifies that adoption of REM could be accelerated and incentivised by:

- Developing and enabling incentives including market drivers
- Making REM a regulatory requirement and imbedding it as a mainstream operational monitoring method for ETP interactions
- Establishing best practice funding models and improving cost-efficiency – including through development and adoption of automated video review and machine learning
- Proactively addressing information management and privacy concerns
- Building networks and creating collaborative environments where REM providers and experts, and end users can work together to share learnings, build the profile of REM success stories and share knowledge of what works and how to overcome challenges.



ARTIFICIALLY INTELLIGENT SOFTWARE IS DRIVING COST AND TIME EFFICIENCIES

RECOMMENDATIONS

The report concludes that while progress has been made in some fisheries, ETP bycatch remains a significant issue in most fisheries globally. ETP bycatch problems are typically poorly documented, if at all, in existing monitoring and reporting programmes.

REM IS THE BEST WAY TO VASTLY IMPROVE AND EXPAND THE INDEPENDENT MONITORING THAT IS SO VITAL FOR EFFECTIVE ETP BYCATCH MANAGEMENT

REM is an important and effective monitoring tool for monitoring ETP bycatch, which has distinct advantages over alternative monitoring methods. Other electronic technology such as VMS, AIS or E-log cannot provide evidence that can be used to detect and quantify ETP species bycatch and interactions – this data can only be captured by at-sea observers or REM. Given various challenges, and high costs of large-scale deployment of observers, REM is the best way to vastly improve and expand the independent monitoring that is so vital for effective ETP bycatch management.

When considering REM, clarity about the monitoring objectives is vital. Considering the suite of monitoring tools available, and what each has to offer in addressing the monitoring objectives is also essential. REM can then be progressed to meet specific monitoring needs, ideally in operational scale programmes where benefits such as cost efficiency are maximised.

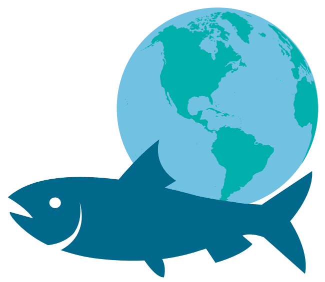
To ensure that REM is as an integral part of the future of fisheries management, recommendations include:

- Formalising the recognition of REM as a mainstream and effective monitoring method for ETP species monitoring
- Ensuring REM is a standard method of monitoring supported by multilateral international organisations, including RFMOs
- Increasing the rate at which pilot projects transition to operational programmes
- Supply chains should consider REM as a condition of seafood sourcing
- Support and enable REM to be recognised as part of a standard transparency measure recognised by global seafood company and retailer led initiatives
- Highlight to major financial institutions which invest in large scale / high risk fisheries companies, the potential of REM to secure their investment (including brand reputation and market share) and mitigate risk
- Encourage and support the development and implementation of automated video review tools that use machine learning and computer vision, to help reduce costs and increase the efficiency of undertaking video review
- Revise scientific modelling techniques and programmes so that REM derived data can be more effectively used in ETP bycatch risk assessments or other ETP population estimation models
- Enable innovative bycatch management, including targeted risk-based prioritisation of management effort, and the potential for tracking fisheries bycatch impact on populations in real-time.

BACKGROUND OF REM IN FISHERIES

In this report, we focus on the application of REM to monitor Endangered, Threatened and Protected (ETP) species interactions with fisheries globally. We consider best practice approaches for monitoring ETP species using REM on fishing vessels and identify barriers and gaps for REM implementation.

We also set out a framework for progressing REM for ETP monitoring, at both the policy and operational levels. REM costs and cost benefits compared to human fisheries observers have been covered in several recent publications, mainly focussed on fish quota uptake and compliance. However, for illustrative purposes an average up to date price for a REM system has been calculated from information supplied by six REM suppliers and discussed in relation to ETP monitoring.



OVER 660 MILLION PEOPLE WORLDWIDE ARE DIRECTLY OR INDIRECTLY DEPENDENT UPON FISHERIES FOR THEIR LIVELIHOODS

The Importance of Sustainable Fisheries Management

Over 660 million people worldwide are directly or indirectly dependent upon fisheries for their livelihoods and there are more than 54 million active fishermen and 40 million fishing vessels around the world [1]. Statistics from 2016 show that the majority of seafood and aquaculture harvested (171 million tonnes which represents 88% of the annual production including aquaculture, in 2016) is for direct human consumption, and global demand continues to grow. Of this, global capture fisheries production accounts for 90.9 million tonnes, of which 87.2% is from the marine environment, meaning a total of 79.3 million tonnes of seafood is landed [2]. In developing countries this reliance is often greatest and fish protein can make up more than 50% of a person's protein diet [1]. Any collapses in fish stocks could have catastrophic implications for local populations and their economies. It is therefore vital to sustainably manage fisheries and the wider marine environment for maximum environmental and social benefits. Key to this will be gathering accurate non-biased fisheries data in order to allow effective fisheries management measures to be implemented and to safeguard the future of fish stocks, and the communities that depend on them.

The Role of Monitoring in Sustainable Fisheries Management

Effective sustainable fisheries management is built on information and the need for accurate data cannot be underestimated. This includes spatial and temporal fishing patterns, catch composition, gear characteristics, compliance information, and at the core of fishery sustainability, the impacts of fishing on non-target marine species, habitats and ecosystems (e.g. [3] [4]). Information used for fisheries management can arise directly from a fishery (e.g. catch and gear characterisation) and independently (e.g. trawl surveys used to evaluate species abundance or species-specific research). Fishery-dependent information is often acquired, or may be verified, through one or more monitoring methods.

A growing global population of consumers and other stakeholders have an increasing interest in the environmental and social impacts of seafood production. Seafood industry stakeholders, including harvesters, processors, distributors, and retailers, are increasingly required – by governments and consumers – to manage their sourcing policies more effectively and transparently than previously (e.g. WWF Traceability Principles for Wild-Caught Fish Products [5] and Global Dialogue on Seafood Traceability [6]).

Increasingly stringent regulations pertaining to the supply and marketing of seafood, changing consumer habits and increased awareness, and growing commercial demands from supply chain partners are now making it necessary for seafood vendors to have access to reliable information about the origins of their products.

Monitoring fisheries is essential for providing assurance that seafood is legally, ethically, and sustainably sourced. Ensuring fish stocks are sustainable is the first principle and forms the basis of assessments for standards and certification. Independent monitoring provides the objective evidence required to ensure that fishing can continue indefinitely, and the fish population and the marine ecosystem can remain productive and healthy.

The Issue of ETP Bycatch

Fishing vessels often unintentionally catch species they are not interested in selling and these are termed 'bycatch'. When the bycatch species are a welcome and legally acceptable addition to the commercial catch, they are retained and landed by the vessel and contribute to the local and national economies. But when they are unwanted because it is illegal to retain them or because there is no commercial market for the species, they are either discarded at sea (dead, dying or healthy and living), or where discarding is banned, they are brought to shore for use as bait, fertiliser, animal feed or disposed of in landfill sites. When bycatch is brought ashore it can be quantified and verified through catch declarations and inspections, but when these unwanted catches are discarded at sea, the quantification processes are harder. These non-target bycatch species may be finfish and elasmobranch species, but they can also be ETP species such as specific teleost or elasmobranch fish species, seabirds, cetaceans, pinnipeds, reptiles and other organisms as specified by the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species [7].

Bycatch of ETP species is often of particular concern to fisheries managers and recognised as a global conservation issue by international governance bodies such as the United Nations. Such species are often inherently vulnerable, having low reproductive rates, and reduced and declining population trends (e.g. [8] [9] [10] [11] [12]). Some ETP species have important ecological value as top predators, and also have high cultural value to many people around the world. Though there are still significant information gaps, ETP interactions are known to occur across a diverse range of fishing methods (Table 1 in Annex 1).

The Challenge of Monitoring ETP Bycatch

Captures of ETP species are often not effectively documented or reported, especially when these species are not commercially valuable, are not part of the target catch, or actual or perceived penalties are in place for capturing them. Despite data limitations, the scale of ETP bycatch is estimated to be significant in fisheries around the world and mortality from fisheries interactions has been recognised as a serious issue for some ETP populations and species. Almost all marine mammals have been recorded as being caught in fishing gear, and bycatch is the main driver of decline and threat of extinction in a number of endangered or critically endangered species [13].

Interactions between fisheries and ETP species present particular challenges for traditional monitoring methods, because these interactions tend to occur at relatively low rates in the context of fishing activity and may be cryptic (i.e. caught animals are dislodged from the gear and are not all landed on the vessel) [14] [15] [16]. Detection and reporting of ETP captures are more likely where human observers are in place. If there is no independent observation and recording of the bycatch event, fishers are less likely to record the event than an observer. However even observers typically have a range of tasks that means they cannot monitor or detect all ETP interactions or capture events [17]. Although 100% observer coverage for all fishing activities for some fisheries is mandatory [18], most observer programmes usually have low coverage rates with observers present only on a small number of fishing trips. For example, in the UK in 2012 approximately 0.4% of fishing trips were sampled by observers [19]. Some fisheries were sampled higher than others for example the Scottish demersal trawl fleet (4.3%) whilst others were not sampled at all, e.g. Scottish pelagic trawl fleet [19]. As a result, fishing impacts on ETP are likely to be undetected, unreported or underrepresented in fishery-dependent data. Bravington and Bisack (1994) [20], estimated that during their study into bycatch of harbour porpoise in set gillnets, 58% of all entangled animals drop out of the nets before they are brought aboard and therefore could easily be missed by an observer if they are undertaking other onboard duties. So even having an observer onboard does not guarantee accurate data when trying to observe some of the protected species groups.

Monitoring Approaches

Traditional approaches to monitoring include both port-based and at-sea methods. For example, monitoring may comprise dock-side inspections (e.g. reconciling landed catch with logbook records), Vessel Monitoring Systems (for at-sea positional information), aerial and on-water patrols (which may include boarding vessels), and human at-sea observers (who conduct a range of monitoring, science and compliance-related tasks) [21]. Despite the recognised value and importance of monitoring information for management (including by multilateral organisations) (e.g. [22] [3]), low levels of monitoring are pervasive among fisheries globally and there are many fisheries in which no monitoring occurs at all (e.g. [23] [24] [25] [16]). As a result, the impacts of fishing on target and non-target species, and the marine environment more broadly, cannot be understood or managed effectively.

There are numerous factors which affect efficacy and feasibility of fishery monitoring approaches. These include cost, quality of information collection (including whether data are comprehensive or representative, and unbiased), and whether information collected can be verified. The logistics required for deploying human observers to collect monitoring information are also significant, and occupational health and safety at sea are key concerns [26] [27] [28]. This is where remote electronic monitoring with CCTV (REM) becomes a useful alternative tool (Figure 1). The efficacy of REM in addressing a range of fisheries monitoring objectives is well established, and includes fishing effort, catch, catch handling, gear, ETP species interactions, and compliance [30] [29].

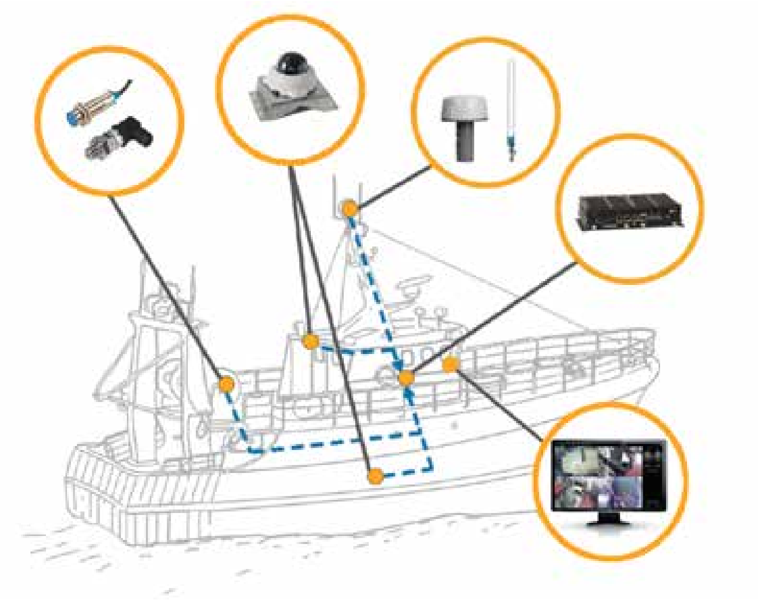


Figure 1. Generalised layout of a REM system, showing (from left to right) gear activity sensors, camera (digital or analogue), GPS and communications antennae, central control box with integrated storage and a GUI (graphical user interface) display screen (courtesy of Anchorlab).

Globally, the challenges involved in effectively monitoring fisheries have catalysed the development of REM ([29] [28]). Public opinion and the growing awareness through greater media coverage and online discussions of environmental issues and the challenges facing wildlife have led to an increase in accountability, with stakeholders and the consumer expecting higher levels of food traceability and evidence of responsible fishing. For ETP species, REM has been used to investigate captures on or in fishing gear (e.g. longline hooks, trawl and gillnets), including components of the gear that do not retain catch (e.g. seabird strikes on trawl warps and third wires). It has also been used to monitor the implementation of mitigation measures intended to reduce ETP species bycatch (see Table 5 in section "Overview of Current Worldwide REM Programmes and Projects"; [30] [31]).

REVIEW OF MONITORING APPROACHES - TECHNOLOGY AND COSTS

40M

ACROSS THE WORLD THERE ARE 40 MILLION FISHING VESSELS

Human observers

The most comprehensive way to quantify ETP species interactions on commercial fishing vessels is to have 100% observer coverage on every single commercial fishing trip, on every fishing event (tow or haul) throughout the duration of the trip and at all locations on the vessel where an interaction event may take place. In this context, observers will see every single interaction and be able to collect biological samples from ETP species brought aboard. But the resources needed to undertake an observer monitoring programme in this way, would be vast, particularly as multiple observers on each trip would be needed to achieve this level of coverage.

To provide an example, in the UK in 2012 there were 6,399 vessels which collectively undertook 135,354 days at sea [19]. If we assumed that an observer could successfully complete 100 days a year on fishing vessels, then the UK would require over 1350 observers, rather than the 20-30 currently employed. Instead approximately 0.4% of fishing effort (trips) is observed in the UK with a total of 574 trips (totalling 714 observed days at sea) being undertaken with an observer in 2012 [19]. The rarity of ETP interactions means that observers spend the majority of their time recording null events.

Across European waters there are approximately 87,000 commercial fishing vessels. Between 2005 and 2008, 6623 dedicated cetacean bycatch observer days were undertaken aboard these vessels under European Council (EC) Regulation 812/2004 The observers recorded 1 spotted seal, 135 cetaceans and 65 loggerhead turtles, an observation rate of 0.03 animals per day, or on average, 1 animal every 33 days at sea, for a total cost of over $6.84[i] million [32].

These 6623 observer days were focussed on specific fisheries thought to have the highest levels of cetacean interactions and only occurred in the set net and pelagic trawl fisheries. Some countries had sample rates as high as 10.5% of the national fishing days in these fisheries e.g. Netherlands observed 647 days out of 6160 days fished. However other countries (France) had sample rates

i All costs where Euros have been used have been converted from Euros (€) to US dollars (US$) using the exchange rate of €1: US$1.14 (correct on 16th July 2020) as low as 1.6% despite having undertaken 2204 observer days which was a third of all observer days completed by the European countries. Some countries were unable to provide the total fleet fishing effort (Latvia, Spain, and UK) so these countries observer effort was removed from the total 6623 to allow a European sample rate to be calculated. This reduced observer days to 5116 and a total fleet effort of 221360 days (pelagic and set net fisheries only for those countries who could supply total fleet effort), equating to 2.3% [32].

Clearly, there needs to be a more cost-effective way of monitoring the relatively rare (depending on fishery) ETP species interaction events, by capturing the same visual data that an observer may see and filtering to the relative points in time. REM can provide this solution. However, the term REM is often used to refer to several different types of technology and not just systems with camera technology included. It is important that the distinctions between these are properly described to ensure that there is no misunderstanding or no misrepresentation of a fishery or programme. This confusion can arise when fisheries claim they are "electronically monitored" when in fact they are "electronically reporting", with no means of further independent verification.

Electronic Catch Reporting – or E-log

The term E-log refers to electronic logbooks where fishermen record their catches at sea or immediately upon landing. It is basically an electronic version of a standard paper logbook which relies on the fishers to enter their catch directly into a database via on-screen software. On larger vessels this is often a mandatory condition of licencing, whereas smaller vessels may still be allowed to use paper logbooks. Prior to the introduction of E-logs the fisher would complete a paper logbook, submit it to the fishery managers or compliance officers, and the paper records would be manually entered into databases by government staff. The workload and staffing levels would dictate how quickly this data could be digitised and available for use. By having fishers enter this data at the time of capture or landing instead, it has allowed the catch data to be available for use almost immediately.

This advancement has helped allow fishery managers and policy makers to react to issues more rapidly as the data is available for use in a shorter timeframe. However, e-log is a form of self-reporting, not a form of independent monitoring. It can therefore be purposely manipulated or fabricated or accidentally completed erroneously, just as the paper logsheets can. In relation to ETP bycatch monitoring it relies completely on the honesty of the fisher to self-report any interactions or bycatch mortality. E-log alone does not provide independence and verification of the collected data and it does not address some strong incentives against accurate reporting, such as when a fisher is concerned that the reporting of an ETP interaction would have a detrimental effect on his fishery and livelihood. Without independent verification of the self-reported E-log data, it should only be considered as anecdotal.

The advances in technology have allowed forms of electronic logbooks either as mobile telephone applications or as software on shipboard computers, to be rolled out worldwide. In Europe it is a legal requirement for vessels over a specified length to report catches using electronic means (Commission Regulation (EC) 1077/2008 [34]). This is also the case in other parts of the world, including India [35], South Africa [36], USA, Canada, Iceland, Norway and Mauritania and the introduction of this technology has helped reduce illegal, unreported and unregulated (IUU) fishing [1].

Electronic Tracking – AIS/VMS

The terms AIS and VMS refer to the electronic tracking systems Automatic Identification System (AIS) and the Vessel Monitoring Systems (VMS), respectively. Both these systems record the position of the vessel and allow it to be broadcast in real-time online and to fishery management and compliance centres. However, they work on different types of technology and serve different purposes.

AIS uses line of sight VHF (very high frequency) radio signals and allows a vessel to display its location and identity to other vessels in its local area. It is mainly used for safety issues so that vessels can be identified and communicated with more readily. However, the general public also have access to this positional and identity data through various web sites and can use it to locate a vessel in near real time. This technology can be switched off and is not mandatory on smaller vessels so is of limited use and is primarily a navigational and safety aid for larger vessels. In remote areas the absence of land-based VHF radio receiving stations means coverage levels can be variable and intermittent.

E-LOG IS A FORM OF SELF-REPORTING, NOT A FORM OF INDEPENDENT MONITORING

NEITHER VMS, AIS OR E-LOG PROVIDE EVIDENCE THAT CAN BE USED TO DETECT AND QUANTIFY ETP SPECIES BYCATCH AND INTERACTIONS

Small VHF AIS receiver units (e.g. the Raymarine AIS 350 Receiver) can cost as little as $536[ii] to purchase and operation is generally free [37]. New satellite AIS systems are now being developed but the costs associated with these makes them only really accessible to the larger cargo vessels rather than small inshore fishing boats. Costs can often be in excess of $5,040/month for a basic satellite AIS unit [38].

VMS is similar to AIS, but it uses satellite communications to relay the position and identity of the vessel to a shore-based data hub. The data is not available to the public and is usually hosted and used by compliance departments to monitor the movements of vessels. By using time and position data, VMS is also used to estimate a speed and deduce an implied activity from this speed. For example, a trawler in the North Sea will usually sail to the fishing grounds at higher speeds (e.g. 8 knots) than when towing fishing gear (e.g. 3-6 knots) and will have times when it is almost stationary during shooting and hauling of the nets, or if broken down, or weathering a storm ("dodging"). But these are assumptions and not proof. The costs of VMS are usually higher than AIS because only a small number of manufacturers are approved to sell to a national fleet - largely because it uses satellite technology and must be tamper proof, as well as meet other technical specifications detailed by the client. A price of $3,024 was provided by the main UK supplier, AST, to purchase and install a system that would be suitable for a 15m trawler (pers. comm. AST, 27/04/2020). However, AST were unable to provide an estimated cost for the transmission of data as this depended on the quantity of messages being sent, although it is expected that this could cost several hundred US dollars per year (from personal discussions with industry).

AIS and VMS are both useful tools for monitoring where vessels are and to indicate what they may be doing, but they do not record *evidence* of fishing activity, they only imply probable activity through interpretation of speed data and positional data. However, if a vessel is excluded from a particular area, is in danger of collision with another vessel, or has gone missing, then these systems are useful in identifying them and their locations. Neither VMS, AIS or E-log provide evidence that can be used to detect and quantify ETP species bycatch and interactions. This data can only be captured by at-sea observers or REM.

REM with Cameras

In this report REM refers to monitoring systems that typically comprise video-capable cameras, fishing activity sensors, a satellite modem, GPS receiver, a user interface and system control centre (Figure 1) and can document fishing voyages in their entirety, or some subset of time or activities on a vessel [29]. The fishing activity sensors allow the fishing effort employed to be quantified and this data links to time and location, through the GPS data, as do the cameras. These systems have been used extensively in trial and operational programmes for more than 15 years [19], in fisheries using a range of fishing methods (e.g., gillnet, pot, purse seine, trap, trawl, and pelagic and demersal longline). Some monitoring programmes have removed the user interface and no manual input is permitted [69] but it can be a useful tool for reminding fishers of responsibilities (through messaging) and getting fishers to complete function health checks or other routine maintenance tasks on the system. These physical checks also transfer the responsibility for ensuring that the vessel sails with a working REM system, to the fisher and should form part of a "Duty of Care" agreement between the programme managers and the participating vessel owners.

The European Fisheries Control Agency (EFCA) recently published a document that recommends the specifications that a REM system should meet for monitoring European fisheries [69a]. It provides details for all aspects of the hardware and also makes recommendations on how to implement and undertake a monitoring programme. This document's main focus is the European Landings Obligation under the Common Fisheries Policy (CFP) [7], but there are useful aspects of this report that could also apply to ETP species monitoring programmes worldwide.

ii All costs where British pounds (£) have been used in cited papers have been converted from British pounds (£) to US dollars (US$), using the Bank of England exchange rate of £1: US$1.26 (correct on 16th July 2020).

Advantages of REM

Significant advantages of REM over observers include reduced cost and potential to increase coverage rates for the same cost, efficiencies for ETP bycatch data and science analysis, improved accuracy of self-reporting and compliance, and improved staff welfare. Some of these advantages are summarized in Table 2).

TABLE 2. COMPARISON OF REMOTE ELECTRONIC MONITORING (REM) WITH COMMON APPROACHES TO COLLECTING FISHERY CATCH INFORMATION.

DATA SOURCE	COMPREHENSIVENESS	BIAS	VERIFIABLE?	ACCURACY	COST EFFECTIVENESS
Fisher logbooks	Should be 100%, if required	Tend to underreport ETP	Not without observer or REM monitoring	Unknown without observer or REM monitoring	High
Observer data	100% possible but rarely occurs	Depends on priorities and tasking at vessel level; depends on coverage at fleet level	May be cross-checked against logbooks	Considered high but usually unquantified	Medium – Low and may decrease
REM	Up to 100% possible on any vessel with a system	Low on participating vessels; fleet-wide, depends on how many vessels are participating	Yes	Comparable with observer data when camera views optimised	Medium – High and will increase
Dockside landing reports	ETP catch not included	NA	NA	NA	NA

Cost savings and increased fleet and vessel coverage

Cost savings and increased fleet and vessel coverage are the main advantages of REM over using seagoing observers for ETP species monitoring. Costs are discussed more fully in the "REM Suppliers" section of this report but it is estimated that REM can cost up to 6.7 times less than using observers [15]. In 2015 it was estimated that to install REM systems on the whole of the over 10m fleet in Europe (18,735 vessels) and review 10% of the video would cost approximately $111m at $5,918/vessel [20]. This cost includes collecting all the sensor and fishing activity data for every vessel (100% sensor coverage) and reviewing 10% of the collected video for finfish bycatch quantification but having all the video available for further checks if needed. Using Kindt-Larsen's (2012) value of 6.7 times more for observers to undertake the same level of monitoring [15], it would cost approximately $743m to undertake the same coverage with at-sea observers.

Efficiencies for ETP bycatch data and science analysis

REM enables efficiencies in producing the essential science outputs from monitoring. To be able to view ETP interactions and capture independent fishing effort and catch data allows the catch per unit effort (CPUE) rates to be calculated and these are important when assessing the impact of fishing on an ETP population. Careful review of the video footage will then allow ETP bycatch events to be reported at the location where the fishing gear was hauled aboard, to give a CPUE by location or aggregated to a sea area. In this way, REM is likely to further a trend towards spatially explicit fisheries risk assessments - which are able to show how ETP bycatch rates vary in space (e.g. in different marine areas), by making it more efficient to link ETP interaction data with geospatial data [39].

Some efficiencies depend on the footage review requirements. If a shore-based REM analyst must watch all the footage captured at normal speed as well as all the traversing time between harbour and fishing grounds, then there will be no time saving compared to using an at-sea observer.

IN THE DANISH INSHORE GILL NET FISHERY, HIGH LEVELS OF DATA ABOUT BYCATCH PROVIDED THROUGH REM HAVE IDENTIFIED SEASONAL RISK HOTSPOTS FOR SEABIRDS IN PARTICULAR MARINE AREAS

There will still be cost savings and health and safety benefits but the time to review the actual fishing events and catch processing will be the same as if an observer had been at sea monitoring that haul event. However, cost savings are still achieved because the REM can record every fishing event and does not need to take rest breaks and if 100% coverage is required, multiple observers on each trip would be needed to achieve this. Also, all REM systems are capable of being reviewed at accelerated speeds, as high as 12 times normal rate in some cases for ETP species [14], and the recording of the video footage can be triggered by the fishing activity sensors and geo-fenced boundaries, to ensure that only relevant footage of the gear being hauled is recorded and reviewed. If a self-reporting mechanism is available to the fisher so that they can alert the reviewing analyst to a particular event and time, even more efficiencies will be achieved. Observers on the other hand need to be on the trip for the full duration including all traversing time (or be transferred at sea which can be highly dangerous and expensive).

REM enables innovative bycatch management

The vastly expanded monitoring coverage made possible by REM provides comprehensive data that can enable new science and innovative management [40] [41]. For example, high levels of data about bycatch and compliance provided through REM in Australia have enabled risk based management where monitoring and enforcement efforts are focused on those vessels where bycatch rates are high or compliance with regulations is low (M. Gerner pers. comm., cited in [27]). In the Danish inshore gill net fishery, high levels of data about bycatch provided through REM have identified seasonal risk hotspots for seabirds in particular marine areas, which can inform spatial management of bycatch risk [26].

As comprehensive data becomes available more quickly via automated bycatch identification and instant electronic reporting, it could be used to produce up-to-the-day estimations of total bycatch across all fleets [42]. Managers can be informed about where bycatch hotspots are in almost real-time, which may enable avoidance of high-risk areas or alerts to vessels to ensure bycatch mitigation technologies and methods are being deployed. Bycatch estimation modelling that can update as new data comes in, will be particularly valuable to help keep track of fisheries impacts on high-risk species and will enable setting and monitoring bycatch limits. Additionally, as the quantity and quality of data increases (as monitoring is expanded), the data can be analysed to identify patterns and relationships between characteristics of fishing (e.g. mitigation use, time and place), and bycatch rates, to learn more about how to best mitigate risk [42].

Addressing Observer Bias

It is not unreasonable to expect that whilst an observer is aboard, the fishers will act in a compliant and responsible manner but on unaccompanied trips there is no incentive for the fisher to be compliant. This is especially the case if there is a financial incentive to act in a non-complaint way e.g. saving quota for subsequent trips by underreporting landings or misreporting catches by species. The presence or absence of an observer may alter the behaviour of the fisher and introduce bias, often called the "observer effect". This observer effect can occur if fishers change where they fish, how long they fish and how they operate their fishing gear when an observer is on board. This means that the observer data cannot reliably infer what the real levels of bycatch are across the fishery from a small observer subsample because the subsample does not represent normal behaviour [43]. This subsampling occurs at the fishery level, for example where 5% of all sea trips are sampled, but also within trip where hauls may be subsampled, and large catches also subsampled.

An observer scheme usually subsamples the fleet because of the high costs and large numbers of observers needed to provide 100% coverage levels, especially where 2 observers would be necessary on long multi-day trips. Subsampling of the fleet and sea trips also occurs where it is unaffordable or impractical to sail on every single trip resulting in low trip coverage levels. For example, between 2005 and 2008, France completed 2,204 days at sea monitoring cetacean bycatch and observed 76 cetaceans. But this sampling was only equivalent to 1.6% of the total fishing effort of 134,784 days at sea [32] and occurred on fisheries that are known to have variability in the size and frequency of bycatch events, so is unlikely to be representative of a typical day's fishing, and could bias the whole dataset for a monitoring programme.

Incidents have been reported where fishers have limited the access to the deck at times when they do not wish observers to view certain activities. Course (2017) [44], undertook interviews of some fishery observers in the UK and reported on incidents of abuse and distrust. Examples where the fisher attempted to affect the results of the monitoring trip include; refusing to let observers sample at night because the catches of a particular species were better at night and the fishers were misreporting these catches; trying to make observers record retained fish as a different species so they could land them and not use up their quota; and to record the retained fish as discarded because they had no quota and were landing them illegally. But if observers are recording data as requested, it could have a serious impact on the accuracy and usability of data collected as part of an observer programme.

If an observer programme monitors 50 days in a fishery in a year (2% of the fleet fishing effort) and records 50 cetaceans being captured in a single hauling event but no cetacean bycatch in the other 49 hauling events, it makes using the data difficult. This would appear to be a very rare event and it could be another 50 or 100 hauls before a similar event occurs again. But if the fishing vessels have been trying to avoid areas of known bycatch or disguising the interactions somehow because an observer is on board, it means that when the observer is not on board the bycatch events could be more frequent or even normal practise compared to the observed days. This uncertainty about what happens on unobserved fishing days should be a concern for managers of observer programmes. The assumption that by randomly selecting a vessel to monitor ensures that the data are representative of an average day at sea, cannot be assured when planning an observer programme. There can also be bias in the observer data collected which may make it unreliable as an indicator of what is going on across the fishery [45].

REM can overcome the observer effect. The REM system is always present and recording sensor and video data and therefore the compliant behaviour encouraged by observer presence, is always there. So in reality, REM doesn't overcome the observer effect but creates a permanent observer effect that encourages accurate reporting, responsible fishing and improved compliance as the new normal practice [46]. It allows wider coverage of the fleet and enables truly random sampling of participating vessels in a way that observers cannot achieve [47]. Fishers are encouraged to avoid seasons and areas where they may catch unwanted or smaller grades of target species, they are encouraged to make technical changes to their gear to enable more selectivity and they are encouraged to diversify into other fisheries. Sandeman *et al* (2016) [48], also reported that some fishers feel that having the REM onboard had made them more profitable as they had moved away from the closer inshore grounds where smaller fish are abundant and were now targeting the larger fish slightly further offshore. This behavioural change ensured that their quota was not exhausted by smaller, less valuable fish.

Improves Accuracy of Self-Reporting and Compliance

The accuracy of self-reported data is questionable when there is an economic advantage to be gained by submitting inaccurate records. Examples can include underreporting commercial catches to preserve limited fish quota for subsequent trips; not declaring the quantities of discarded commercial fish species so they are not taken from the quota; not reporting ETP interactions in case they have a negative impact on access to grounds or create poor public perception of the fishery leading to low demand and low prices or increased regulation. Traditionally, only a subset of observed and verified fisheries data could be used to estimate ETP bycatch and risk assessment modelling. Studies show that with REM on board fisher self-reporting is comparable in accuracy to when an observer is onboard [49], which means that 100% of fisher reported data, where REM was on board to verify these self-reported interactions, may be used in risk assessments and bycatch estimation. This will vastly strengthen estimations and risk assessment modelling and reduce scientific uncertainty.

Most REM systems can transmit the fishing activity sensor data and the GPS time and position data, in near real time. This allows fishery managers to know where fleets are operating at all times and ensure they are not fishing in restricted areas. Fleet management can become more dynamic and port inspections can be targeted based on activity. On small inshore vessels where electronic systems are not mandatory for tracking vessel movements and estimating assumed fishing activity, a REM system allows all geospatial and temporal data to be automatically collected and communicated together with fishing activity sensor data and video for verifying the sensor data outputs. This removes the need to make assumptions and allows all data to be communicated but it also makes fishers more accurate in their self-reported data because they know that at any time, their records can be compared with REM evidence. If a penalty system is established where deliberate misreporting is punished (in a pre-agreed way) then REM creates an incentive to be compliant.

As REM can be configured to always record video of the fisher's catch handling processes, the incentive to be compliant is ever present. Even if only 10% of the video is randomly reviewed (often called the audit approach), the fisher will not know which 10% is being scrutinised so will still be encouraged to operate responsibly. Sensor data and video is collected for 100% of trips and is always available for extended review rates if the subsampled review indicates suspicious activity. Having agreements in place where the additional video review (above the normal audit rate) required during a suspicious event, is paid for by the fishers if found guilty of breaking any rules, creates another incentive for compliant behaviour.

MOST REM SYSTEMS CAN TRANSMIT THE FISHING ACTIVITY SENSOR DATA AND THE GPS TIME AND POSITION DATA, IN NEAR REAL TIME

Not only does REM encourage compliance, it also provides an evidence base to enable enforcement. If REM was mandated for high risk fisheries, such as those exploiting tuna species, it would provide independent evidence for prosecutors to enforce regulations such as EC Regulation No 1005/2008 and 1010/2009, which controls access of illegal fisheries products from third countries into the EU market. Video data allows both defendants and prosecutors access to the same evidence which can be reviewed by both parties and/or independently by an agreed expert, to provide definitive answers to an event. If undertaken prior to court cases it could also lead to considerable savings on legal fees for both sides.

The influence of REM on the accuracy of self-reported data has been demonstrated in several studies.

In Denmark, vessels that were fully monitored with REM landed considerably more of the smaller less valuable size grades of fish, than those with no monitoring. It was concluded that high-grading takes place if fishing is not fully monitored and documented and that REM is a clear deterrent to illegal or irresponsible practices [50]. In Australia, Larcombe *et al.* (2016) [51] showed that the discards reported in logbooks for all the major target species caught in the Australian Eastern Tuna and Billfish Fishery (ETBF) increased dramatically with the introduction of REM. This increased reporting was not just limited to target species, but also secondary commercial and by-product species, and to common but usually discarded species. Only lancetfish species did not follow this pattern. This all suggests that fishers have not been accurately reporting discards for years, and this can seriously impact on the accuracy of stock assessments as this unaccounted mortality would not have been added to the fishing mortality estimates. What is also interesting is that the self-reporting in logbooks of discarded ETP species increased significantly (see Figure 2) by over 750% in the case of marine mammals.

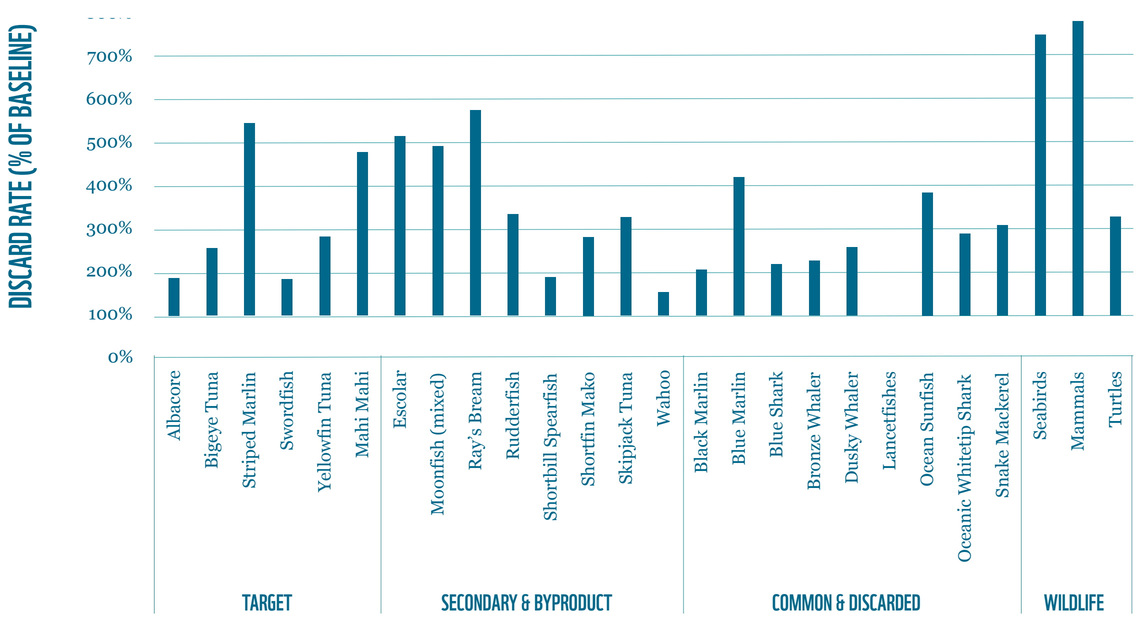


Figure 2. Percentage increase in reporting of discards, by species, in the Australian ETBF fishery [51].

Gear conservation measures also seem to have been improved when REM has been installed. Ulrich *et al.* (2015) [52], found that installing REM on vessels linked to a fully documented fishery (FDF) scheme where discards were counted against quota, stimulated fishers to think of innovative ways to reduce discards without having to increase any technical management rules. It also found that quota management was improved because logbooks could be treated as a reliable source of information for both retained and discarded catch components because of the presence of REM and the ever present deterrent of comparing declarations against video evidence [52]. For vessels without REM (non-FDF) the logbooks should be considered useless for management purposes as there is no verification (or incentive) to be accurate unless there are very high levels of compliance checks through at-sea boarding and port-side landing inspections.

Other examples of improved adherence to legislation and a move towards more responsible behaviour when effectively monitored with REM are provided by Sandeman *et al.* (2016) [48] in the UK catch quota trials (CQT) and others (e.g. [50] [53] [54] [17] [18] [29]).

Improved Staff Welfare

In the UK the Health and Safety Act 1974 states that the safety of staff should always take equal precedence to the work being undertaken and that employers should minimise all risks as far as is reasonably practicable and provide the necessary information, instruction, training and supervision to undertake their work safely [55]. Similar guidance and legislation exist in most countries.

Fishery observers work in some of the harshest and most dangerous and unfamiliar work environments known. As well as heavy machinery and overhead moving equipment, there is the issue of working on an unpredictable moving platform. The weather can be dangerous and on occasions the crews can be unfriendly if there are perceived or real conflicts of interest between observer data and fisher livelihoods. If vessels are at sea for long periods, then observers may feel isolated and unsupported. Accidents, injury, and abuse have been reported in some monitoring programmes [17].

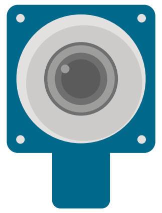
Course (2017) [44], reported that over the last few years, 2 at-sea observers from the USA and 3 from the Pacific Islands have been lost in suspicious circumstances, or possibly even murdered. As recently as March 2020 another suspicious death was reported from Kiribati, bringing the total deaths of observers in this area to 10, with 5 being considered as suspicious and under investigation[56]. The risk of COVID-19 to observers in their workplace has also been recognised, with some jurisdictions removing observer requirements to address this risk (and losing fishery-dependent monitoring data as a result) [57]. Other observers have felt threatened and bullied and others have voiced concerns about the mental health issues associated with being left in isolated and vulnerable situations for months at a time. These incidents could lead to litigation and prosecution of employers and individuals.

The International Fisheries Observer and Monitoring Conference (IFOMC) dedicates a significant proportion of its time to safety and welfare issues due to the seriousness of the safety concerns and its implications on staff and monitoring programmes [17]. These seagoing safety issues and possible legal responsibility issues in an injury, illness, abuse incident or fatality, are removed when observers are replaced by REM. In one case to date, a REM programme was implemented under urgency due to COVID-19 risks to human observers [58].

Potential Disadvantages of REM

There are some disadvantages to using REM instead of observers. The face to face interactions with fishers is reduced and there is less opportunity for fishers to discuss issues or provide anecdotal information and insights, compared to using an observer. However, by incorporating a formal feedback route so that all findings can be communicated back to the fishers, including face to face dissemination of results, communication between fishers and REM project managers can be improved.

The ability to capture biological data from the ETP bycatch is also lost, unless the animals (or samples, e.g. feathers, teeth) are brought ashore. Recent developments in REM tools are allowing some of this data to be estimated from the footage, such as overall length or sex of an animal, but physical tissue samples cannot be collected. Species identification may also be more difficult due to the viewing distance, but video can be reviewed several times to form a consensus if needed, whereas there is no verification of species identification from observers unless genetic samples or photographs showing the identifying features are taken. Even if exact species identification is not possible it will at least provide an opportunity to reach a consensus at a higher taxonomic level (e.g. genus, family).



MULTIPLE STUDIES SHOW REM TO BE THE MOST COST EFFECTIVE METHOD TO MONITOR AND QUANTIFY BYCATCH EVENTS FOR COMPLIANCE OR SCIENTIFIC PURPOSES

REM Costs

To help inform those wanting to explore the viability and options of developing/rolling out REM, we have reviewed the technology supplier community and costs and provided a summary.

Worldwide suppliers of full REM systems that incorporate video cameras are currently limited, with our investigations revealing 7 suppliers of full REM systems with video cameras. These companies were contacted and all except one provided cost information and system specifications for comparisons (Annex 2). These were averaged to get an anonymised average system cost for illustrative purposes. Costs of hardware were investigated in previous WWF reports ([19] [44]) and in other publications ([59] [60] [61]) and they also described the other additional costs associated with REM programmes and compared these against other monitoring methods. It was clear from these that REM was the most cost-effective method to monitor and quantify bycatch events for compliance or scientific purposes, over a long-time frame and large fleet. It allowed the “decision point” to be monitored, i.e. where the fisher decided how they would react to a bycatch event, without the need for 100% observer coverage at all potential discarding locations on every vessel and for every fishing event.

For a 4-camera system with activity sensors, user interface, GPS, and an onboard control box with data storage the average price was $10,043. But if the fleet being monitored is comprised of smaller inshore vessels then a 2-camera system may be sufficient, and this was costed at an average purchase price of $8,068. The lifespan of these REM systems is expected to be approximately 5 years so these prices should be costed over the full lifetime of their system (Table 3). For some REM systems a licence for the vessel operating software is mandatory and where applicable this is included in the system purchase price.

TABLE 3. ESTIMATED COSTS TO PURCHASE A REM SYSTEM WITH 2 OR 4 CAMERAS.

SYSTEM SPECIFIC-ATIONS	PRICE RANGE ($)	AVERAGE OVER 6 SUPPLIERS ($)	COST PER YEAR OVER 5 YEAR LIFETIME ($)
2-Camera System	4,269 to 12,061	8,068	1,613
4-Camera System	5,113 to 14,006	10,043	2,009

NB: Each system uses digital cameras and includes fishing activity sensors, GPS, user interface, data storage, control box and licenced onboard software (if applicable).

Other costs associated with a REM programme include:

- Installation costs
- Maintenance and servicing costs
- Software licencing costs
- Communication of data costs, either through satellite communication or swapping of hard drive storage
- Programme management costs and supporting systems ashore e.g. data storage
- Analyst staff costs for reviewing video footage

Some of these costs will be set by suppliers (e.g. software licence costs) whilst others will be country and programme specific (e.g. salary scales or data transmission costs). Video review costs will be highly dependent on what the analyst is trying to quantify and the skills levels of the reviewers. If the programme’s primary aim is to quantify all retained and discarded finfish species by count or estimated weight, it can often take multiple hours to review 1 hour of real time catch processing with highly skilled staff. However, if the programme is only interested in identifying and counting ETP interactions, the video can often be reviewed at up to 12 times normal speed [14], making it rapid and cheap compared to deploying an observer for the same trip/haul.

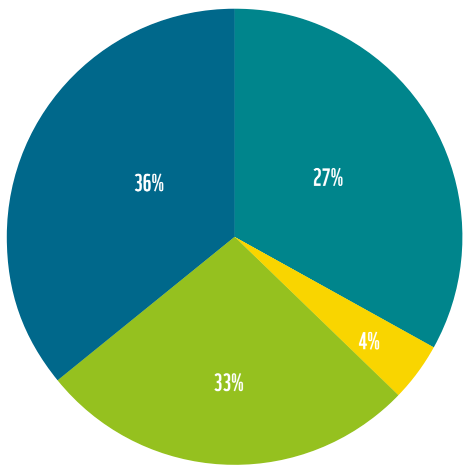
A 2-camera REM system is considered adequate for small inshore vessels and cetacean bycatch monitoring. The annual cost to purchase this system, assuming a 5-year lifespan was estimated at $1,613/year. Installation costs were also obtained from the suppliers and the average cost for installing a 2-camera system was $1,244 (or $249/year). When all the additional running costs of operating a REM programme of $1,992/year are included (this includes $829/year for monthly system health checks, $798/year for servicing and maintenance, $137/year for hard drive swapping/postage, $23/year for purchasing 2 extra hard drives for the 5 year deployment for swapping out, $205/year for remote data transfer by mobile phone communications) [33], the average annual cost of a 2-camera system REM ongoing cetacean monitoring programme is $3,853 per vessel per year (see Table 4 and Figure 3).

Staff costs to undertake the video review for 100% of all video and sensor data collected on 20 fishing vessels was estimated at $2,217 per vessel per year (for a 5-year programme). This was based on an annual salary of $31,920, plus 30% employer overhead costs and an annual video review software licence of $2,861 (to be spread across the 20 vessels) [33].

Therefore, the total cost to undertake 100% video and sensor data review on a typical inshore gillnetting vessel, would be approximately $6,071 per year per vessel. [33]. If the vessel undertook 100 days at sea per year, then the cost per vessel would be approximately $61 per seaday per vessel. The video review rate of 100% has been used for this example because cetacean bycatch events are rare and the video can be reviewed at high speeds, so it is important to review as much footage as possible.

TABLE 4. COSTS ASSOCIATED WITH INSTALLING A 2-CAMERA SYSTEM ON BOARD A VESSEL AND UNDERTAKING VIDEO AND SENSOR DATA REVIEW ON 100% OF ALL DATA COLLECTED (ADAPTED FROM COURSE, 2020 (IN PREP)) [33].

ITEM	OVERALL COST ($)	ANNUAL VESSEL COST ($). ASSUMED 5-YEAR LIFETIME
Purchase	8,068	1,613
Installation	1,244	249
REM Operating Running Costs	9,958	1,992
Video Review Staff Costs (20 vessels/ year/person)	44,357	2,217
Total Vessel Cost per Year		6,071



REM PROGRAMME COSTS
- PURCHASE
- INSTALLATION
- RUNNING COSTS
- VIDEO REVIEW STAFF COSTS

Figure 3. The costs presented in Table 4 as a percentage of the overall cost of a REM programme.

So for illustrative purposes an inshore fleet of 50 vessels with an average priced REM 2 camera system, with 100% video and sensor data review, where each vessel undertakes approximately 100 seadays per year (a total of 5000 seadays), costs approximately $305,000 (50 vessels x 100 fishing days x $61/seaday). If this is compared to the costs of ETP observer monitoring programme, it is considerably cheaper. Between 2005 and 2008 a total of 6623 observer days were undertaken by European countries to monitor for cetacean bycatch at a total cost of over $6.84m [32], which equates to $1033 per monitored seaday. If these days were all undertaken on this same inshore fleet using observers, it would be approximately 17 times more expensive than using REM. Even if the vessel required a 4-camera system at a cost of approximately $6,684 per year over a 5 year project (comprised of $2,009 purchase cost/year, + $466 installation, + $1,992/year annual running costs + $2,217 video review staff costs) [33] or $67/ seaday, it would still be approximately 15 times cheaper to use REM than at-sea observers for cetacean bycatch monitoring.

Note: All costs are subject to local and fleet specific factors.

Undertaking the video review is usually the costliest element of a REM project and is estimated at approximately 36% (Figure 3) [33]. If this can be streamlined REM will become a more affordable and preferred option for undertaking monitoring of ETP bycatch events. There are two ways of achieving this:

1. have a mechanism that allows the fishers to reliably self-report the event at the time it occurs, to focus the video reviewer's attention to the relevant footage, or
2. remove the need for human video review through the development of automatic detection of the events through machine learning.

The first of these is relatively easy to achieve through the introduction of an additional sensor in the REM system that is triggered by the fisher when an event occurs. It is far more likely to be carried out than the completion of paperwork after the event. However, it would require video review as quality control (at a reduced rate) to ensure that fishers are accurately reporting the events. Machine learning on the other hand could be completely autonomous of the skipper, although it would also require an element of quality control video review until the software algorithms are refined and certified as accurate.

TYPICAL COST FOR 100% REVIEW OF INSHORE VESSEL WOULD BE AROUND $6,071 PER VESSEL PER YEAR

Machine learning and the future of REM review

Definitions:

- *Machine learning – Applications of artificial intelligence that provide systems the ability to automatically learn and improve from experience without being explicitly programmed, for both image-based and non-imaged-based data.*
- *Computer vision – Machine learning applications for acquiring, processing, and analysing digital images, and extraction of high-dimensional data from electronic monitoring systems* [62].

While REM involves the remote collection of fishing information, human reviewers are essential onshore to access this information and enable its use. This process can be laborious, even when imagery review speeds of many times real time are possible (as is often the case for ETP, especially large animals). Machine learning (ML) and computer vision (CV) together have immense potential to reduce the amount of time required for human review, such that the rate at which imagery and associated information can be processed will increase significantly in future. Further, as components of the review processes are streamlined by the application of ML, human analysts' time can be focused on the more challenging elements of review and programme implementation. REM programme documentation would reflect review systems and processes overall, including the automated tasks completed using ML. The high-level integration of machine learning into a REM review process is set out in Figure 4.

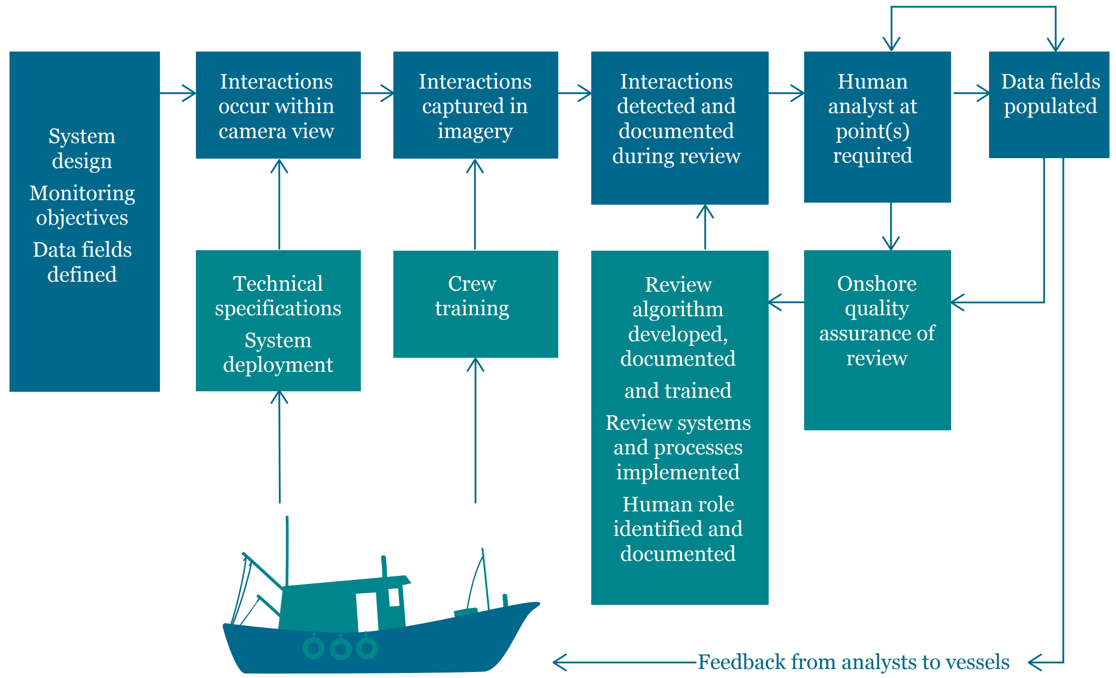


Figure 4. Selected process steps, and inputs to those steps, enabling the effective collection of information on ETP interactions with commercial fisheries using remote electronic monitoring and incorporating automated review [30].

The review process is one of the main cost pressures associated with using REM for identifying and quantifying catch. Machine learning applications that effectively identify and flag events of interest will reduce review time and costs significantly. This is because human analysts will no longer need to sift through larger volumes of imagery to find events of interest. Instead, they are able to focus on extracting data from events identified by ML. For example, in the US Atlantic pelagic longline fishery targeting swordfish, yellowfin and bigeye tuna, automated detection of catch items on hooks has doubled REM review capacity [63].

In contrast to the focus on activity recognition for algorithms in the Atlantic longline example, characterising catch utilises algorithms that focus on object identification. Significant progress has been made in automation of fish species identification and length measurement. In 2006, researchers undertook trials that utilised camera technology to sort fish by species and obtain length measurements and obtained a 99.8% success rate over the 7 species tested. They also stated that the technology could identify different round fish species with an accuracy of 99% and that the only limiting factor to the system was the need to feed the fish under the camera individually [64]. French et al. (2015) [65], conducted research that utilised video collected from a standard REM system and attempted to automate the "tedious and expensive" video review process to allow finfish to be identified and quantified. They took footage from 12 different conveyors installed on fishing vessels and found that the video from 6 belts was unusable due to permanent structures occluding large portions of the belt, that the field of view was not sufficient or because the camera became too dirty during catch handling and fishing operations. Of the remaining 6 conveyor data sets, a further 3 were found to have high errors when comparing counts of fish. A range of 2-16% error between relative counts of fish were reported. When the results of this study are compared to the longline fishery example, it can be seen that there are considerable differences in the results mainly due to how a vessel is set up with the cameras in the first place and how the catches are handled, with approximately three quarters of the data collected in this second example being almost unusable. However, the significant potential for automated fish identification is further emphasised by accuracy rates of 92% in identifying four different types of orange-coloured rockfish from a longline fishery during testing and training of computer software [66]. So, with good quality video footage and the right catch handling procedures implemented, high accuracy species identification and counts should be possible.

Measuring length has variable complexity, depending on the location and surroundings of the catch item. Automated measurements are straightforward to record when a fish is on a marked measuring board, for example, in contrast to when it may be moving through space at variable distances from the REM camera [67].

MACHINE LEARNING APPLICATIONS THAT EFFECTIVELY IDENTIFY AND FLAG EVENTS OF INTEREST WILL REDUCE REVIEW TIME AND COSTS SIGNIFICANTLY

For ETP specifically, lab-based work tested approximately 200 images of seabirds, to determine the efficacy of identifications after camera systems were exposed to around 1,800 training images of a variety of seabird species (including albatrosses, fulmars, shearwaters, and gulls). Black-footed and Laysan albatrosses were identified with a 100% accuracy in this setting. Across all images tested, 93% were identified correctly. The number of training images appeared to affect the accuracy of identification [68]. Identification of seabirds in simulated hook and line capture events has had similarly promising results. Seabird species identified with 100% accuracy included a range of procellarids, alcids, and 2 species of Anatidae. Three species of auklets were the most challenging for automated identification, with 33 – 90% accuracy [69].

An important part of REM imagery review is identifying anomalous events or unexplained behaviours. Such instances may indicate that an event of interest has occurred which would not otherwise be detected. For example, in a New Zealand pilot REM programme that sought to monitor Hector's dolphin (*Cephalorhynchus hectori*) captures in a gillnet fishery, there were three instances of unexplained or unusual behaviour observed in imagery, which may have resulted in catch items of interest not being documented on video [70]. Using ML to detect unexplained behaviour is challenging, given the diverse range of behaviours that could occur. Identifying 'regions of interest' on a vessel in this context, may facilitate detection. For example, net hauling is characterised by a sequence of crew activities in a particular area. Therefore, if a crew member enters an area that is not normally used during hauling, this could indicate an anomaly, in turn highlighting an event of interest that is deliberately being obscured from camera view (e.g. cutting a cetacean or pinniped out of a gillnet whilst it is still in the sea). Best practice to support the use of ML to detect such anomalies is providing an unobstructed camera view of the region of interest, and an overhead view if possible [67].

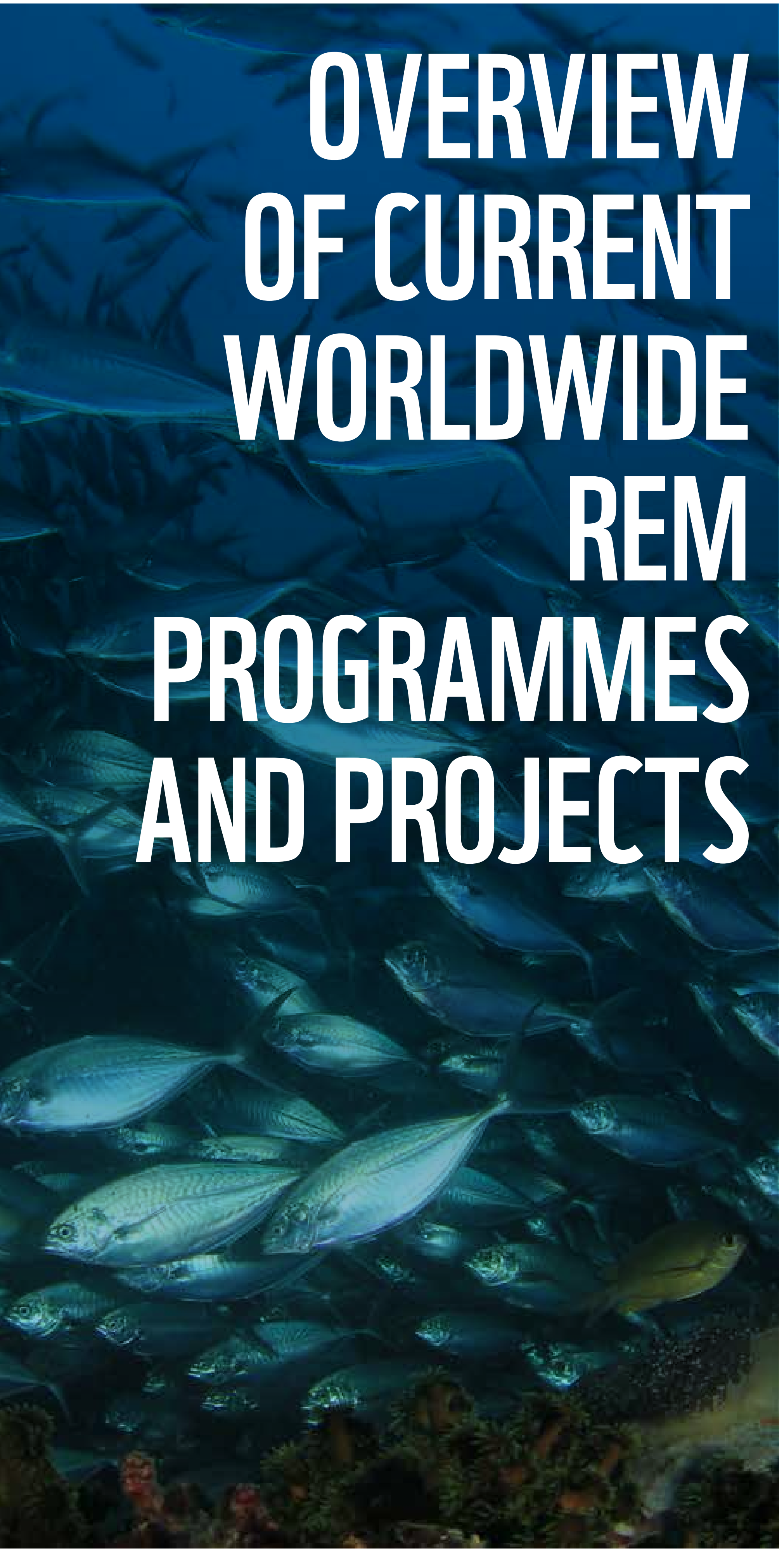
Machine learning for ETP monitoring

Early exploration of computer-based image recognition software and technology for detecting ETP bycatch used computer generated montages of images overlaid on top of each other to try and highlight the presence of a cetacean. However, this approach proved no more efficient than watching the video footage of the hauling event at 12 times normal speed (Kindt-Larsen et al, 2012).

To progress image review focused on ETP specifically, training datasets are needed, and the impetus for developing these is most likely to be increased interest in ETP monitoring among REM programmes. The sporadic nature of ETP bycatch means that a lot more hours of imagery is required to develop a training dataset than for fish. Image libraries are being developed for other catch items (e.g. by CSIRO, NOAA and as fishnet.ai led by The Nature Conservancy) and these are similarly important for ETP species to support the progression of ML for REM review.

The technological development of ML and computer vision continues apace and an ongoing increase in the efficiency of REM review is expected to result from its application. Analogous to systems and processes that support human review, technological considerations and on-board practices optimise the performance of ML [71]. Further, just like the transition from observer-focused monitoring regimes to using REM (or a combination of both REM and observers), the definition of an implementation pathway is vital to support the continued development and facilitate the widespread adoption of ML [72].

Māui dolphin: Cephaloynchus hectori māui



OVERVIEW OF CURRENT WORLDWIDE REM PROGRAMMES AND PROJECTS

Table 5 provides a global review of references and reports of projects/trials where REM has been used to monitor bycatch of ETP species, as well as programmes currently being implemented worldwide. It is clear from this table that the issue of ETP bycatch is of major international concern.

Interactions with fisheries are precipitating the extinction of some ETP species (e.g., the vaquita porpoise (*Phocoena sinus*) [73] [74]), and the worsening conservation status of others (e.g. wandering, black-browed and grey-headed albatross (*Diomedea exulans, Thalassarche melanophris, T. chrysostoma*) [75] [76]. Further, without robust data on the nature and extent of ETP interactions with fisheries, efforts to address unsustainable bycatch rates are considered less likely. In some areas and fisheries, the first steps towards identifying and quantifying the ETP and fish bycatch issues have been taken, through the introduction of REM pilot projects. These should facilitate the introduction of management measures to help mitigate the bycatch issue.

TABLE 5. SUMMARY OF RESEARCH USING REMOTE ELECTRONIC MONITORING TO DETECT AND MONITOR ENDANGERED, THREATENED AND PROTECTED (ETP) SPECIES INTERACTIONS WITH FISHING GEAR. TABLE UPDATED FROM PIERRE (2018) [30].

ETP SPECIES GROUP	FISHING METHOD	COUNTRY/REGION	SOURCES
Seabirds	Pelagic longline	Australia, Solomon Islands, USA (Hawaii)	McElderry *et al.* 2010 [77]; Piasente *et al.* 2012b [78]; Hosken *et al.* 2016 [79]; AFMA 2019a [80]; Carnes *et al.* 2019 [81]
	Demersal longline	New Zealand, South Georgia, USA (Alaska)	Ames *et al.* 2005 [82]; McElderry *et al.* 2008 [83]; Benedet 2016 [84]; Middleton 2016a [85]; Thompson and McKenzie 2018 [86]; AFMA 2019a [80]
	Trawl	New Zealand, USA (Alaska)	McElderry *et al.* 2004 [87], 2011 [88]
	Set net / Gillnet	Denmark, New Zealand, USA (northeast), Peru	McElderry *et al.* 2007 [89]; Tilander and Lynneryd 2010, cited in ICES Advisory Committee 2010 [90]; Northeast Fisheries Science Center 2014 [91]; Pria *et al.* 2014 [70]; Bartholomew *et al.* 2018 [92]; Glemarec *et al.* 2020 [93]
Cetaceans	Pelagic longline	USA (Hawaii)	Carnes *et al.* 2019 [81]
	Trawl	New Zealand	McElderry *et al.* 2011 [88]
	Set net / Gillnet	Australia, New Zealand, North Sea, Peru, USA (northeast)	McElderry *et al.* 2007 [89]; Evans and Molony 2011 [94]; Kindt-Larsen *et al.* 2012 [14]; Lara-Lopez *et al.* 2012 [95]; Pria *et al.* 2014 [70]; Northeast Fisheries Science Center 2014 [91]; Bartholomew *et al.* 2018 [92]; Scheidat *et al.* 2018 [96]; AFMA 2019a [80]
	Trammel net	North Sea	Scheidat *et al.* 2018 [70]
Pinnipeds	Gillnet	Australia, USA (northeast), Peru	Lara-Lopez *et al.* 2012 [95]; Northeast Fisheries Science Center 2014 [91]; Bartholomew *et al.* 2018 [92]; AFMA 2019a [80]
Marine reptiles	Pelagic longline	Australia, New Zealand, Solomon Islands, USA (Hawaii)	McElderry *et al.* 2008 [83], 2010 [77]; Piasente *et al.* 2012b [97]; Hosken *et al.* 2016 [79]; AFMA 2019a [80]; Carnes *et al.* 2019 [81]
	Gillnet	Peru	Bartholomew *et al.* 2018 [92]
	Trawl	Australia	Piasente *et al.* 2012a [78]
Fish	Pelagic longline	e.g. Australia, New Zealand, Solomon Islands, USA (Hawaii, Atlantic)	e.g. McElderry *et al.* 2008 [83], 2010 [77]; Piasente *et al.* 2012b [97]; Hosken *et al.* 2016 [79]; Larcombe *et al.* 2016 [51]; NOAA 2016 [98]; AFMA 2019a [80]; Carnes *et al.* 2019 [81]
	Demersal longline	e.g. Canada (British Columbia), New Zealand, USA (Alaska)	e.g. Ames *et al.* 2007 [99]; McElderry *et al.* 2008 [83]; Al-Humaidhi *et al.* 2014 [100]; Stanley *et al.* 2014 [101]; Northeast Fisheries Science Center 2014 [91]; NOAA 2016 [98]; AFMA 2019a [80]
	Pot/trap	e.g. USA (Alaska)	e.g. Al-Humaidhi *et al.* 2014 [100]; Buckelew *et al.* 2015 [102]; NOAA 2016 [98]
	Set net/gillnet	e.g. Australia, USA (northeast), New Zealand, Peru	e.g. McElderry *et al.* 2007 [89]; Lara-Lopez *et al.* 2012 [95]; Northeast Fisheries Science Center 2014 [91]; Pria *et al.* 2014 [70]; Bartholomew *et al.* 2018 [92]
	Purse seine	e.g. Indian, Atlantic, Pacific Oceans	e.g. Ruiz *et al.* 2013 [103], 2014 [104]; Briand *et al.* 2018 [105]
	Trawl	e.g. New Zealand, Netherlands, USA (Alaska)	e.g. Al-Humaidhi *et al.* 2014 [100]; Northeast Fisheries Science Center 2014 [91]; van Helmond *et al.* 2014 [31]; Middleton *et al.* 2016b [106]; Pria *et al.* 2016 [107]; NOAA 2016 [98]
Sharks and rays	Pelagic longline	Australia, New Zealand, Solomon Islands, USA (Hawaii)	McElderry *et al.* 2008 [83], 2010 [77]; Piasente *et al.* 2012b [78]; Hosken *et al.* 2016 [79]; Larcombe *et al.* 2016 [51]; AFMA 2019a [80]; Carnes *et al.* 2019 [81]
	Demersal longline	New Zealand, USA (northeast)	McElderry *et al.* 2008 [83]; Northeast Fisheries Science Center 2014 [91]; AFMA 2019a [80]
	Pot/trap	USA (Alaska)	Buckelew *et al.* 2015 [102]
	Set net/gillnet	New Zealand, Australia, USA (northeast), Peru	McElderry *et al.* 2007 [89]; Evans and Molony 2011 [94]; Lara-Lopez *et al.* 2012 [95]; Northeast Fisheries Science Center 2014 [91]; Pria *et al.* 2014 [70]; Bartholomew *et al.* 2018 [92]
	Trawl	New Zealand, USA (northeast)	McElderry *et al.* 2011 [88]; Northeast Fisheries Science Center 2014 [91]
	Purse seine	Indian, Atlantic, Pacific Oceans	Ruiz *et al.* 2014 [104]; Briand *et al.* 2018 [105]
Corals	Demersal longline	South Georgia	Benedet 2016 [84]

Seabirds

Seabird species are at particular risk in longline, trawl and gillnet fisheries. Globally, it has been estimated that at least 160,000 seabirds per year are incidentally killed in longline fisheries [108]. A compilation of regional estimates of seabird bycatch in gillnets suggests that 400,000 seabirds may be caught annually [109]. For trawl fisheries, no global estimates are available. However, regional studies and single-species estimates highlight that incidental mortalities can be significant, particularly where bycatch mitigation measures are not in use [110] [111] [112] [113] [114].

During longline setting, the baited hooks are deployed, and birds are attracted to the baits before they sink which can lead to accidental bycatch through hooking and drowning, or they are entangled and hooked during hauling operations. Some diving bird species can also reach pelagic longline baits once they are set or can become entangled with gillnets as they swim down to prey on the entangled fish. In trawl fisheries, seabirds may be injured or killed in flight, when they strike the warps that tow trawl nets. Birds may also be injured or killed when they are pushed underwater by trawl warps moving through the water astern vessels. Birds can also be captured in trawl nets during hauling or shooting operations.

REM projects focused on seabird interactions have been undertaken in several countries (Table 5). In New Zealand, petrel and shearwater species are caught during demersal longlining operations but quantifying these has been unreliable due to low levels of observer coverage (approximately 0.5% of fishing effort [85]). During a small-scale trial using "bird proxies" (fake birds made from flax) it was found that approximately 90% of all bird proxies deployed were observed during video review and, in addition, 6 interactions with real birds were also observed. The REM reviewer was able to make the same assessment of life status and injury observations that an observer would have. There were issues with visibility due to spray on the camera lens, but that could be overcome through agreed cleaning procedures or the application of spray resistant coatings [85]. Captures of actual seabirds have also been documented by REM in New Zealand longline fisheries ([83] [86]) (Figure 5).

Figure 5. A live Parkinson's petrel caught at the line hauler on a demersal longline vessel [83].

A larger pilot project was undertaken on 10 vessels in the eastern tuna and billfish fishery (ETBF) of Australia by Piasente *et al.* 2012 [78]. Only 8 interactions with ETP species were recorded during a 62-fishing set comparison between onboard observer and REM, by the REM video reviewer (5 turtles and 3 seabirds), whilst the observer reported an additional bird and turtle bycatch incident. Despite multiple reviews of the REM footage it was not possible to determine whether the discrepancy was due to the interactions occurring outside of camera view(s) or that there was a potential error with the observer's observations and/or data.

Seabird bycatch in trawl fisheries is widely documented (e.g., including gannets (*Morus* spp.), penguins (Spheniscidae), albatrosses (Diomedeidae), fulmars, petrels and shearwaters (Procellariidae) and cormorants/shags (Phalacrocoracidae) ([108] [115] [116] [11] [117]).

The live capture of a gannet (*M. serrator*) was recorded by REM in a coastal trawl fishery in New Zealand [88]. Further, the efficacy of REM for monitoring seabird strikes on trawl cables (warps and third wires) has been assessed in New Zealand and Alaska [87] [88]. Challenges with placing cameras and interpreting imagery appropriately led McElderry *et al.* (2004, 2011) to conclude that REM was more effective for enumerating seabirds present around cables, as an indicator of bycatch risk [87] [88]. The relationship between trawl warp strikes and seabird abundance is well documented, e.g., by Abraham (2009) [118].

Seabirds have been observed being caught in gillnets in several REM projects. Pria *et al.* 2014 [70] reported two incidents of seabird bycatch during their pilot project to detect and quantify bycatch of Hector's dolphins in gillnets. Review of the footage allowed them to observe that these birds were released alive. Also, during a REM project comparing observers with REM as a monitoring tool in a Peruvian gillnet fishery, a Humboldt penguin was recorded being caught and discarded dead [92]. In 2018, Glemarec *et al.* [26] reported 490 seabirds being caught in 1607 days of fishing effort on small gillnet vessels in the Oresund (the strait between Denmark and Sweden) between 2010 and 2018. Of these 54% were Eider ducks (*Somateria mollissima*), with razorbills (*Alca torda*), cormorants (*Phalacrocorax carbo*) and guillemots (*Cepphus grylle*) making up the majority of the rest.

Other gear types such as traps do occasionally catch seabirds. For example, captures of cormorants/shags have been recorded in some lobster creel fisheries [119]. Figure 6 shows a dead cormorant *(Phalacrocorax carbo)* that became trapped in a lobster trap during a REM project on small Scottish creel fishing vessels. The skipper commented that this was a very rare event and he caught less than 1 bird per year. If an at-sea observer had reported this as representative of the fishery from their single trip (or a very limited number of sea trips), it could lead to over-estimation of bycatch if raised to fleet level. **This illustrates the importance of REM as a long-term coverage tool to avoid observer bias.**

Figure 6. A dead cormorant that was accidentally trapped in a shellfish creel (Copyright SeaScope Fisheries Research Ltd.).

While data are poor or absent from many fisheries, there are some robust studies of the known or potential effects of bycatch on seabirds [120]. Using data available from longline fisheries globally, it has been estimated that up to 320,000 birds are killed per year.[108] Seventeen of the 22 species of albatross are threatened with extinction, with interactions with fishing gear a key cause of anthropogenic mortalities. Other species where populations are threatened include shearwaters and petrels. But the true extent is largely unknown, as the data comes from self-reported estimates and observer programmes with very low coverage rates where data confidence is rated as "poor". Some fisheries never report bycatch data and are unregulated. If the mortality from all other fisheries is included then this estimate will be considerably higher [108].

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Cetaceans

The most recent estimate of the global bycatch of cetaceans is still that adopted by the IWC in early 2000, i.e. at least 300,000 animals per year [121]. More recent estimates are available for some fisheries (e.g. [122] [123] [124]), though extensive knowledge gaps remain.

Monitoring of cetacean bycatch using REM is being trialled throughout the world and in different fisheries. In 2010 in the North Sea and Skagerrak, Denmark began experimenting with REM to monitor harbour porpoise (and seabird) bycatch in the inshore small vessel gillnet fishery. Using the REM systems, they were able to detect the bycatch of 36 cetaceans compared to the 25 self-reported by the fishers [14]. This discrepancy is thought to be due to two main issues; fishers are very busy during hauling so can miss cetaceans that drop out of the net during hauling; or they simple don't, or forget to, report them. There is also very little incentive for fishers to self-report bycatch, as they fear that the reporting of bycatch may have negative repercussions for their fishery, so there is the possibility that failure to report bycatch can sometimes be a deliberate act.

In a New Zealand inshore set net fishery, a trial was conducted by Archipelago Marine Research into monitoring the bycatch of Hector's dolphins (*Cephalorhynchus hectori*). Only 1 incident of bycatch cetacean was detected, although there were 2 incidents of unusual behaviour by the skipper and crew that may have been intended to prevent bycatch detection. Therefore, to test the efficacy of the REM, they used shark bycatch events recorded by at-sea observers and compared them to those detected by the REM reviewer. They found that the REM reviewer had a 97% detection rate compared to 95% by the observer [70].

Cetacean bycatch REM projects have also been conducted in South America. For example, Bartholomew *et al.* (2018), undertook a study on the elasmobranch gillnet fisheries of Peru which attempted to identify all bycatch species (not just cetaceans). However, they found that although the REM was effective in detecting and quantifying elasmobranch target catch and pinniped bycatch, it was not thought reliable in detecting and quantifying sea turtle and cetacean bycatch [92].

This is contrary to most REM studies mentioned and this difference may be due to programme or equipment design, for example, the system used, collected a stills image (photograph) every 40 seconds rather than continuous video and may have created data gaps, where cetacean interactions were not recorded.

Cetaceans are also caught in other gear types including longlines, trawlers, traps (entanglements in the ropes) and purse seines.

In the Hawaiian deep and shallow set longline fisheries, a project was undertaken to compare REM collected data against at-sea observer data for the same trips. This found an exact match between the two recording methods for cetacean bycatch (one false killer whale, *Pseudorca crassidens*, was caught) and also for turtle bycatch, but found that seabird bycatch (17 albatrosses) was not captured as well by REM because fishers removed the dead birds at the stern of the vessel out of camera view [81].

Bottlenose dolphin (*Tursiops truncates*) bycatch in a New Zealand coastal trawl fishery was documented by REM, with a moribund animal hauled onboard and clearly visible in the trawl net but then discarded out of camera view (Figure 7) [88].

Figure 7. REM imagery from a New Zealand inshore trawl fishery: a dead bottlenose dolphin. (Source: McElderry et al. 2011) [88].

Pinnipeds (seals)

No recent global estimate of pinniped bycatch is available. However, in the mid-1990s, a worldwide annual bycatch estimate was 345,000 [125]. More recent estimates are available for some fisheries, though knowledge gaps remain significant. For example, pinniped mortality reported from gillnet fisheries in 2000 – 2010 ranges from single animals to thousands, with one estimate of over ten thousand seals bycaught [123].

There is no doubt that seal bycatch is an issue in some fisheries. For example, in the Icelandic lumpsucker (*Cyclopterus lumpu*) gillnet fishery alone, fisheries inspectors undertook 193 observer trips between 2014 and 2017 and recorded 201 individual seals from 6 different species being caught. When this is extrapolated to the total fleet's effort for this fishery, the total seals bycaught is 3620 during this period. The fleet only self-reported 1528 seals during this period (700 reported in 2017 alone), which is approximately 42% of the observer raised estimate. In addition, the fishers also self-reported 397 bycaught cetaceans between 2014-17, of which 286 were reported in 2017 [126]. The actual incidents of bycatch may be increasing for some reason (as the data suggests), or it may be that fishers are reporting more often than in previous years and catches were under-reported previously. It could also be that the extrapolated observer estimates are inflated due to observer bias during the trips, but without constant coverage as provided by tools like REM (or 100% observer coverage), it is impossible to determine exact bycatch mortality. It should also be remembered that these levels of bycatch are happening in just one fishery in one country and if other fisheries around the world operating in a similar way also have similar bycatch rates then pinniped bycatch may be a serious concern.

As with most REM projects they are not usually designed to look at one species group only. Usually they will be designed to record imagery of either the fish discards and catch handling, or ETP species interactions, or both. This has typically been the case with pinniped bycatch. The authors are aware of one REM project that started out looking solely at pinniped bycatch but usually seals are generally quantified as part of other bycatch REM projects. For example, as well as looking at cetacean bycatch, Bartholomew *et al.* (2018), also quantified the bycatch of pinnipeds and observed a total of 5 South American sea lions (*Otaria flavescens*) being caught during video review. This matched the number reported by the onboard observer during the trial and led them to conclude that REM is an effective tool for detecting and quantifying pinniped (and elasmobranch) catches [92].

REM was explored in a pilot project, then implemented in an operational programme to monitor captures of Australian sea lion (*Neophoca cinerea*) in an Australian gillnet fishery. REM was progressed to monitor sea lion bycatch due to industry concerns about the cost of human observer deployments. In this case, fishery closures are introduced if specified capture rates of this threatened species are exceeded (See Case Study 2).

Single captures of gray seal (*Halichoerus grypus*), harbour porpoise (*Phocoena phocoena*) and harbour seal (*Phoca vitulina*) were recorded in REM imagery from 10 gillnet hauls (8 trips) in a multispecies fishery in the northeastern USA [64]. Great shearwater (*Ardenna gravis*) bycatch was also recorded caught in REM imagery from this pilot project.

Marine Reptiles

Turtles and sea snakes are the main groups of reptiles caught during fishing operations. Few REM projects are specifically established to monitor reptile bycatch and instead they are usually quantified as part of a general ETP REM project.

Worldwide annual bycatch estimate for sea snakes is unknown, but in one Australian fishery alone it was estimated at over 119,500 [129]. Found mainly in the Indian and Pacific Oceans, sea snakes are most commonly caught in trawl nets and gillnets, with occasional bycatch recorded in other fishing gears e.g. in Rampan nets (a form of beach seine net) used in India. Sea snakes are protected species, but populations are reported to be in decline due to fishing operations, pollution and coastal development activities among many others [130].

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In Australia, Vietnam and south east Asia, there have been studies looking at the impact of fishing on sea snake populations ([131] [132] [133] [134]) but in other areas with reported high bycatch (e.g. India) little is known.

The mortality rates associated with sea snake bycatch are high because they are delicate and air breathing. Wassenberg *et al.* 2001, reported a mortality rate of 48.5% for all sea snakes caught during their study. This combined the initial mortality caused through crushing and drowning in the net and the mortality caused by stress after release, through survival experiments [131]. Post capture survival rates in gillnet caught snakes is thought to be higher than trawl caught snakes, and this is likely due to the damage and crushing caused by the larger catches and hauling processes associated with trawling [130]. No annual worldwide estimate of sea snake bycatch rates could be found but Milton *et al.* 2009 [129], states that in the Australian Northern Prawn trawl fishery in 1991, up to 119,500 snakes were thought to have been caught and that half of these would have died. They also state that during their bycatch mitigation study they caught snakes in 350 of the 1367 hauls made, or approximately 1 in 4 hauls. By using bycatch reduction devices, this was reduced from approximately 7000 snakes to less than 1500. This clearly illustrates the pressures facing sea snake populations from fishing activities, but that scientists are aware of the issue and wish to reduce the impact of fishing on such vulnerable reptiles. There are no dedicated REM projects for sea snakes and little information is available from other REM projects, with most data coming from at-sea observer programmes or bycatch mitigation experiments. For example, Piasente *et al.*,2012 [97] detected sea snakes in their pilot REM project conducted in the Australian northern prawn trawl fishery.

Worldwide annual bycatch estimate for sea turtles is largely unknown but was estimated at 85,000 in 2009, but is thought to be 2 orders of magnitude higher. [127] Other studies estimated turtle bycatch at over 250,000, but this estimate focussed on loggerhead and leatherback turtles caught in longline fisheries only [128] so can be considered low. Turtles are also heavily affected by fishing activities with bycatch occuring in longline, gillnet and trawl fisheries [127, 135]. In Central America alone more than 80,000 turtles are estimated to be killed each year, consisting mainly of hawksbill (*Eretmochelys imbricate*) and green (*Chelonia mydas*) turtles. Although trading in turtle products is banned, there is still illegal trading in some products (shell, eggs and meat) and some countries are even trying to reintroduce international trade in these products [135]. In the Pacific Ocean the leatherback turtle (*Dermochelys coriacea*) population is thought to have decreased by 95% in the last 25 years and fisheries bycatch has been identified as a significant cause of this decline [136]. In the Mediterranean Sea, Italy reported a bycatch of 65 loggerhead turtles (*Caretta caretta*) between 2006 [137] and 2008 [138], being discarded during their observer trips [32].

In the Solomon Islands, Hosken *et al.* (2016) [79], reported bycatch of Olive Ridley (*Lepidochelys olivacea*), green, hawksbill, and loggerhead turtles during a 4-trip comparison trial between on board observers and REM video review, with numbers reported between 10 and 20 individuals. In Peru, Bartholomew *et al.* (2018) [92], undertook a trial to compare on board observer data and REM collected data. During the study 172 sets of gillnets occurred with observers on board and they recorded a total of 33 hard shell sea turtles (19 green, 9 olive ridley, and 5 unidentified turtles) in 20 of the sets.

For these same sets, the REM reviewer only detected 12 bycaught turtles which would suggest that REM is not an effective tool for identifying turtle bycatch compared to an onboard observer. That said, when the video was reviewed for sets where the at-sea observers were not present, the video review team reported a further 48 hard shell sea turtles in 21 sets, including 1 leatherback turtle. This demonstrates the importance of greater coverage levels that are provided by REM programmes when observers are not present. So, the evidence that turtles are being caught in alarming numbers in South America and elsewhere is obvious no matter how that data are collected, especially when the number of vessels that have been involved in these trials is considered relative to the size of the fishing fleets.

Figure 8: Green turtle (Chelonia mydas) entangled in commercial fishing gear

Elasmobranchs

Nearly all types of fishing can accidentally catch sharks and rays. Larger specimens such as basking sharks can become entangled in static gear or be caught in trawls. Most other species can also be caught in trawled and static gear, on baited hooks (Figure 9), encircled in purse seine fisheries, or after entering fishing traps and creels. Entanglements also occur in the buoy ropes of traps and in some types of Fish Aggregating Devices used by purse seine fisheries [139]. Often these catches are treated as a marketable bycatch where legal, but often they can be harvested illegally, or discarded back into the sea. Globally across all fishing gears, shark discards were estimated at 1,135,000 tonnes per year, in 2000. This estimate included 227,000 tonnes of animals released alive. Excluding discards and artisanal fisheries, the illegal catch of sharks was estimated at 111,000 tonnes [140]. While the estimation of shark landed catch and bycatch is significantly constrained by the lack of empirical data, estimation of skate and ray catch is even more so [10].

Figure 9. A pelagic stingray (Pteroplatytrygon violacea) accidentally caught on a tuna longline (Copyright SeaScope Fisheries Research Ltd).

As with all fisheries data, elasmobranch catch quantities are seldom self-reported unless the fish are legally landed. So, quantifying the amounts discarded independently has traditionally relied on at-sea observer monitoring programmes. These programmes have their limitations in regards to reliability of data quality primarily because of the low monitoring levels (due to the high costs associated with observer programmes), especially if an event is considered rare, which can then be easily missed if subsampling of a fishery is necessary.

As with other ETP and fish species, REM can be a valuable tool in estimating elasmobranch bycatch rates because it allows higher coverage rates due to its lower cost per day monitored.

Several REM pilot projects that have included the quantification of elasmobranchs, have been undertaken in the last 10 years. In the UK, a study was undertaken on an otter trawling vessel to capture discard data on the common skate species complex (*Dipturus batis* complex) which consists of two very similar species, the flapper skate (*D. cf. intermedia*) and the smaller bodied blue skate (*D. cf. flossada*). This study adopted the video review procedures of the UK Catch Quota Trials [48] but focused on elasmobranchs, rather than the fish species subject to the Landing Obligation. The vessel undertook 28 voyages and completed 280 fishing tows during the project and bycatch of skate were reported on 69 of these, either by the video analyst or by the skipper of the vessel. Unfortunately, there were only 6 tows out of these 69 where the skipper and the video review analyst both reported bycatch of skate with less than 28 individual fish observed on these 6 tows [141]. This suggests that REM is not suitable for quantifying elasmobranch catches but the poor level of tow correlation between self-reported data and REM analyst data makes the data unusable for quantifying discards or evaluating the use of REM as an elasmobranch monitoring tool in this case.

Other studies on different gear types (Table 5) have been more conclusive. For example, a pilot study conducted on a vessel in the South African hake trawl fishery demonstrated the efficacy of REM for characterising the diversity of chondrichthyans caught, which include ETP species [142]. When observers are present on vessels, they report these species to relatively high taxonomic levels such as families. However, the review of REM imagery enabled species-level identification and enumeration [143].

In the Peruvian small-scale gillnet fisheries Bartholomew et al [92] monitored 5 vessels for 30 fishing trips over a period of 10 months. This study compared observer reported data and REM obtained data and found that during the project, both reported catches of 12 different genera of elasmobranchs and that for 9 of these the REM analyst was able to detect more than 90% of those reported by the observer. The authors concluded that REM is an effective tool for quantifying ray and shark bycatch and was more accurate than the observers, with observers failing to report when catch was of low economic value or eaten on board. The authors also noted that when the numbers of catch were higher it became harder to quantify the bycatch due to them being piled on top of each other and that it was easier to see the retained catch [92]. However, this could likely be improved upon by increasing the frames per second, setting cameras up to see the exact decision points in the catch handling processes, and developing agreed catch handling procedures. Conversely in the Australian shark gillnet fishery, it was found that REM was an effective tool for quantifying all elasmobranch catches and was more effective at detecting the bycatch element than the retained catches [95].

Longlines also catch unwanted elasmobranchs. Although not a threatened species, Figure 9 shows a pelagic stingray (*Pteroplatytrygon violacea*) accidentally caught whilst targeting tuna with baited longline hooks. However, longlines can also catch other shark and ray species including those that are classed as ETP species (Figure 10). REM projects have been conducted on longline vessels in New Zealand, Australia, Fiji, the Solomon Islands and the US ([77] [78] [79] [51] [144] [81]). Among ETP shark species caught in the tuna fishery REM pilot conducted from the Solomon Islands, silky sharks (*Carcharhinus falciformis*), oceanic whitetip (*Carcharhinus longimanus*), and pelagic thresher (*Alopias pelagicus*) sharks were detected by REM. Other shark species identified from imagery included crocodile (*Pseudocarcharias kamoharai*) and blue sharks (*Prionace glauca*). Piasente et al. (2012) [78] also documented a variety of shark species in REM imagery from their longline fishery work in Australian waters (e.g., bronze whalers (*Carcharhinus brachyurus*), hammerheads (*Sphyrna* spp.), shortfin mako (*Isurus oxyrinchus*), oceanic whitetip and silky shark). The sex of sharks was also assessed from REM imagery in the Solomon Islands trial and compared with observer determinations. Congruence in distinguishing male sharks was higher than females, 76% and 53% respectively, for the onboard observer's assignation being matched using REM [79].

Rays detected from REM imagery in the Solomon Islands included pelagic stingrays and Mobulid (devil) rays (protected in some jurisdictions). These species were detected from REM imagery in similar numbers to observer detections [79].

In tropical purse seine fisheries targeting tuna, REM review provided some information on the bycatch of sensitive shark species, but catch was underestimated. Briand et al. (2018) [105] considered that catch documentation may be improved with more effective camera views, especially where catch retrieval and sorting occurred. Species-level identification from REM imagery has been reported for some sharks caught in purse seine fisheries (silky, oceanic whitetip, and scalloped hammerhead (*Sphyrna lewini*) sharks, with higher taxonomic levels of identification necessary at times (e.g. family and Order) [104].

Figure 10. A dead Silky shark (Carcharhinus falciformis) on a longline hook, Indian Ocean, South of Java and Bali (© Jürgen Freund / WWF) [145].

Corals and other benthic invertebrates

Benthos, Corals, Protected Habitats and Priority Marine Features: Worldwide annual bycatch and destruction estimation is unknown, though some local information exists from research and fisheries operations [146] [84] [147] [148] [149] [150]. Further, the collection of bycatch information on Vulnerable Marine Ecosystems, for example, is gradually improving especially where required by RFMOs [151] [152] [153].

The use of REM to document fishery interactions with benthic invertebrates is in its early stages. Working with a demersal longline fishery operating from South Georgia, Benedet (2016) [84] compared the detection and identification of benthos landed at the haul by a human observer and from REM imagery review. Sea cucumbers, crabs, basket stars, sea stars and black coral (Antipatharia) were most consistently detected in REM imagery, with matches of REM and observer detections at or close to 100%. In contrast, Gorgonians, hydrocorals and sea sponges were significantly less reliably detected on video. The large size and vibrant colours of some invertebrate species facilitated detection and identification. Further, pausing line-hauling to release live lithodid crabs (a management requirement) also enhanced detection and identification of benthos caught. Benedet (2016) considered that increasing the focal length of one camera in the hauling area would improve the accuracy of invertebrate detection and identifications made [84].

STAKEHOLDERS

There are a range of players in the seafood supply chain from net to plate that have a potential role in influencing the adoption of REM. In this section we identify some of the key players and how they are, or could be, engaged as a source of influence, support or advice in the process of implementing REM at a local, national or regional level.

Food and Agriculture Organization (FAO): The FAO has published voluntary International Guidelines on By-catch Management and Reduction of Discards for states and RFMOs. At present, these voluntary guidelines do not mandate the use of REM for management of bycatch. To strengthen guidelines, they need to be negotiated and endorsed by technical committees on fisheries, which work by consensus.

International Council for the Exploration of the Sea (ICES): ICES believes that remote monitoring provides detailed, interlinked data; and plan to develop efficient ways of analysing, sharing and presenting big data [154]. Their dedicated working group, the Working Group on Bycatch of Protected Species (WGBYC), specifically focuses on the bycatch of ETP species (primarily and initially cetaceans but being broadened to include other sensitive species) in the Northeast Atlantic, North Sea and Baltic Sea. They have been meeting and correlating data from EU national monitoring programmes since 2009, which has allowed a database of fishing effort, observer monitoring effort and cetacean bycatch (data from 2006 onwards), to be constructed. This is added to every year and allows the group to analyse data and produce annual summary reports [155]. Additional data from non-EU countries is also included in their data sets.

The efficacy of WGBYC is hampered by late or no submission of observer and fleet effort data from some participating countries (as required by EU Regulation 812/2004); time lapse between data sets and report publication (2 years difference); and a lack of observer programmes specifically dedicated to monitoring sensitive species (most programmes are undertaken under the Data Collection Framework with the focus more on commercial fish species than protected species). Regulation 812/2004 was repealed in 2019 and data submission to this working group is now through EU-MAP which may improve data submission and reduce the time frame of reporting. The most recent report from ICES WGBYC was in 2019 and it concluded that the effort data being provided was considered inadequate [156] and this is essential for making population and total mortality estimates from limited/low levels of monitoring.

There is a need to improve the quantity of data collected on ETP bycatch in European waters and REM may allow this to happen. This would require ICES and its working and study groups, to encourage this avenue of data collection and provide uniform data collection protocols and data analysis tools so that information collected from different national programmes can be combined and summarised. In 2017, Read *et al* concluded that the DCF is inadequate for monitoring cetacean bycatch, that the fishing effort data being produced and submitted needed to be improved, and that mandatory observer or REM coverage was necessary. They went on to say that REM would result in the best data to ensure compliance with all cetacean monitoring and mitigation requirements [157]. This was an important review of the state of cetacean bycatch monitoring and it details where improvements in data collection and monitoring are required. ICES are in the ideal position to recommend that REM is adopted as the main monitoring tool, wherever appropriate and possible, and to help develop the protocols to allow the data to be combined across sampling programmes and used in assessments.

Regional Fisheries Management Organisations (RFMOs): RFMOs are the main institutions in charge of high seas fisheries. They are tasked with collecting fisheries statistics, assessing resources, making management decisions and monitoring activities. RFMOs play a pivotal role in facilitating intergovernmental cooperation in fisheries management. With recently strengthened mandates, most RFMOs now have the power to manage according to an ecosystem approach to fisheries.

However, RFMOs rely on guidelines produced by the FAO and management is often complicated by deficient or unavailable data and inadequate systems of administration. Challenges exist in enforcing conservation and management measures adopted by regional fisheries organizations, including ETP bycatch.

Convention on The Conservation of Antarctic Marine Living Resources (CCAMLR) is a good example of a multilateral organisation that manages fishery resources embracing technological advances and mandating the use or REM for monitoring bycatch of sensitive species is in the longline fishery for toothfish (*Dissostichus eleginoides, D. mawsoni*) operating around South Georgia and South Sandwich Islands (SGSSI). This fishery operates within the CCAMLR Area, and vessels are registered as UK Overseas Territory vessels. Management and enforcement are the jurisdiction of the SGSSI government because the fishery operates solely within their Maritime Zone (MZ). They issue licences on a 4-year basis and stipulate the requirements that need to be met by vessels wishing to apply for a licence to participate in this fishery [158]. These include:

- mandatory installation and use of VMS
- a minimum 2-year historical record of active VMS tracks validated by the flag state
- mandatory catch reporting on a daily basis
- mandatory installation and use of Class A AIS system
- mandatory carrying of a CCAMLR fisheries observer
- vessel operators must provide evidence of crew welfare standards, vessel safety, previous contributions to science, and commitment to the raising of fishery standards

Seabirds are the main ETP species group of concern in this fishery (other bycatch includes grenadiers, blue antimora (*Antimora rostrata)* and elasmobranchs). Methods implemented to manage seabird bycatch risks include temporal fishing restrictions, bird scaring devices, identifiable hooks (to individual vessels), offal management, and hook/bait shielding devices. All vessels are required to carry at least one observer on 100% of their fishing trips and often the vessel's owners deploy an additional observer to contribute to the regional scientific programmes and to improve knowledge and sustainability of the fisheries [159].

In 2018, the SGSSI Government introduced REM as part of the fishing licence conditions and required vessels to record video of line setting and hauling operations, so that independent verification of fishing procedures could be carried out. The licence also stipulates that these electronic monitoring records must be retained and available for up to 12 months following the expiry of the vessel's licence [158].

All 6 vessels operating in this fishery now have REM systems installed [159]. They collect sensor and video data which is independent of the vessel's normal systems required by the licence. These data include time and position of all shooting and hauling operations; video footage of these operations; activity sensors that detect and record all fishing operations through detection of winch activity; blast freezer operations; bird-scaring line deployment; and ambient light sensors to detect light levels at the time of fishing operations.

Currently these data are owned by the vessel operator and analysed by an independent contractor for scientific research and to monitor bycatch interaction events. The vessel operator then chooses data it wishes to report for compliance and scientific purposes [160]. This is a good model, but it could be further developed. The video of the hooks as they are deployed and hauled provide high quality data for monitoring and reporting of accidental bycatch events, especially birds, and verifies that mitigation devices are being used. However, the current model would not necessarily support fisheries compliance or monitoring of the use of mandatory mitigation devices.I It is unlikely that a vessel operator would choose to voluntarily report data on incidental (or accidental) bycatch events involving ETP species. Agreements between operators and compliance agencies, or legal instruments, would need to be established that ensure that all data are properly scrutinised. Observers could be used to highlight any issues, but it is often important that scientific data collection and compliance data collection are undertaken separately to avoid introducing observer bias, especially when access is voluntary.

Opportunities to increase the value of such mandatory REM deployments include use as an independent source of auditable compliance information by the management body (which would require amendments to the current operating and information ownership models) and comparing the video recordings to the observer records to determine the delivery of each monitoring method on a range of objectives and therefore optimise the suite of monitoring methods implemented longer term.

***Recommendation 1:** RFMOs, States, NGOs, Scientists and others with an interest in REM should be active participants in relevant international and regional forums, so that they can identify opportunities to advance the adoption of REM.*

Catching Sector Operators and Producers' Organisations

Fully monitored fisheries eliminate questions of trust and allow industry to build a transparent relationship with fisheries regulators, management, science and the public. Success can be defined as when catching sector operators regard REM programmes as "paying for insurance of their licence to operate" within a fishery which is defensible. [161]. Trials of REM on fishing vessels have proven that bycatch has reduced as catching sector operators made an effort to avoid unwanted species, including ETP [162].

Experience from catching sector operators indicates that creating incentives, rather than ultimatums, in implementing REM in fisheries works well. Initial installations of REM for time limited 'research programmes' prior to introducing sanctions have helped build trust in both Chilean and Canadian programmes. The use of independent scientific or non-governmental professional facilitators or contractors to assist interactions or manage and analyse REM data is also an aid to success.

***Recommendation 2:** To gain acceptability by the catching sector, consider introducing REM projects as trials in a collaborative system of co-management and using independent scientists to monitor the performance of trial participants, trial managers and to quality control (or undertake) the data analysis.*

Seafood Market Companies and Industry Initiatives

Seafood market players include retailers, brand owners and seafood suppliers. They are committed to responsible sourcing and concerned about sourcing sustainably caught fish and traceability to source. They are concerned that their products are responsibly sourced from sustainable fisheries and that growing public awareness and the need for transparency will impact on sales. They aim to avoid the risk of IUU in their fisheries supply chain. This means that they tend to focus on fisheries management, certification standards, fishery improvement projects and key data elements of what is caught for market to feed into traceability systems.

While retailers usually do not have a direct contractual relationship with fisheries from which their suppliers source, their suppliers or brand owners have direct relationships with the fisheries they source from and therefore the opportunity to influence the adoption of REM, perhaps as part of their traceability requirements.

Catch certificates have been widely used as proof of evidence of legality in the seafood supply chain. Catch certificates record what is caught for sale to markets but do not provide a reliable record of wildlife bycatch. Nor do they provide real evidence that retailers need to prove that they are reducing or do not have ETP bycatch in their fisheries supply chains. These catch certificates are provided by suppliers to the retailers, or if dealing with an exporter directly, the brand owners will maintain these certificates. Furthermore, many seafood companies have developed or adopted seafood sustainability risk assessments (e.g. NGO seafood guides and websites) which will cover ETP bycatch. The risk assessments make use of published ETP bycatch data which may or may not be fisheries specific. Some retailers and brand owners may have gone further to develop their specific policies on ETP species

The majority of the seafood companies make use of specifying standards and schemes to which their suppliers need to comply. Therefore, maintaining the robustness of certification standards, multi-stakeholder platforms and fishery improvement projects they accept is essential. Thus, it is crucially important that the fisheries management programmes and standards deliver robust mechanisms to monitor and mitigate ETP bycatch in fisheries.

In order to implement their seafood sustainability commitments, seafood market players seek support of the fishing industry, supply chain, regulators and NGOs on specifying standards and requirements. They prefer to ensure that their policies and implementation are supported by multi-stakeholder standards and initiatives.

ETP bycatch in their supply chain could pose potential reputation risk to seafood market companies and they have the interest, resources and power to require fisheries they source from to deploy ETP mitigation and if necessary, to convene co-management trial projects to prove its efficacy. A number of seafood industry led initiatives have been identified to promote the adoption of REM.

The **Global Seafood Standards Initiative (GSSI)** provides a benchmarking tool for standards, which are accepted by a wide range of leading retailers and brand owners. However, it does not require that those standards specify REM or other tools to monitor and mitigate bycatch in the net.

The **Global Tuna Alliance** is working with retail and other tuna supply chain businesses to eliminate illegal, unreported and unregulated (IUU) fishing and ensure tuna meets the highest standards of environmental performance and social responsibility. Initiatives like the GTA provides a good opportunity for advocacy for REM in tuna fisheries, supported by Western markets.

The **Sustainable Seafood Coalition** (SSC) is formed by a group of UK based seafood companies to follow agreed and voluntary Codes of Conduction on seafood sourcing and package claims. The Code of Conduct on sourcing requires seafood companies to assess and mitigate potential risk in their supply chain which include ETP bycatch. Initiative like SSC can be used to promote the adoption of REM to monitor the effectiveness of mitigation measure on ETP bycatch.

A number of the **Fisheries Improvement Projects (FIP)** have adopted 100% human observers or REM in their projects such as the Pacific, Indian and Atlantic purse seine tuna fishery improvement projects (OPAGAC, SIOTI, EASTI). FishChoice manages the FisheryProgress.org platform which provides a useful directory of their progress. These projects focus on fisheries management.

Standards and Certification

Fisheries and seafood certification schemes aim to provide some assurance of better fishing practices toward sustainability.

The **Marine Stewardship Council (MSC)** is a non-profit organisation which aims to set a standard for sustainable wild fisheries. Fisheries that wish to demonstrate they are well-managed will compare against the MSC standard and they are assessed by a team of experts who are independent of both the fishery and the MSC. However, because the fishery usually pays for the assessment to be undertaken, it is difficult for it to be fully independent. Seafood products can display the blue MSC ecolabel only if that seafood can be traced back through the supply chain to a fishery that has been certified against the MSC fisheries and Chain of Custody standard.

The mission of the MSC is to use its ecolabel, for which the MSC receives royalties for licensing it to products, and fishery certification program to contribute to the health of the world's oceans by recognizing and rewarding better fishing practices, influencing the choices people make when buying seafood, and working with partners to transform the seafood market.

However, MSC's governance and standards have been widely and repeatedly criticised by various stakeholders like NGOs, academics and others for some key failings, including those related to bycatch and the failure to take account of the capture of non-target species including endangered, threatened and protected species; e.g. [163].

MSC fisheries standards cannot be prescriptive on what type of tools are used; while some fisheries are well suited to REM, REM may not be the ideal tool for others. MSC acknowledges that the merits of REM are that it provides independent data, which can be monitored in near real time or provide evidence to be reviewed later [164].

REM can be an enabler for both addressing management gaps and traceability. Effective management not only ensures the continued productivity of the target resources but also the accomplishment of other elements of fisheries sustainability, such as avoiding incidental bycatch in the net. Effective traceability (tracking fish products from vessel to the final buyer) underpins sustainability efforts as it creates transparency and accountability within the supply chain, thereby connecting fisheries to markets, enabling markets to directly support improved fisheries performance.

Reliable and affordable seafood traceability is needed to address core operational issues such as supply chain visibility and risk management, so there is a daily need for rapid access to verifiable information about product origins across the sector. The **Global Dialogue for Seafood Traceability (GDST)** advocates for interoperable data processes through the supply chain. It specifies key data elements for traceability through the supply chain. However, any traceability system relies on the quality and accuracy of data and information entered at the start of the chain. GDST v1.0 does not specify requirements about the independence and veracity of the data input sources.

Recommendation 3: *Retailers, brand owners and seafood suppliers to work with certification standards, fishery improvement projects and multi-stakeholder initiatives to lobby for the adoption of REM as a tool for monitoring ETP bycatch, to improve ETP bycatch data to allow it to be used as an indicator of sustainability .*

SUMMARY

To overcome potential issues and barriers, REM should be introduced with stakeholder engagement throughout the supply chain and as part of collaborative co-management approaches. Rollout of REM can be hampered by fisher's concerns about on-board surveillance and potential privacy issues. Effective co-management approaches are helpful in building trust in the benefits of REM, and overcoming suspicion and concerns.

Given the increased interest in adopting REM for standard fisheries management, systems can and should be adapted to monitor ETP bycatch where required.

CASE STUDY EXAMPLES

This section describes case studies that show best practices used in REM programmes and trials across diverse geographic settings, and different types of fisheries and fleet segments. We have chosen these case studies also because they are focused on monitoring ETP species bycatch for conservation purposes, rather than other monitoring objectives.

CASE STUDY 1: AUSTRALIAN EASTERN TUNA AND BILLFISH FISHERY (PELAGIC LONGLINE)

Background

Australia's Eastern Tuna and Billfish Fishery (ETBF) manages commercial fishing operations that primarily target yellowfin (*Thunnus albacares*), bigeye (*Thunnus obesus*) and albacore (*Thunnus alalunga*) tuna and swordfish (*Xiphias gladius*). The fishery operates within the Australian Exclusive Economic Zone (Figure 12), and on the high seas in the Western and Central Pacific Fisheries Convention (WCPFC) Area [165]. The ETBF is managed by the Australian Fisheries Management Authority, which is the federal fisheries management agency [166]. The fishery operates within a well-developed management framework, including overarching legislation, a detailed management plan [167], and more recently, a comprehensive management strategy [144]. A variety of data collection, monitoring and enforcement activities occur[4].

Managers of the ETBF became interested in REM in part because of seabird bycatch in the fishery, but also to improve the cost effectiveness of the monitoring programme. Longline fishing was identified as a key threat to seabirds, given their propensity to feed on baited hooks leading to hooking and entanglement in the longline during setting and hauling operations. Typical of ETP species, populations of some affected seabirds are inherently vulnerable, as these species are naturally long-lived, mature late, and have low reproductive output. Further, many of these seabird populations are already depleted [120]. Longline fishing was formally recognised as a threat to seabirds by a Threat Abatement Plan [168], which required a reduction in seabird bycatch in the ETBF and evidence of an ongoing bycatch rate of less than 0.05 birds/1,000 hooks.

Piloting REM in the ETBF

In this context, the feasibility of REM as a monitoring method for the ETBF was investigated by conducting a pilot project with the following objectives [78]:

- Deploy and operate REM systems on 10 commercial vessels for up to one year
- Evaluate REM for meeting specified fisheries monitoring objectives, including understanding protected species interactions with the fishery
- Develop an audit approach to REM data analysis to evaluate the quality of logbook data
- Undertake a cost – benefit analysis of monitoring options and programmes required to meet fishery data needs; and
- Develop and evaluate the feasibility of establishing a third-party service delivery structure for an ongoing REM programme in the fishery.

REM systems were installed to monitor the deployment and retrieval of fishing gear, and catch handling and processing. To set out the requirements of the project for skippers and crew involved, a code of conduct and memorandum of understanding were prepared. A compliance strategy was included in the code of conduct, such that the course of action was clear if compliance issues were identified during the project. Data analysis protocols were also established.

Overall, the pilot project succeeded in addressing its objectives, and provided the basis for AFMA's decision to use REM as a monitoring tool in the ETBF on an ongoing basis [78].

An Operational REM Programme in the ETBF

An operational REM programme has been in place in the ETBF since 2015. The programme is designed to address two main monitoring needs:

- verification of fishers' logbook data on total catch and discards, for all commercial, retained and discarded species; and
- verification of fishery interactions with protected species, how these species are handled after capture, and the use of bird scaring lines (tori lines) during longline setting.

The legal requirement for REM to be deployed on ETBF vessels is set out in the Direction for E-Monitoring [169] under the Australian Fisheries Management Act 1991. All vessels conducting 30 (or more) longline sets must operate a REM system [80]. Penalties exist for not following the Direction's requirements. Programme information is made available to fishing operators in an overview document which includes the programme objectives, roles and responsibilities for operators, AFMA and the REM supplier, operational requirements, privacy and security of information, data provision processes, and key contacts [80].

There are 39 vessels operating REM in the ETBF currently. The REM supplier (Archipelago Asia Pacific (AAP)) provides end-to-end service of the programme. This includes providing, installing and maintaining REM systems, and reviewing imagery in accordance with AFMA's requirements and protocols. Operators send REM system hard drives to AFMA, who create a copy of the drive and then provide it to AAP for analysis. AFMA remains the data custodian and retains all REM information under secure storage for a minimum of 6 months. If matters of concern are detected, information may be retained for longer periods. After each drive is analysed, fishers receive a report on findings, including any issues identified (e.g. quality of footage or catch handling issues that affect data collection from imagery) and how closely the logbook data and REM data align [80]. The baseline for imagery review is 10% of fishing events, which can be increased in accordance with perceived risk [51]. The programme is fully cost-recovered from industry (C. van der Geest, pers. comm.).

Findings

Over the first two years of operational REM deployments in the ETBF, imagery analysts detected over 30% more seabird interactions than were reported in logbooks. However, for turtles and marine mammals, logbooks documented more interactions than were recorded from imagery. This difference may be due to ETP species falling from the gear ("drop-offs") and not being landed on deck in camera views, or animals being released by crew when still in the water and out of camera view (e.g. marine turtles) (Figure 11, [170]). Relatively higher logbook reports may also result from operators reporting what they consider to be "interactions". In this context, interactions are defined as physical contact with a protected species, that causes death, injury or stress, such as being hooked, netted or entangled, or if a collision occurs [171]. By contrast, there can be instances of fishers reporting a sighting of a protected species as an interaction in Australian fisheries (C. van der Geest, pers. comm.). Differences in the number of ETP interactions reported by fishers and detected in REM analysis can be a prompt for follow-up to improve data comparability. Further, it is noted that even if imagery analysts detect fewer ETP interactions than are reported by fishers, the presence of cameras is likely to have incentivised fisher reporting and so still delivers an improvement in data quality. To ensure the efficacy of REM in detecting interactions, and that this incentive is maintained going forward, camera views have since been reviewed on some ETBF vessels [170]. Further refining of permit conditions now require that all catch is handled within view of existing cameras.

Figure 11. Comparison of protected species interactions reported by fishers in logbooks and by REM analysts, for longline vessels fishing in the Eastern Tuna and Billfish Fishery [153].

In addition to addressing the monitoring objectives set out by AFMA, REM has also been used as a tool to monitor and improve (through compliance action and education) bycatch handling practices in the fishery, with the goal to maximise post release survival and eliminate mistreatment. In this way, REM provides information that supports ongoing management of the fishery's impact on bycatch species (especially sharks and rays) [172]. Fishers are required as a condition of their concession (a form of fishing permit) to handle bycatch such that post-capture survival is maximised. On some occasions, this was clearly not taking place. AFMA responded to this issue by developing an education programme for fishers, including a video [173] and guidebook on appropriate handling practices [174]. AFMA is also able to take compliance action relating to mistreatment of bycatch, using REM information. Therefore, REM provides information that supports ongoing management of the fishery's impact on bycatch species.

With the information provided by REM, fishery managers are now able to focus attention on vessels with particular challenges, such as unusually high seabird interaction rates. Such vessels can be required to adopt additional mitigation measures, while vessels performing well are able to continue their normal operations without additional requirements (M. Gerner pers. comm., cited in [27]).

Elements of best practice demonstrated

- Feasibility / pilot study conducted that tested specific objectives
- REM in place operationally to address specified objectives
- Roles, responsibilities, and operational requirements, systems and processes set out in writing for fishers and other stakeholders.
- Timeframe for retention of REM imagery is stated.
- Programme review and evaluation undertaken regularly (annually).
- Incentive for fishers (allows vessels with high seabird catches to be targeted for management, while vessels performing well continue their normal operations)
- Feedback is provided to fishers on REM findings, including how these compare with logbook information. If fishers consider the REM review results inaccurate, they can take this up with AFMA.
- REM is integrated into the broader management framework.

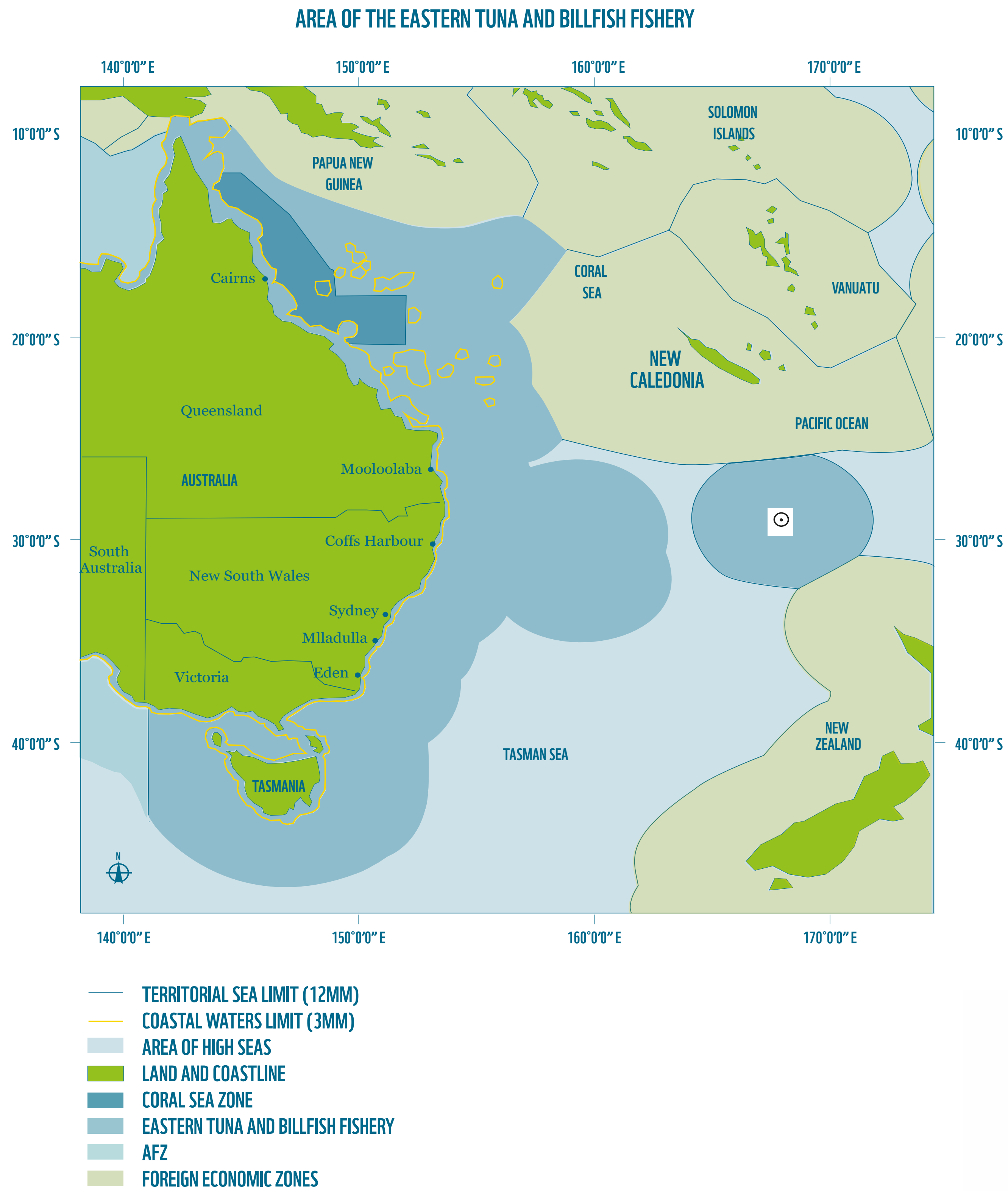


Figure 12. The area of operation of the ETBF (Source: https://www.afma.gov.au/fisheries/eastern-tuna-and-billfish-fishery-page).

CASE STUDY 2:
AUSTRALIAN SCALEFISH AND SHARK FISHERY (GILLNET AND HOOK FISHING METHODS)

Background

In Australia, the gillnet and hook sectors of the Southern and Eastern Scalefish and Shark Fishery (SESSF) operate primarily using gillnets and line-fishing gear. The species mainly targeted are the gummy shark (*Mustelus antarcticus*), pink ling (*Genypterus blacodes*) and blue-eye trevalla (*Hyperoglyphe antarctica*, *Schedophilus labyrinthicus*) [175]. The fishery operates in south and east of Australia (Figure 14) under the management the Australian Fisheries Management Authority (AFMA). Fishery management is supported by a legislated management plan [176] and a harvest strategy for fish stocks [177]. Management arrangements are set out by AFMA annually [175]. Data collection (including catch reporting by fishers) and monitoring occur in the fishery, using both on-vessel and remote methods [178].

Prior to 2010, less than 2% of fishing activity was monitored in the gillnet component of the SESSF and the accuracy of fisher reporting was broadly unknown. Consequently, there was significant uncertainty about the nature and extent of protected species interactions. Captures of the Australian sea lion (*Neophoca cinerea*) are of particular interest in the SESSF fishery [95]. This species is classified as vulnerable under Australia's Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The species is classified Endangered by the IUCN, and the population is reported to be decreasing [179]. Around 70% of the global population of this sea lion occurs in southern Australia. At sea, there is high overlap between the foraging area of the Australian sea lion and fisheries in South Australia and Commonwealth waters, including for example the shark gillnet fishery. In addition, sea lions tend to forage close to the sea floor, increasing their risk of interacting with demersal fishing gears including gillnets ([95], and references therein).

After considering the information available on Australian sea lions and their interactions with the shark gillnet fishery, AFMA developed a management strategy for this sea lion in 2010. The strategy included provisions for area closures and increased monitoring [180].

Piloting REM in the SESSF shark gillnet fishery

The cost of deploying human observers to effectively monitor interactions with Australian sea lions in the shark gillnet fishery was a significant issue for industry. Alternative monitoring methods were considered, and a pilot REM project was established [95].

After the initial deployment of REM systems for the pilot project, there was a marked increase in dolphin interactions reported by fishers. In the four years before REM, fishers had reported a total of 0 – 6 dolphin captures annually. This increased to 21 and 44 respectively, in each of the two fishing years 2010/11 and 2011/12. All dolphin capture reports in this two-year period were from vessels carrying REM systems. In response to this increase in capture reports, AFMA excluded gillnet fishing from the area in which the dolphin interactions had occurred and required 100% monitoring in adjacent areas. The monitoring requirement could be met using human observers or REM. AFMA also enabled some operators to transition to hook fishing methods instead of gillnets [95].

The unprecedented incidence of reported dolphin interactions (mainly with shortbeaked common dolphins (*Delphinus delphis*), and bottlenose dolphins (*Tursiops truncatus, T. aduncus*) broadened the investigation of REM to include interactions with these mammals. The objectives of the pilot REM project overall were to [95]:

- Assess the feasibility of REM for providing high quality data on interactions between the shark gillnet fishery and the Australian sea lion and other protected species, in a timely manner
- Better understand the true level of interactions occurring with Australian sea lions, and consequently the level of impact the gillnet fishery has on sea lions
- Investigate the efficacy of REM in collecting data traditionally recorded by human observers at sea (e.g. catch composition); and
- Assess the costs and benefits of using REM in the shark gillnet fishery.

The pilot programme delivered on its objectives and showed that REM offered significant cost savings when monitoring requirements exceed around 10% coverage of fishing activity.

An operational REM programme in the Gillnet, Hook and Trap (GHAT) fishery

Building on the pilot REM project conducted in the gillnet sector of the SESSF [95] and deployments of REM elsewhere in longline fisheries (e.g. [30]), AFMA initiated an operational REM programme. The REM programme is mandated by the E-monitoring (Southern and Eastern Scalefish and Shark Fishery) Direction 2015 [181]. It covers the gillnet, longline and autoline fishing methods in the SESSF. The main objectives of the REM programme in gillnet and longline operations are:

- During hauling, to detect and record protected species interactions
- To determine the composition of fish catches; and
- To record retention or discarding of fish caught.

In autoline operations, the objectives of the REM programme are to:

- Record seabird interactions with the haul
- Verify whether offal discharge occurs during the set
- Document the deployment of seabird mitigation devices on the set and haul
- Determine the composition of fish catch; and
- Record retention or discarding of fish caught.

For each fishing method, AFMA specifies the required views of the REM system cameras. For example, for gillnet operations, a view outboard of the roller is required to enable drop-outs to be detected. In autoline operations, views of the de-hooking and processing areas are required [80].

In the SESSF, vessels using gillnet and auto-longline fishing methods for 50 days or more per year must carry REM systems. For those using manually baited longlines, REM is required if 100 days or more of fishing is undertaken. In addition, inside designated Australian sea lion management zones, all vessels must use REM in order to legally fish and 100% of imagery is reviewed to document ETP interactions. Similarly, 100% monitoring is required for vessels fishing in a designated Dolphin Zone [80]. Outside the designated Australian sea lion management zones, 10% of imagery is reviewed [172], depending on risk (see below). Currently, 34 vessels operate REM in the GHAT fishery (C. van der Geest, pers. comm.).

REM programme information is set out in a document published by AFMA. This includes programme objectives, roles and responsibilities for operators and the REM supplier, operational requirements, privacy and security of information collected, data processing, and key contacts [80]. As for the ETBF, AAP is the supplier of REM services to the GHAT fishery. AFMA specifies programme requirements and review protocols. AAP supplies, installs and maintains REM systems, and reviews imagery and associated information returned from vessels. Vessel operators send REM system hard drives to AFMA (the data custodian), who create a copy of the drive and then provide it to AAP for analysis. AFMA retains all REM information under secure storage for at least 6 months. Longer retention periods may apply if matters of concern are observed. Fishers receive a report on the findings of AAP's review, and this includes any issues identified (e.g. quality of footage or catch handling issues that affect data collection from imagery). Feedback is also provided to fishers on the alignment of their logbook data with the REM dataset.

Findings

Overall, imagery analysts documented more retained and discarded fish per set than fishers reported in their logbooks in the gillnet and hook sectors of the SESSF. The difference between the logbook and analyst reports decreased in the second year of the programme. Up to 33% more protected species interactions were detected by REM analysts, compared to logbook reports. The difference between protected species interactions documented by imagery analysts and logbook reports decreased for marine mammals and protected shark species but increased for seabirds in the second year of the REM programme on gillnet vessels. The sample size was small for these comparisons which were not statistically significant, though the trend suggests logbook reporting could be improved (Figure 13). Logbook reports of protected species interactions increased after REM was introduced, compared to prior to its introduction ([170] and references within).

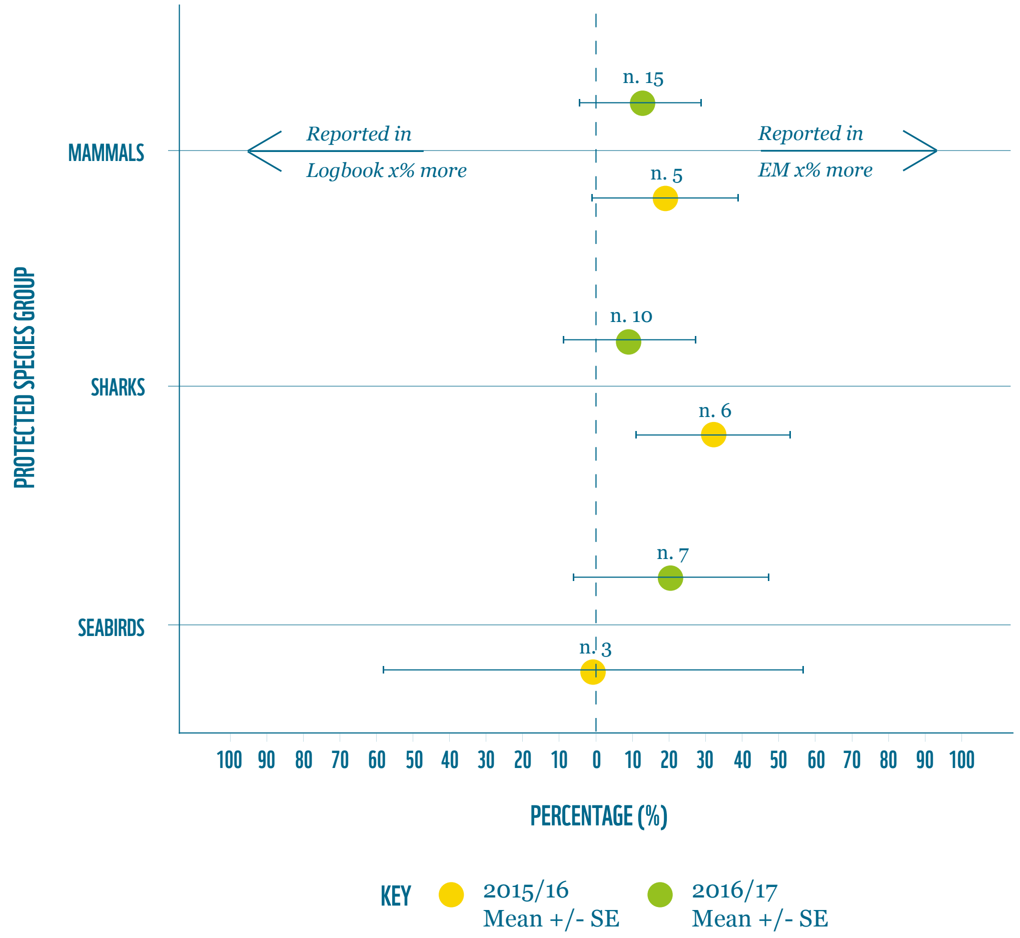


Figure 13. Comparison of protected species interactions reported by fishers in logbooks and by REM analysts, for vessels fishing using gillnets in the Australian gillnet hook and trap fishery [170].

Integration with the management framework

AFMA identified supporting REM uptake as a specific action in its mitigation strategy for managing the impacts of the SESSF gillnet sector on dolphins [182]. As well as detecting interactions with dolphins, REM imagery can be reviewed to evaluate whether an operator's legally required Dolphin Mitigation Plan is in place (vessel-specific Dolphin Mitigation Plans were required from late 2017, on all gillnet vessels and the number of dolphin interactions per metre of gillnet set is the key performance indicator for these plans). This review is required when dolphin interactions exceed a specified rate. Increased monitoring may also be required (by a human observer or REM, at the operator's cost) to confirm appropriate mitigation measures are being implemented on a vessel [182]. With the vessel-specific information provided by REM imagery, vessels exceeding specified rates of dolphin interactions can be excluded from a fishery, while others continue to fish. Prior to the introduction of REM, fishery managers could not effectively target management on a vessel-specific basis and could only introduce area closures that excluded all vessels in the fishery in response to dolphin interactions.

For Australian sea lions, spatial closures result if specified bycatch triggers are exceeded in management areas [183]. Outside Australian Sea Lion management zones (for which 100% of REM imagery is reviewed), AFMA may vary the 10% baseline of imagery reviewed based on perceived risk of interactions with protected species that are bycaught. For example, if a vessel has a track record of relatively higher captures of an ETP species, the amount of imagery monitored may be increased to better understand capture risks.

Elements of best practice demonstrated

- Feasibility / pilot study conducted that tested specific objectives
- REM in place operationally to address specified objectives
- Roles, responsibilities, and operational requirements, systems and processes set out in writing for fishers and other stakeholders.
- Timeframe for retention of REM information is stated.
- Programme review and evaluation undertaken regularly (annually).
- Creates incentives for fishers (allows vessels with high ETP bycatch to be targeted for management, while vessels performing well can continue their normal operations).
- Fishers receive feedback on the findings of REM analysis, including comparisons with logbook data. If fishers do not agree with the findings of REM review, they can follow up with AFMA.
- Integrated with the broader management framework for management of interactions with ETP, e.g. spatial management.

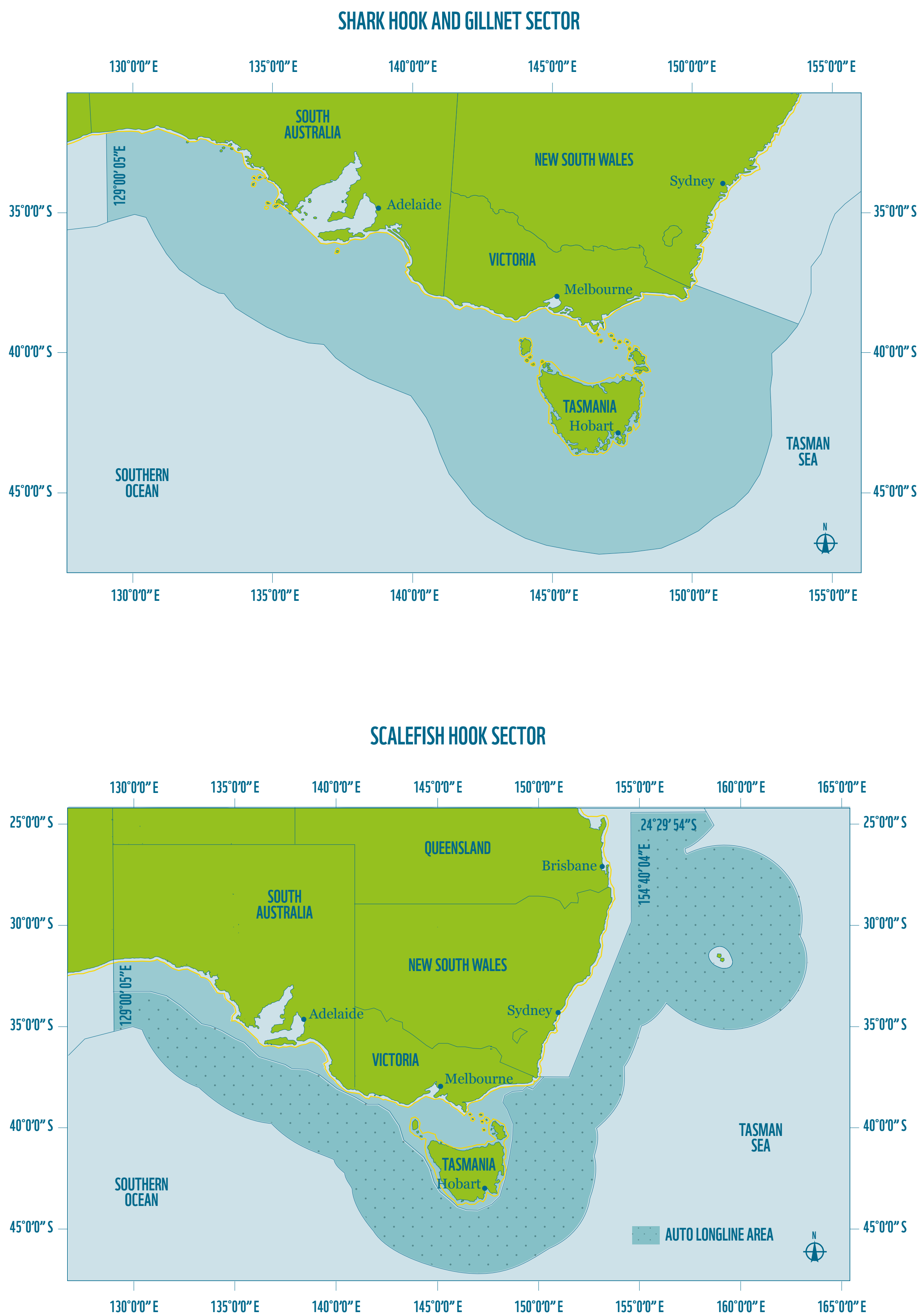
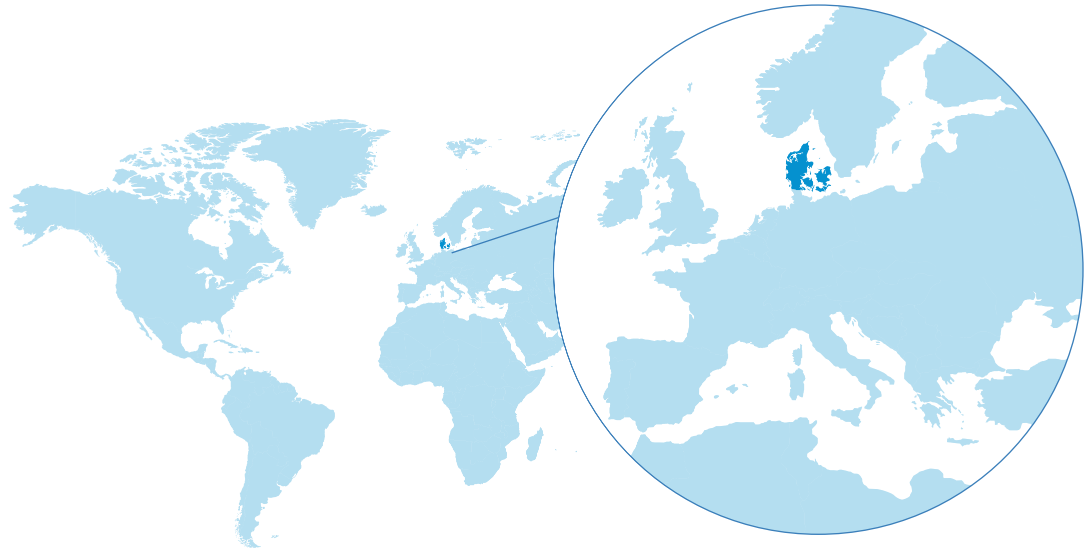


Figure 14. The area of operation of the Australian Southern and Eastern scalefish and shark fishery: (a) hook and gillnet methods targeting sharks and (b) hook methods targeting scalefish (Source: https://www.afma.gov.au/fisheries/southern-eastern-scalefish-shark).

CASE STUDY 3: DANISH INSHORE GILLNET FISHERIES



Background

Between May 2008 and September 2009, the Danish government became the first European country to test REM technology in its fisheries. Initially the aim was to address the issue of cod (*Gadus morhua*) discards, through the introduction of a Catch Quota Scheme (CQS) with self-reporting and using REM to review and evaluate these self-reported catches. An additional aim was to test the efficacy of REM systems on different types of fishing vessel fishing different types of gear so that metiers where REM could be a useful monitoring tool, could be identified. REM systems were installed on a range of vessels including 6 otter trawlers, 1 Danish seine vessel and 1 gillnetting vessel, ranging in size from 14.39m to 31.3m. A subsequent review of the sensor data and video footage collected was used to determine the future deployments of REM [184].

This initial project did not focus on marine mammal bycatch, only finfish discards, but the inclusion of the gillnetting vessel allowed the scientists to develop some useful best practise that could transfer to other REM projects and also identify that REM could potentially be used for cetacean bycatch monitoring. This led to the Danish National Institute of Aquatic Resources (DTU Aqua) undertaking a pilot project specifically to investigate the use of REM as a marine mammal bycatch monitoring tool.

Piloting REM in the Danish Inshore Gillnet Fisheries

This pilot project was conducted for 1 year beginning on 1st May 2010 on six vessels less than 15m in length. These vessels operated in 3 different sea areas (North Sea, Skagerrak and Oresund) but all used trammel or gillnets to target cod and plaice (*Pleuronectes platessa*). Vessels were fitted with an AMR REM system that comprised a control box with a 500mb removable hard drive, 4 CCTV cameras, a GPS system, and a hydraulic pressure sensor to detect fishing activity. The aim of the project was to detect bycatch of harbour porpoise and therefore one camera was installed to view the net as it was breaking the water surface, so that any accidental dropouts or deliberate cut-outs could be recorded. The other cameras (usually only two cameras were installed) focused on the catch handling and fish processing areas on deck. The fishers were required to document any marine mammal catches or interactions and the REM system was again used to verify these self-reported incidents.

During the 1 year trial, fishers reported that 25 harbour porpoises had been caught during 776 fishing trips (which includes 3 incidents that were not detected during video review) whilst review of the video and sensor data detected 36 porpoise being caught during 758 fishing trips. Video reviewers determined that 7 of the non-reported bycatches were thought to have "not been seen" by the fishers (along with a bycaught seal), whilst the other 7 non-reported incidents were clearly noted by the crew because they actively disentangled the carcasses. The 3 reported incidents that were not detected during video review are thought to have been dropouts that happened below the water surface and therefore missed by the cameras. The differences in fishing effort was due to fishers forgetting to complete logbooks and paper records being lost in the mail. Interpretation of what constitutes a trip is also of importance. When vessels left port but could not fish (due to weather or mechanical issues) the fisher had to report this as a trip, whereas the REM system only included trips where fishing actually occurred, as triggered by the hydraulic pressure sensor.

It was concluded that REM was more accurate for collecting bycatch data than using unverified self-reported data. Other advantages included the monitoring of mitigation measures (e.g. acoustic pingers), no bias introduced by having an observer on board, that video could be reviewed at 12x normal speed and on multiple occasions, and that all fishing effort could be reviewed if needed as there was no need for rest breaks. It also compared the costs of using at sea observers or REM to monitor bycatch of cetaceans, and found that the observers were 6.7 times more expensive than REM. There were also some ongoing challenges that need to be addressed around stakeholder acceptance, system reliability and data storage and confidentiality, but on the whole this project successfully proved that REM was an effective tool for monitoring and quantifying bycatch of marine mammals, on small gillnetting vessels, although detailed biological data cannot be automatically collected [14].

An operational REM programme in the Danish Inshore Gillnet Fisheries

Following on from the successful pilot project, the REM gillnet monitoring project remains ongoing and has now been in place for 10 years. It is providing insights into running a full-time programme, as well as providing valuable data that is being used in ETP bycatch risk modelling. In 2019 the pilot project became part of the national surveillance of bycatch of protected species and therefore a part of a larger operational programme. This programme is a continuation of the pilot to some degree, but it has also evolved through time. The geographical area and fleet size have remained the same with 8 vessels operating with REM monitoring but 3 vessels that operate in the Oresund have been used as a special case study for researching seabird bycatch in gillnet fisheries. It should be noted that all ETP species interactions are recorded on all the Danish REM vessels, including seabirds. Figure 15 shows the area where the project is being undertaken (the Oresund, the strait between Denmark and Sweden) and the seasonal distribution of gillnet fishing effort between 2010-18.

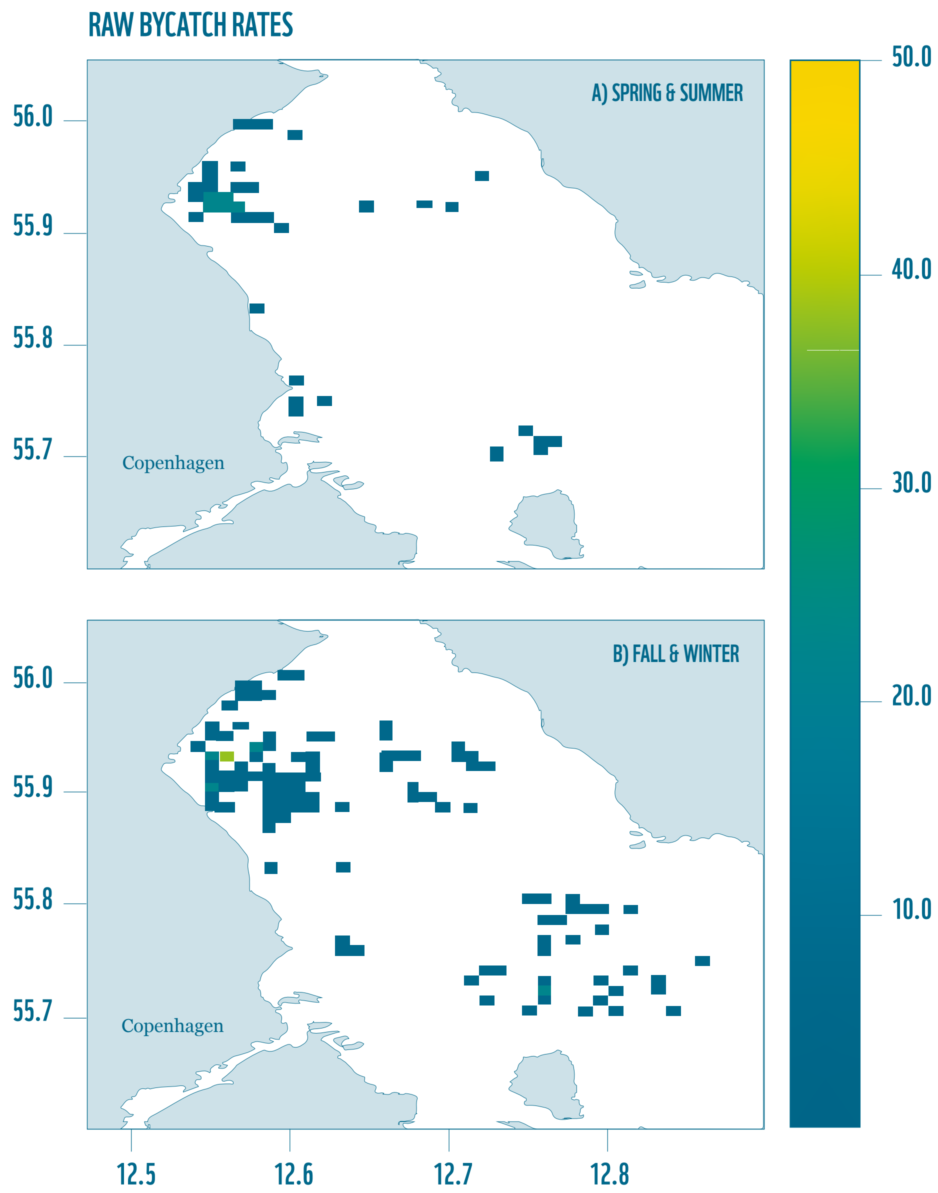


Figure 15. Location of fishing effort during the Oresund gillnet REM project [26].

The 3 static netting vessels were fitted with a REM system with a minimum of 2 cameras installed as well as the activity sensors, control box, user interface and GPS tracking device. The cameras were installed in such a way that would allow the areas where the net broke the surface of the water during hauling and the catch sorting areas, to be viewed and recorded. Between 2010 and 2018 the 3 boats collected information that allowed 1607 days at sea and 8485 net hauling events to be monitored and reviewed for bycatch. During the sensor and video review processes, the analyst's recorded all ETP bycaught species (excluding fish species). Additional observations about the type of gear used, e.g. mesh size, hanging ratios, mesh colour; and the amount of fishing effort deployed, e.g. lengths of nets, soak time, location of nets, were also collected. This allowed catch per unit effort to be calculated for each bycaught species at different locations and in different seasons, which then allowed maps of the bycatch incidents to be drawn. For example, Figure 16 shows the locations and season for the combined bird bycatch during the project lifespan.

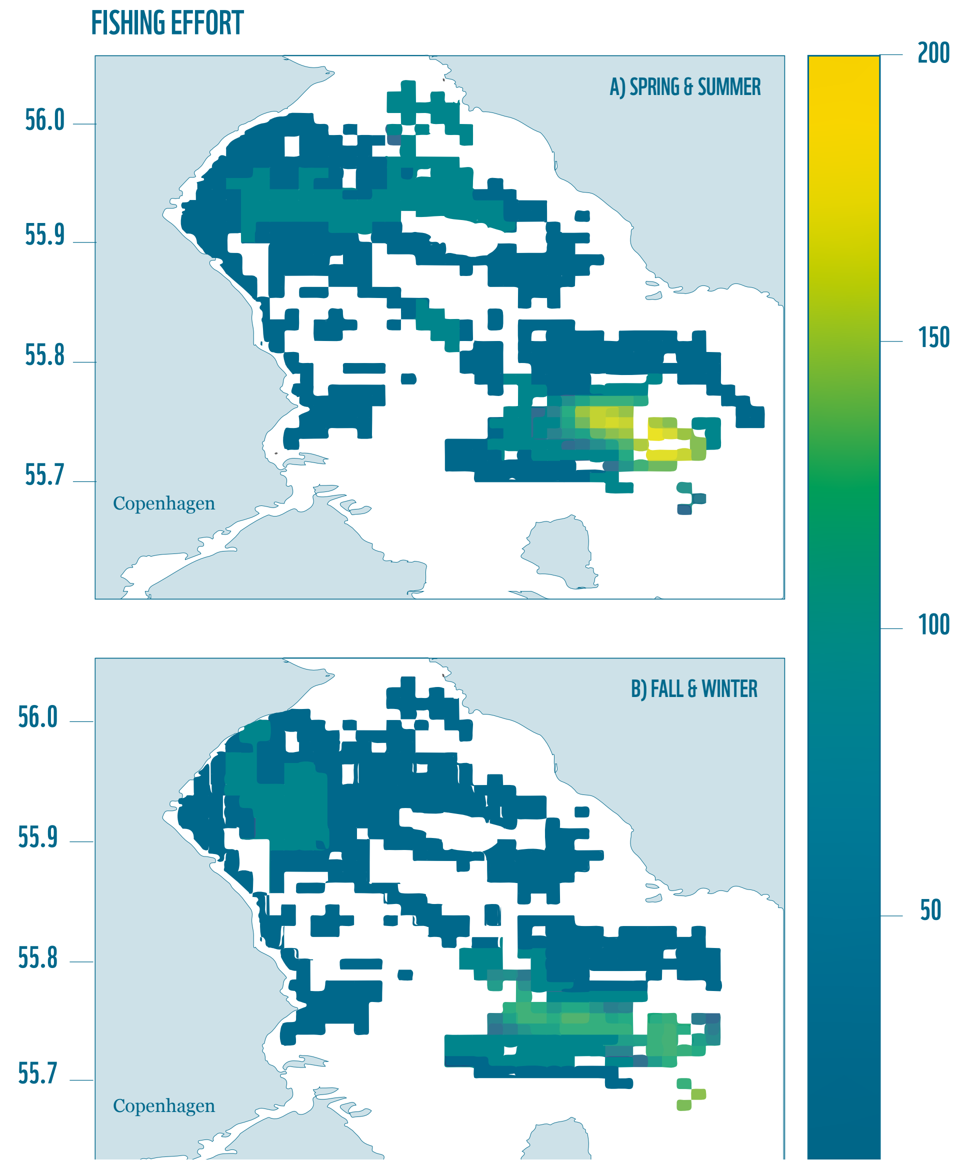


Figure 16. The locations of seabird capture during the gillnet bycatch project in Oresund [26].

BETWEEN 2010 AND 2018, THE 3 ORESUND VESSELS WITH REM INSTALLED ACCIDENTALLY CAUGHT 490 SEABIRDS.

Findings

w Of these 335 were from the duck family (Anatidae) of which 80% were Eider ducks. The rest of the bird bycatch species were mainly the surface diving birds of cormorants and razorbills/guillemots (total of 91 individuals). A further 60 birds could not be identified to species due to video failure and there were additional mortalities of 2 gulls (*Laridae*), a grebe (*Podicipedidae*) and a species of loon (*Gavidae*). It was also found that 83% of all the seabird catches occurred in the autumn/winter. These higher bycatch rates were also geographically centred around areas of high feed [26], in this case mussel beds (*Mytilus edulis*) which are a preferred diet of Eider ducks, along with cockles (*Cerastoderma edule*) [185]. From this information, scientists are able to determine where and when the interactions between gillnet fishing and bird activity is occurring. This science is essential to inform managers who will determine whether bycatch levels are too high and what management action may be required.

Elements of best practice demonstrated

- Feasibility / pilot study conducted that tested specific objectives
- REM in place operationally to address specified objectives
- Roles, responsibilities, and operational requirements, systems and processes set out in writing for fishers and other stakeholders.
- Programme review and evaluation undertaken regularly (annually).
- Integrated with the broader management framework for management of interactions with ETP, e.g. spatial management

CASE STUDY 4: TROPICAL TUNA PURSE SEINE FISHERIES

Background

There are three main types of tuna purse seine fishery methods:

1) those that target free swimming shoals of tuna
2) those that use Fish Aggregation Devices (FADs)
3) and those that target tuna associated with schools of dolphins (eastern Pacific Ocean only) [104].

The levels of bycatch associated with purse seining is generally considered to be low at approximately 1.4% by weight, of the target tunas caught [98], but rates can vary depending on the way the tuna are targeted, with free-swimming shoal fishing having an estimate bycatch rate of <2% by weight, compared to up to 9% by weight for FAD purse seine fishing [186]. Sharks are the main bycaught species, but other species e.g., minor tuna species or common associated species such as triggerfish or dolphinfish, as well as cetaceans, rays or sea turtles, whale sharks [105].

The free-swimming shoals of tuna are usually spotted from the sea surface by the vessel, or helicopters, or by using acoustic devices. The fishermen identify a shoal and then can target that predominantly single species shoal. It is encircled by the purse seine and the catch is brought aboard. Discards and bycatch of ETP species in this fishery are generally low due to the single species shoaling nature of fish and often ETP species can be released alive.

In FAD fisheries, an artificial floating platform is deployed for a time period to attract fish to it. The platforms attract planktonic organisms and generate marine growth, which then attracts small fish and other organisms, and then larger fish (including tuna) that feed on these, creating a mini ecosystem. The FADs can be made from a range of materials, from "homemade" bamboo, to FADS complete with integrated satellite tracking devices and echo sounders, that can alert the fishers when fish levels around the device are high, so that they can sail to the FAD and encircle it with their purse seine. This method of targeting tuna is less species specific than free swimming shoal fishing because it is not possible to predict exactly the mix of species that will be attracted to the device. Therefore, when the FAD is encircled and the fish removed, there is generally a more diverse range of species in the catch and this can include ETP species, as well as juveniles and other non-target tuna species. It is estimated that 100,000 devices are deployed annually in the tropical purse seine tuna fisheries [98] and that 10% are lost at sea every year and can continue to ghost fish, ensnaring ETP and other species. Accidental ensnaring can also occur even when the FADs are not lost and depends on how the FAD has been constructed and depths to which it reaches. The mortality rate of purse seine caught ETP species is thought to be very low e.g. 90% of all sea turtles caught are returned alive, but those that become ensnared are likely to die as they cannot be released by the crew [187].

The practice of targeting tuna associated with schools of dolphins is mainly restricted to the eastern Pacific Ocean, off the coasts of Mexico and central America. Here yellowfin tuna (*Thunnus albacares*) can be found swimming with several species of dolphins: including the pantropical spotted (*Stenella attenuata*), spinner (*S. longirostris*) and common (*Delphinus delphis*) dolphin. The fishers encircle both the tuna and the cetaceans and then release the cetaceans during the hauling operations. It is estimated that this fishery has killed over 6 million cetaceans since it was first introduced, with highs of over 700,000 per year in the late 1960s [98]. However, public outcry, strict conservation management measures and 100% coverage observer programmes have successfully reduced bycatch to less than 1000 individuals in recent years [98]. However, this 100% coverage only applies to the larger Class 6 vessels which are defined as being capable of carrying over 363 tonnes. The smaller Class1-5 vessels that have a carrying capacity of less than 363 tonnes [188] and which are typically less than 35m overall length, are excluded. The reduction in bycatch demonstrates that having transparency, adequate data, active and effective management measures and fisher accountability, either through the use of 100% observer coverage (which is expensive) or 100% REM coverage, can make a huge difference to the fate of an ETP species group and bycatch levels.

Due to the nature and value of all tuna purse seining fisheries, the vessels can often be very large and nomadic. They can fish in several areas and target several different stocks of yellowfin, bigeye (*Thunnus obesus*) and skipjack tuna (*Katsuwonus pelamis*), and be owned by countries

REM HAS BEEN TRIALLED IN SEVERAL DIFFERENT PURSE SEINE FISHERIES INCLUDING THE IVORY COAST, GHANA, THE INDIAN OCEAN, THE SEYCHELLES AND THE EASTERN PACIFIC OCEAN TUNA FISHERY.

such as Spain and France, even though they operate at great distances from their home nations , e.g. from Ghana or the Seychelles, and in the Indian, and Pacific Oceans. Therefore, for the purposes of this report, these different targeting methods have been aggregated into one fleet (tuna purse seine) for discussion and in relation to REM. This has been done because the vessels described in some studies can be the same vessels that are operating in other studies or the vessels can undertake different fish targeting methods during a single sea trip. In addition, the information available on these REM projects is very limited due to the recentness of introducing REM to these fisheries.

Piloting REM in the Tuna Purse Seine Fisheries

REM has been trialled in several different purse seine fisheries including the Ivory Coast, Ghana, the Indian ocean, the Seychelles and th**e** eastern Pacific Ocean tuna fishery**.**

On the Ivory coast in 2013 a pilot study was undertaken on the Ivory coast on purse seine fisheries to assess the capabilities of REM systems to monitor and collect information on fishing effort, retained and discarded portions of the target species catch, and the ability to collect data on the incidental bycatch species e.g. turtles, sharks or other teleost (bony) fish species [103]. The study was conducted on one purse seine vessel operating out of the Ivory Coast for 3 consecutive trips. This vessel undertook fishing operation using FAD devices but also targeted free swimming schools of tuna. Two AMR v4.2 systems were used in the trial, operating with 4 CCTV cameras each, GPS, hydraulic pressure, and rotation activity sensors. One system recorded activities above the main deck whilst the second system recorded imagery from the catch handling areas below the main deck. This project was one of the first to be undertaken on large industrial purse seine vessels and therefore the project design, including things like the position of the cameras, were highly dynamic, and adjustments were made during the sea trials to try and improve performance and results. Fisheries observers were also on board to provide comparative data when undertaking the video review ashore.

Video review was able to distinguish the right type of fishing activity (FAD or free swimming school) on 60 of the 61 sets through the use of vessel speed data, images of the skiffs and speed boats being utilised and to a lesser extent, through the analysis of the hydraulic pressure sensor data. The results of the catch comparisons between the observer data and the EM video analysts' estimates were mixed. Identification of tuna species is difficult, especially when large volumes are caught, and reviewing the video had to be done from a distance because of the location of the cameras in relation to the catch. Also the data was presented as weights rather than as counts of individuals, which required bulk estimations from observations of how full the brailer (dip net device that removes the catch from the purse seine to the vessel) was and how many times it was used. Conversely counting of individual animals was successful, for example, both sea turtles recorded by the observer at sea were verifiable by the video review analyst and all billfish were also reported accurately. However, shark species were not, with only 58 of the 109 reported by the observer being correctly identified during video review.

Differences between observer and video analyst estimates were mainly due to the positioning of the cameras and the way the crew handled the catch. Too many discarding points were available to the crew and the 4 cameras on each deck were not enough to cover all possibilities. Also, this study was undertaken using analogue cameras as it was before digital cameras were available and therefore the quality of the imagery was not as good as it would be using digital cameras. If this project was carried out today the results would be greatly improved by the progress in technology, by limiting the discarding opportunities of the crew and having a duty of care arrangement with the vessel to clean the camera lenses and present the catches to the cameras, where possible. This study was one of the first of its kind on this class of vessel and provided essential information to inform future trials, especially in regard to camera positioning and catch handling processes to improve video review accuracy.

OVER 10% OF GHANA'S GDP IS GENERATED BY FISHERIES

In 2015 **Ghana** undertook a trial REM project on 5 purse seine vessels to evaluate its use in monitoring their fisheries and by the end of 2018 this had been extended to their entire national fleet of 14 purse seine vessels. A total of 163 fishing trips were monitored with 154 of these being reviewed ashore by the video analysts during the trial. The need to undertake this research was generated by the requirement to demonstrate transparency and reduce or eliminate illegal, unreported and unregulated (IUU) fishing activities of face trade embargoes on importing tuna and related products to the EU. With over 10% of the Ghanaian GDP (gross domestic product) being generated by fisheries it was important that Ghana could demonstrate that they were controlling and regulating how their tuna was caught [189]. The trial utilised the Satlink Seatube EM system with 6 cameras and related positional and fishing activity sensors and was undertaken and reported on by MRAG Ltd. This trial was different from some of the other worldwide trials as it looked at the whole concept of introducing an electronic monitoring regime into a national fishery framework, and not just the onboard aspect or a particular species group. The aims of the study were to investigate the business case of introducing mandatory REM on the Ghanaian purse seine fleet to ensure their tuna industry and trade was not restricted by the EU because of lack of transparency and traceability. The study looked at the basic infrastructure required to support REM implementation to the Marine Stewardship Council (MSC) standards; the costs and benefits of replacing the existing systems; the regulations and policy changes that would be needed; the staffing levels required; and possible options for recovering the costs [190].

Also in 2015, Legorburu *et al.* [53] conducted an EM trial aboard 5 Spanish registered supply vessels that deploy, recover, check and maintain the FAD devices for the purse seine fishing vessels operating in the **Indian Ocean.** The trial ran from June to November 2015 and consisted of 8 sea trips totalling 371 sea days. The main aim of the project was to test the efficiency of EM to monitor supply vessel operations to better understand the impact of fishing operations that use FADs devices, how these attract organisms to them, and the occurrences of accidental bycatch in their netting and structures. Also, FAD devices have strict controls placed on them regarding deployment numbers, locations, seasons and construction materials and these specifications can only be checked at sea. This project used a 2-camera system called SeaTube Lite, supplied by Satlink in Spain. Specialised video analysts were supplied by Digital Observer Services (DOS), also based in Spain. They found that the REM had been able to detect discrepancies between what was occurring and what was being recorded in the vessels' logbooks, mainly related to FADs being collected and retained on board. However, it was also able to verify the accuracy of data recording in logbooks too, e.g. when the FADS are being deployed at sea. No data regarding entanglements of ETP were reported but the authors acknowledge that this was not a primary aim and would probably require an additional camera unit to view these events. This camera could also be used to verify the construction materials of the FAD to ensure they meet agreed conservation standards.

A trial of REM was conducted on 2 purse seine vessels in 2016 by the **Seychelles** Fishing Authority (FSA) using Satlink equipment, as part of the Common Oceans ABNJ Tuna Project. The aim was to assess whether REM could be used by FSA to monitor uptake of catches, monitor licencing of domestic and foreign vessels, and to test its use as a management tool. A total of 10 fishing trips over a 6-month period were monitored using REM and in addition the project managers continued to collect their usual logbook, effort and observer data for comparisons against the video review data. Local fisheries observers were trained as video review analysts.

The trial was very successful from some perspectives. It was found to be extremely accurate at monitoring the vessel activities, including tracking of vessel position and speed, as well as using this data to identify the vessel's activities e.g. searching for shoals of tuna, actively fishing, and FAD-related activities. It was also accurate at assessing total catch, total retained catch (combined species) and identifying quantities and fate of discarded species including ETP species. Information on discards and whether bycatch is released alive is extremely important (especially ETP species) from a conservation and management point of view and this would usually require high levels of coverage to gather the same information using at-sea observers. The retained catch was more difficult to identify to species, but the project managers report that these can be overcome through changes to camera configuration and placement, revisions of catch sampling protocols and changes to how the video is reviewed ashore [184]. The success of this trial has led to the Organisation of Associated Producers of Large Tuna Freezers (OPAGAC) requesting that REM be made compulsory on all purse seine vessels fishing in Seychellean waters. However the SFA have so far ruled out compulsory installation as the REM needs further adjustment in the configuration of the system in order to yield more precise and accurate catch figures on purse seiners and needs to be used as a complementary tool with sea going observers but they acknowledge that REM could be a very useful tool on longline vessels [185].

In the **eastern Pacific Ocean** tuna fishery, 4 Ecuadorian vessels (2 large and 2 smaller vessels) are currently participating in a REM trial aiming to allow coverage of the smaller vessels in the fleet and to complement the AIDCP (Agreement on the International Dolphin Conservation Program) observer programme that is currently undertaken on larger vessels. This trial commenced in January 2018 and is ongoing, with an expected completion date of October 2020. The vessels have all been installed with REM systems with 7 cameras (see Figure 17) and are currently collecting data which is also being reviewed on an ongoing basis [188]. As this is still an ongoing trial, no results are yet available, but it is promising to see the issue of collecting bycatch data from the smaller classed tuna vessels being addressed in this way.

Looking at each of these five separate REM trials on large industrial pelagic fisheries it can be seen that each project has stimulated improvements and developments in the subsequent projects. The developments in REM equipment and the positioning of cameras has improved the quality of the video captured, the use of installation plans and catch handling agreements has improved the video quality and reviewing processes, and the holistic approach of looking at all aspects of implementing a national/fleet monitoring programme has led to confidence in the monitoring approach and calls for full mandatory REM programmes in some fisheries. The open approach by the project managers was important, and the accurate publication and dissemination of the results, best practises and challenges from each project, has helped inform subsequent research and programmes, improve the accuracy of the data collected and streamline the processes involved.

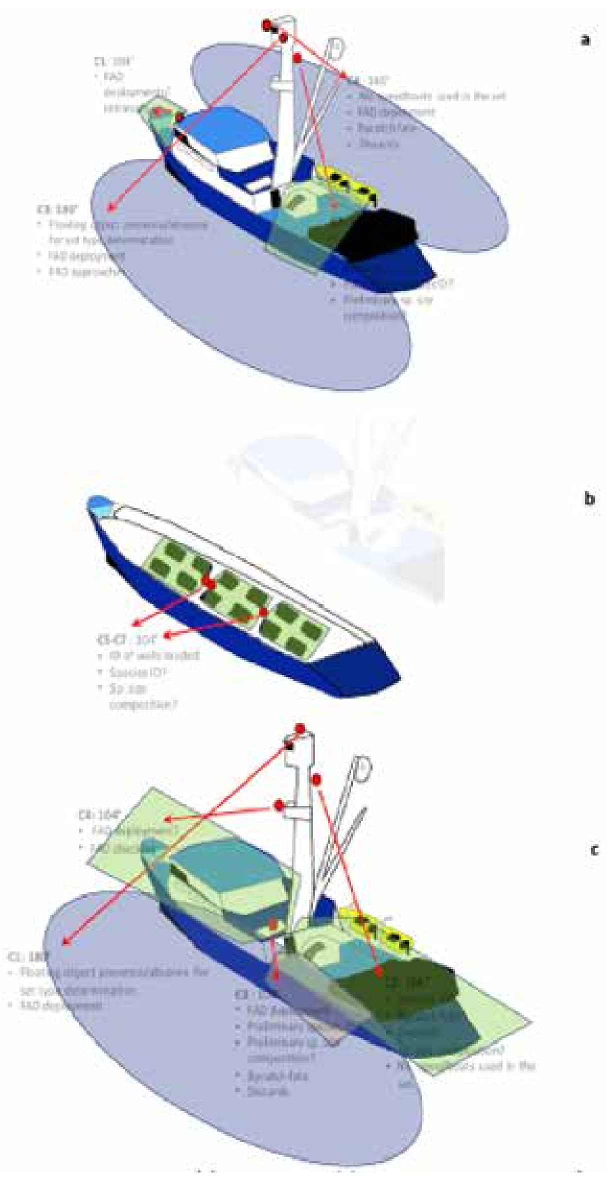


Figure 17. Field of view of the installed REM cameras on the purse seine vessels [188].

An operational REM programme in the Tuna Purse Seine Fisheries: Ghana

The only fishery from the above examples that could be considered as a possible operational project at this time is the Ghanaian programme because it has been operating on its entire purse seine fleet for several years. However, this programme is not strictly an ETP species focused monitoring programme. Any ETP interactions that are monitored are only recorded as an additional aim of the project, with the main focus being to ensure that Ghanaian tuna is not banned from the EU markets due to a lack of transparency and potential IUU activities.

In 2015 the first 5 vessels in the tuna purse seine fleet were installed with Satlink Seatube REM systems and at the same time the land-based support of video review analysts, data management and technical support were also established. The video analysts were trained to observe and quantify the target species catch (tuna), the discard rates, any incidents of bycatch of other marine organisms, and any infringements of fishery regulations. Now all Ghanaian purse seine vessels have REM installed (14 vessels) [191]. This project was initiated in 2014 with funding from the Global Environment Facility (GEF) Common Oceans/ABNJ Tuna Project, a 5-year study being implemented for GEF by FAO and by the Worldwide Fund for Nature (WWF) with a large number of partners including the Ghanaian government, the International Seafood Sustainability Foundation (ISSF), and the Ghanaian tuna industry [192]. The main goals of this pilot were to have a functioning REM system on board the entire purse seine fleet, test relevant uses of the data and to develop a legal framework so that the data could be used for the purposes of compliance. Currently ISSF requires 100% observer coverage and the REM was initially introduced to complement and improve the observer work and to gather accurate and independent data on location of the vessel at any time, fishing activity and effort, to verify compliance and get better estimates of catch composition. The lack of data has been an issue for these fisheries and the REM information will allow the Ghanaian government to ensure its catch limits are not exceeded and that ICCAT (International Commission for the Conservation of Atlantic Tuna) regulations are being adhered to.

All 14 ICCAT registered tuna purse seine vessels were fitted with REM during the project. The Satlink Seatube system was used and additional analytical, technical, and training services were provided by Digital Observer Services (DOS). The Seatube system consisted of 6 CCTV cameras. Three of these were situated above deck, with one facing forward to cover FAD related operations, one viewed the port side of the vessel to identify the fishing set type (to view FADS or small boat usage), one viewed the working deck to allow total catch and large bycatch estimation. The other three were below deck, to record different sections of the conveyor belt to allow estimation of the catch composition (species and size range) and to estimate bycatch and discarding of small species. The system also incorporated a GPS system to allow position, date, time, course and speed of the vessel data to be collected independently of the vessels systems (although it also has the capacity to connect with the vessels' VMS system). All data were automatically encrypted and stored on the systems inbuilt hard drive storage device (and a backup storage device). The system also carried out an automatic technical health check of the REM system which could alert DOS to any maintenance issues that could then be communicated to the crew to rectify [190].

The project also looked at the staffing levels required to review the video and analyse the sensor data, along with the facilities (offices, computers, secure storage, hard drive courier services etc.) needed to undertake the review work.

Other aspects of the project included establishing a legal framework that would allow REM to be integrated into the management and compliance systems of Ghana, as well as provide data that could be used for enforcement (primarily), accreditation and scientific purposes.

Findings: Ghana

Up to March 2017, the review analyst had completed analysis of 3012 sea days on 94 sea trips, an average of 32 days per trip. 10 reviewers undertook the analysis and found that it took them 1 day to analyse 3 sea days. However, the accuracy of the review processes is difficult to assess as no comparisons between observer data and review analyst catch estimates are available at present. Similarly, no data related to interactions with ETP species have been published and it is unclear if these estimations have been undertaken. Concerns from some project partners have been raised and one has even paid for

separate additional review to be carried out independently by DOS. This is a failing in the design and verification processes of the programme as independent quality control (QC) checks should have been included. Indeed, these QC checks were planned but data has not been supplied to allow this to occur as yet [190].

It should be remembered that the main benefit of this project was to allow Ghana to continue to have access to the EU markets and remove the "yellow card" status it had been given. This project has allowed this to happen. It has also allowed a collaborative and voluntary participation project between a whole national fleet segment and the management agencies to be successfully undertaken which is an impressive and positive achievement Not only that, industry have shared the costs as they recognise that the right to sell fish into the lucrative European markets is essential to their continued livelihoods. There have been many successful elements to the programme, and these should be applauded. However, if the accuracy of the video review data and the catch estimates, as well as the recording of the interactions and bycatch of ETP species could be improved and independently verified, the profile and status of this Ghanaian initiative and its fisheries will be greatly improved. Ghana has investigated and invested in the REM equipment, the equipment maintenance, the shore based analysis, the training of staff, the legal frameworks, the privacy issues, the chain of custody issues, the traceability of the vessels, the costs associated with REM and the engagement of stakeholders. The only thing missing is verification of review accuracy through routine QC and verification that the monitoring of ETP interactions and bycatch quantification is occurring and that these should be fully reported.

Elements of best practice demonstrated – Ghana

This section has described several pilot projects associated with pelagic species and purse seining. All projects demonstrated some elements of best practice, however only the Ghanaian project has been considered as an operational programme and therefore the following best practice relates to this programme only.

- Feasibility / pilot study conducted that tested specific objectives
- REM in place operationally to address specified objectives
- Roles, responsibilities, and operational requirements, systems and processes set out in writing for fishers and other stakeholders.
- Timeframe for retention of REM information is stated.
- Programme review and evaluation undertaken regularly (annually), however external QC procedures needs to be improved to ensure transparency.
- Creates incentives for fishers (allows vessels access to markets that were under threat of being withdrawn).
- Vessel-specific monitoring data fed back to fishers to ensure full transparency of process and results
- Integrated with the broader management framework for management of interactions with ETP, e.g. spatial management.

CASE STUDY 5: ARTISANAL FISHERIES

Background

Artisanal or small-scale fisheries are an extremely important part of the global fisheries. It is estimated that 95% of vessels are classed as small scale and that they contribute over 50% to the world's total catches [193]. Over 50 million fishermen are employed in this sector and over 10% of these earn less than US$1/day [194]. Nearly every type of fishing practise can be undertaken by this sector of the fleet, other than offshore large-scale operations, and vessels can often be polyvalent, which means that undertaking REM projects on these can often be challenging. This part of the fishing fleet is very much a subsistence sector of fishing in some areas of the world and investing in expensive electronic video and tracking systems may not be appropriate for some fisheries. Vessels can be typically less than 10m in overall length and some may have no engine to power the vessel, never mind a REM system, so it may not be possible (even if appropriate), to monitor using video technology. That said, there is recognition that this is an important sector regarding fish mortality and stock management and that in some fisheries there is the potential for high levels of ETP interactions. Also, one additional benefit to REM in small scale fisheries is the vessel tracking aspect of the system to provide effort data and the potential to improve safety of these vessels. Figure 18 shows a typical small-scale fleet.

Piloting REM in Artisanal Fisheries

There are several trial projects being undertaken around the world on small-scale fisheries but very few are utilising video technology, as would be the case with a modernised fleet trial where a full REM system would be used (as previously described). Some companies and administrations are attempting to tackle the IUU aspect of small-scale fisheries by having satellite or mobile phone tracking technology onboard. Sometimes this is also marketed as an aid to safety, as the last known whereabouts of the vessels will be transmitted, to help in any search and rescue activities. A good example of this type of monitoring is being undertaken by CLS in Greece and Mauritania, on a project called STARFISH 4.0 which uses their Nemo tracking system. This system also includes a robust, low-cost VMS transponder with a satellite/mobile communication device (dependent on coverage), software and mobile applications for fishermen to record catches and effort, as well as provide data to the fishers' families, vessel owners, and the fishing authorities. It is a 2-year project (2020-22) and will involve 100 fishermen in Greece and 50 fishermen in Mauritania [194].

Other companies are also providing similar solutions to CLS. The AST Group has a Guardian SMART phone vessel monitoring application that combines with their AVMS

Figure 18. Example of an artisanal or small-scale fishery fleet (Source: https://blogs.wwf.org.uk/wp-content/uploads/mireilleblog3-735x466.jpg).

Figure 19. A Basking shark (Cetorhinus maximus) accidentally entangled in static fishing gear aboard a small inshore vessel, with the imagery captured by an installed REM system (Courtesy of SeaScope Fisheries Research Ltd.)

tracker system. This is described as being "power self-sufficient though advanced solar powered solutions" and is suitable for vessels with intermittent or no mains power, especially the artisanal fleets. It is comprised of a built in GPS, anti-tamper technology, internal high capacity long life rechargeable batteries and marinised solar panel.

Some of the providers of the larger REM systems also supply "lite" versions of their systems for use on small-scale and artisanal fisheries, but most still require a reliable power supply, rather than rely on solar power. The main difference between their normal REM system and the lite version is in the number of cameras used. That said, several suppliers have indicated that they are either in the process or considering the development of, a REM system specifically for small scale fisheries.

In the inshore waters of Scotland, full REM systems were trialled on vessels down to 7m in overall length and was found to be highly effective for observing target species and bycatch species catch, including ETP interactions (Figure 19). Although these fisheries could not be considered as artisanal due to the value of their catches, they could be described as small-scale and the project did demonstrate that REM could be used effectively on small sized vessels irrespective of the gear type that was being used and therefore the technology and procedures could be transferred to some artisanal fisheries where vessels have a reliable power source [119].

A company called Shellcatch has developed a system called Virtual Observer which is similar to the other small-scale VMS style systems but goes one step further by including a single video camera along with the GPS sensors. It can be configured to track sets and hauls of fishing gear, record video, track and manage a boat's energy consumption autonomously. It can also link to a dedicated cloud platform to allow the data to be uploaded remotely via a Wi-Fi connection. It is described as a rugged and compact solar (or hard wired to boat) powered system and has been used in trials in Puerto Rico [195].

In 2016 the Shellcatch system (Figure 20) was also used in a trial project in Peru as an alternative to using at-sea observers [92]. The trial was conducted in much the same way as an operational programme and in the absence of alternatives, this trial will be described further as if it was an operational programme.

Figure 20. The Shellcatch REM system for monitoring small scale fisheries [92].

An operational REM programme in an Artisanal Fishery

As stated above, the absence of an artisanal or small-scale operational example has meant that the most suitable and recent REM trial was used for more in-depth discussion.

In some Peruvian inshore fisheries, gillnets are used to target elasmobranchs, but some studies have shown that these fisheries often have high encounter rates with seabirds, turtles and marine mammals. It is estimated that over 100,000km of gillnets are fished in Peruvian waters each year [196] by over 9500 small inshore vessels and during a recent at-sea observer project, over 800 turtles were observed being caught [197]. Although 91.8% of these turtles were released alive there is concern that due to the size of the fleet bycatch numbers could run in to the tens of thousands and that with a historical but illegal trade in turtle as "bushmeat", it is reasonable to assume that the mortality rates will be higher when observers are not on board. Monitoring such a large fleet effectively with at sea observers is virtually impossible because of the large number of vessels and the small size of the boats, which severely limits accessibility due to lack of space to accommodate an at-sea observer. Therefore, the logical step is to use REM.

Bartholomew *et al.* (2018) [92], reported on the first trial of REM to monitor gillnet fisheries in Peruvian inshore waters. They installed 5 small scale inshore vessels, operating out of northern Peru, with the Shellcatch REM system. The vessels averaged just over 10m length overall and fished with mono and multi filament gillnets. A total of 30 fishing trips equating to 228 fishing operations were monitored between December 2015 and September 2016.

The Shellcatch system included a single fixed 3.6mm lens camera and a GPS logger, connected to a portable power pack, that was rechargeable through a solar panel. The camera was programmed to take photographs continuously at 40 second intervals. Although Shellcatch systems are able to take video there was not enough resource to store or review the amount of video that could have been recorded and so the single photo every 40 seconds represented a compromise between data collection, data storage, data management and data processing. All images were stored on the built-in hard drive and were subsequently downloaded to a computer via online cloud storage when the vessel was in harbour. Camera positioning was undertaken in liaison with the vessel's crew and all vessels and crews volunteered to be involved in the study.

On 4 of the 5 volunteer vessels, at-sea observers were deployed to collect data that could be used in comparative trials. These observed and recorded counts for all target and bycatch species including ETP species, as well as length or width data on a subsample of some of the shark and ray species caught.

The images captured by the Shellcatch system were subsequently linked together to create a 10 second time lapse video of trips using GoPro software, to speed up video review processes.

Findings

A comparison was made between the ETP interactions detected by the video reviewer and those recorded by the at-sea observer on 172 of the fishing operations. The remainder of the 28 fishing events could not be compared because one vessel could not accommodate an observer and 12 fishing sets on one vessel, were unusable because the camera view was accidentally obscured during fishing operations.

A total of 33 turtles, 7 cetaceans, and 5 South American sea lions were recorded by the at-sea observers. During video review of the same fishing operations a total of 12 turtles, 4 cetaceans and 5 pinnipeds were detected. In addition, imagery where an observer was not on board was also analysed and a further 48 turtles, 1 penguin, 10 cetaceans and 6 pinnipeds were detected. Identification to species was not always possible because of the low resolution of the collected imagery but on 85% of turtles caught, a match was possible. It should also be added that the target elasmobranch catches were also analysed, and the REM was found to be capable of collecting data to allow good species identification, depending on the quantities caught and how catch was handled on deck.

The low level of correlation in bycatch counts is thought to be due to how the cameras were configured and positioned. The 40 second interval and low resolution may have missed some instances of bycatch and the cameras were positioned primarily to verify target species catches rather than incidental ETP interactions. It was also suspected that ETP species that dropped out of the net during hauling were also missed during video review.

The authors concluded that REM is an excellent low-cost alternative to using at-sea observers and could provide cost savings of over 50%, but the issues related to data storage and camera resolution should be resolved. Where possible video rather than linked stills imagery should be used, as the 40 second interval between stills images did not allow enough imagery of the bycatch species to allow it to be fully identified in all cases. Combining this observational data with GPS data would allow REM to be used to identify fishing grounds, areas of high bycatch risk, monitor the effectiveness of bycatch mitigation devices, detect fishing in protected areas or other management issues. If also linked to an effective regulatory and enforcement framework it would be a useful tool in monitoring illegal fishing practises. Given the size of the fleet it is unlikely that REM could be used on every inshore vessel, but it could be rolled out on a risk-based approach or on a reference fleet basis.

Elements of best practice demonstrated

- Feasibility / pilot study conducted that tested specific objectives
- REM partially in place operationally to address specified objectives (stills rather than video)
- Roles, responsibilities, and operational requirements, systems and processes set out in writing for fishers and other stakeholders
- Programme review and evaluation undertaken regularly
- Creates incentives for fishers (allows vessels continued access to markets and removes the allegations of participating in the illegal trade of turtle meat and shell)
- Vessel-specific monitoring data fed back to fishers to ensure full transparency of process and results
- Integrated with the broader management framework for management of interactions with ETP, e.g. spatial management, illegal trade in turtle meat and shell.

Summary of best practices from case studies

A summary of the best practices demonstrated by the different case studies is shown in Table 7. To summarise the case studies are 1: Eastern Tuna and Billfish Fishery, Australia; 2: Scalefish and Shark Fishery using gillnets and hooks, Australia; 3: Inshore gillnet fisheries, Denmark; 4: Tropical purse seine fisheries targeting tuna, Atlantic, Pacific and Indian Oceans; 5: Small-scale and artisanal fisheries, selected locations.

THE AUTHORS CONCLUDED THAT REM IS AN EXCELLENT LOW-COST ALTERNATIVE TO USING AT-SEA OBSERVERS AND COULD PROVIDE COST **SAVINGS OF OVER 50%**

TABLE 7. SUMMARY OF BEST PRACTICE ELEMENTS DEMONSTRATED BY CASE STUDIES OF REMOTE ELECTRONIC MONITORING (REM).

BEST PRACTICE ELEMENT	DEMONSTRATED BY CASE STUDIES	ANALYSIS OF WHAT MAKES THIS ELEMENT OF BEST PRACTICE SO VALUABLE
Feasibility / pilot study conducted that tested specific objectives	1, 2, 3, 4, 5	It is clear whether the monitoring objectives can be met by REM, and pilot approaches can be refined to optimise operational deployments.
REM in place operationally to address specified objectives	1, 2, 3, 4, 5	The monitoring objectives REM is in place to achieve are clear to fishers and other stakeholders.
Roles, responsibilities, and operational requirements, systems and processes are documented (in writing)	1, 2, 3, 4, 5	There is a common understanding of how the programme will work, who does what, and where responsibilities and accountabilities lie. If issues arise during implementation, there is a single documented 'source of truth' that underpins the REM programme. There is also transparency around the REM programme, which builds credibility.
Timeframe for retention of REM information is stated.	1, 2, 4	There is a clear understanding of how long data can be collected from REM. This is a key element of programme transparency, and can ameliorate fisher concerns, e.g. about privacy, retrospective detection of compliance breaches, or the potential for inappropriate future usage of sensitive imagery (such as that showing captured ETP).
Programme review and evaluation undertaken regularly (annually).	1, 2, 3, 4, 5	As with any monitoring programme, ongoing review and evaluation of REM programmes is essential to ensure programme objectives are being met effectively and are appropriate to management needs. Where this is not the case, changes are expected to address issues arising. Documenting review and evaluation processes and findings contributes to credibility and evidences programme evolution over time.
Creates incentives for fishers (e.g. allows vessels with high ETP bycatch to be targeted for management, while vessels performing well continue their normal operations; allows vessels access to markets; could be used to prioritise access to new fisheries/ quota; evidence removes inaccurate allegations and builds trust).	1, 2, 4, 5	Humans are more likely to perform well when incentivised to do so, i.e., when their actions are rewarded. Overall, REM works best when fishers are prepared to work with the system (e.g. ensuring that activities of interest take place in front of the camera). Therefore, the outputs from a REM programme are likely to be optimal (and most cost-effective) when fishers consider that benefit is delivered by that programme.
Vessel-specific monitoring data is regularly provided to fishers and there is an identified channel for follow-up when there are differences of view on findings.	1, 2, 4, 5	REM can be used to build a common understanding among fishers, managers and other stakeholders about fishing operations and events at sea. When analysts record something that fishers do not agree with, that can be reviewed by both parties and discussed (unlike, for example, when a human observer records an event that cannot be verified subsequently). This increased transparency and unprecedented ability to verify data serves to build trust, promotes improvements in reporting, and improves data quality overall. It may also contribute to continuous improvement in REM programmes.
REM integrated with the broader management framework for management of ETP interactions	1, 2, 3, 4	The purpose and benefits offered by REM are all clear, including how it contributes to fisheries management overall. This maximises the return on programme investment.

BEST PRACTICE REM FOR ETP MANAGEMENT

Best practice for REM is constantly evolving, as pilot and operational REM programmes are conducted, and technology and application improves.

While each fishery is unique, and REM has to date been more often used to address more standard fisheries management objectives we believe that a generalised best practice approach can be set out for implementing REM to monitor ETP interactions (Figure 21).

Exactly how each programme element is implemented is likely to differ due to a range of factors, such as the purpose of implementing REM, how 'REM ready' a fishery is, and the resourcing available.

Further, while it may result in departures from best practice in some cases, adapting programmes to local context is critical for successful REM implementation overall.

Figure 21. REM for ETP: Key steps for implementation and programme elements. Most elements are common to both pilot and operational programmes and those relevant only to operational programmes are identified separately.

FIGURE 21. REM FOR ETP: KEY STEPS FOR IMPLEMENTATION AND PROGRAMME ELEMENTS.

STAGE OF IMPLEMENTATION	REM PROGRAMME DEFINED	REM PROGRAMME DESIGNED	SYSTEMS AND PROCESSES SUPPORTING IMPLEMENTATION DEVELOPED	REM PROGRAMME IMPLEMENTED	PROGRAMME REVIEWED
Pilot and operational REM programmes	• Policy context established, e.g., relevant fishery management objectives • Business objectives of the REM programme are defined, e.g., to grow social licence to operate by increasing the transparency of the focal fleet's operations • Monitoring objectives to be met by REM are defined • Business requirements are defined, i.e. what data will be collected using REM • Programme outcomes are defined, e.g. skipper and vessel-based accountability is enabled across a fleet • Programme governance and management in place • Industry incentives for REM adoption considered, established • Transitional arrangements are considered, that address migration from the current state to a future state that includes REM	• Level of monitoring coverage set • Focal fleet or vessels identified • Barriers to adoption identified and mitigation considered • Programme costs estimated • Funding and supply models defined • Data management policy and practice defined, e.g., imagery retention timeframes, privacy provisions, delivery of REM information from vessel to review facility • Review delivery model defined (e.g. internal government or contracted third-party review) • REM information review process defined • Roles and responsibilities defined for programme participants • Implementation plan developed • Outreach and communications plan developed • Outreach workshops programme design and implementation plan with fishers (and other stakeholders as relevant)	• REM system specifications finalised • Data management infrastructure developed • Response to detection of potential compliance issues developed and documented • Reviewer training developed • Quality assurance process for review developed (e.g. 10% audit of reviewer findings) • Personnel recruited to support programme implementation including review • Transition plan developed, that addresses transitional issues identified at the programme definition stage • Outreach and other communications actions resourced, for industry and other stakeholders	• Outreach communicates purpose, scope and approach of programme, and roles and responsibilities of participants • REM systems deployed • REM imagery and associated information collected • Imagery and associated information reviewed and findings documented • Review quality assurance process in place • Feedback communicated to vessel operators, skippers and crew on REM review findings, and appropriate follow-up actions set out (e.g. need for more frequent lens cleaning, or adjusted camera angles)	• Delivery on programme and monitoring objectives evaluated (e.g. quarterly at first, then annually for an operational programme) • Review involves industry and other stakeholders as appropriate • Appropriate modifications to programme identified • Findings of review documented • Changes implemented (revisiting implementation stages as necessary)
Operational REM programmes	• Integration of REM data with existing time series considered, if required • Legislative framework (e.g. new regulations) for use of REM developed	• Standards and specifications for data collection defined and documented	• Programme guide completed for vessel operators, and other stakeholders as relevant		• Programme guide updated as appropriate

FISHERY 1

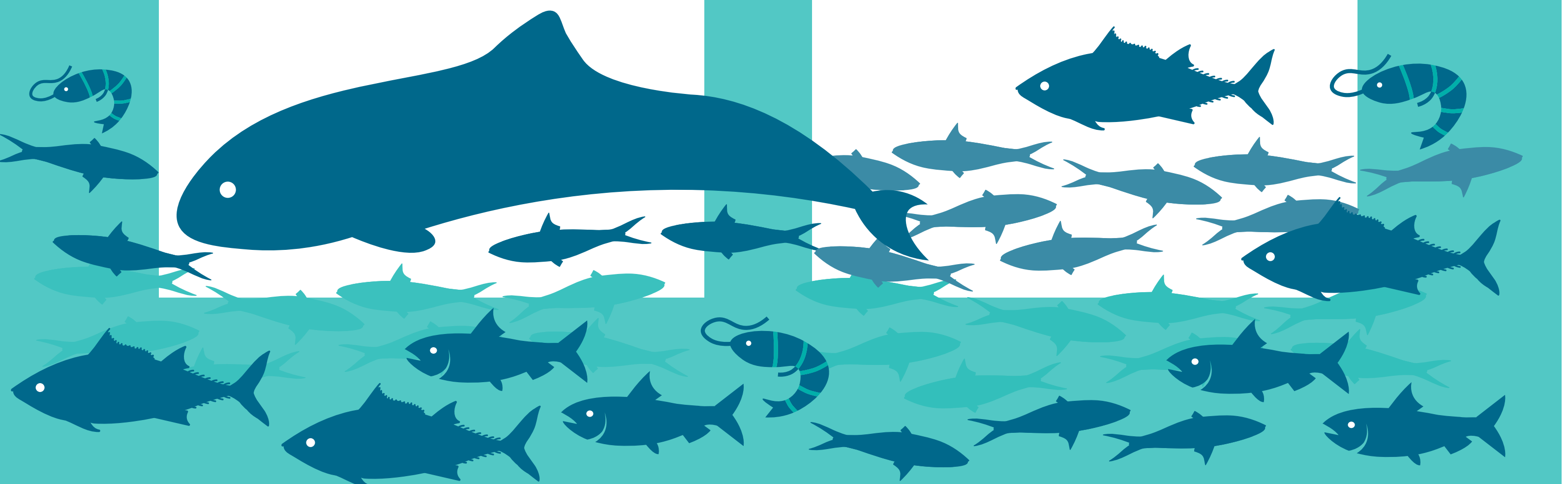
AN INDUSTRIAL TRAWL FISHERY INVOLVING 10 VESSELS

In this fishery, cetaceans interact with trawl nets frequently and there is a relatively high number of mortalities per vessel. The fishery is managed by a government agency such that when cetacean captures reach a specified annual limit, the fishery is closed. In the last 10 years, human observers have been deployed to monitor all trawl tows (100% coverage). Observers have enumerated cetacean captures and fishers also document captures in their logbooks. Observers have also documented fish catch. Two large companies own the vessels involved in the fishery, and these companies are interested in alternative monitoring approaches that are more cost-effective than deploying human observers. A pilot REM project has not been conducted in this fishery but was undertaken to monitor pinniped captures in a similar trawl fishery managed by the same national fisheries agency. Vessels in this fishery are large (more than 40 m in length), and they can be at sea for one or more weeks per trip.

FISHERY 2

A COASTAL GILLNET FISHERY INVOLVING 100 VESSELS

In this fishery, seabirds are caught in gillnets occasionally. A small amount of monitoring (1% of fishing effort) has been conducted using human observers and fishers record ETP captures in their logbooks. Operators consider that there is a relatively low number of seabird mortalities per vessel, as shown by logbook information. The fishery comprises independent operators of one or two vessels, who have formed an association. The association wants to determine the fishery impact on ETP seabird populations to inform a decision by members on whether to seek sustainability certification. If certified, REM may subsequently be used to monitor seabird captures on an ongoing basis to demonstrate that fishery impacts on seabirds are sustainable. A pilot project has been conducted, which confirmed that seabirds could be detected among fish catch. Vessels in this fishery are small (lengths of 15 m or less) and do short trips of one to several days.



FISHERY 1

1. Defining the REM programme

In this trawl fishery, the **policy context** for the REM programme is management of the fishery in accordance with a bycatch limit. The primary **business objective** is to introduce REM as it has been demonstrated to be a more cost-effective monitoring solution than human observers. The key **monitoring objective** is to document all cetacean captures to determine if/when the bycatch limit is reached. Recording each cetacean capture event is the critical requirement. The outcome sought is that cetacean bycatch is accurately known relative to the bycatch limit, such that the appropriate course of action can be taken for fisheries management (in this case, management of the fishery to avoid reaching the bycatch limit, or fishery closure if it is reached).

In this fishery, REM can be accommodated within the pre-existing legal framework, which allows the fisheries management agency to use any monitoring method that is appropriate for collecting information to meet a specified fishery monitoring objective. No new legislation or regulation is required. There are also no transitional requirements anticipated. The fishery has been well monitored for some time, and the REM-captured information will continue the time series of cetacean capture data that already exists. The existing legal framework sets out clearly that it is the responsibility of the vessel operator to ensure that REM systems effectively meet any legal requirements. (This applies regardless of any contractual relationship with a service provider and is the same situation as for any other equipment fitted on the vessel, e.g. VMS).

The two companies operating in the fishery have ongoing relationships with the government fisheries agency. A representative from each company is present on the REM programme governance group, with government agency staff and independent experts comprising the other members. The government agency is responsible for REM programme management, and regular meetings with nominated contacts in each of the two fishing companies ensures effective communication between government and industry on an ongoing basis.

2. Design of the REM programme

The fisheries management agency and the two companies operating in the fishery discussed different approaches to acquiring REM capacity and capability. Primary concerns were ensuring competitive pricing for REM technology, only acquiring REM systems that would meet government requirements, ensuring quality review systems, processes and programme outcomes, and facilitating accessibility to the market space by new suppliers over time.

Given the scale of the programme, two suppliers of REM systems were invited to provide estimates on the costs of the programme. The government agency and two companies active in the fishery discussed these and agreed to progress with one supplier, to maximise cost efficiencies. The supplier entered into a contract with the government agency to manage and review REM information in accordance with a set of standards and specifications, and to provide the emergent data in an agreed format. Standards and specifications were reviewed by the REM programme governance group and one external independent expert located offshore, prior to incorporation into the supplier's contract. The supplier also entered into contracts with each of the fishing companies, to supply, install and maintain REM systems for their vessels. These contracts clearly set out the responsibilities of the supplier, the fishing companies and the vessel operators. With the contractual arrangements in place, the standards and specifications were published by the government agency to facilitate transparency, and to inform decision-making by other providers who may be interested in the same market (or fisheries managed by the same agency) over time.

REM programme managers developed an outreach and communications plan and an implementation plan for the REM programme. Among other information, the implementation plan sets out the timeframe for programme roll-out. Nominated contacts at the two fishing companies provide input and feedback on the draft plans.

Because the monitoring objective is to document all cetacean captures, all catch landings by vessels must be monitored and so 100% of REM imagery is reviewed. REM imagery captures trawl nets coming on deck, emptying into pounds below deck, and catch sorting. There is a run-on period to ensure that all catch is sorted before cameras cease recording, and consequently, all cetaceans among catch can be detected. Fishery operators are motivated to support and facilitate the adoption of REM because they are seeking a cost-effective alternative to human observer coverage. As a result, there are no barriers to REM adoption in this fishery.

The government agency recovers the costs of programme administration and REM information management and review from industry. Industry pays the supplier directly for services relating to the installation and maintenance of REM systems.

3. Development of systems and processes supporting REM implementation

With contracting out the information management and review, the government fisheries agency has a reduced requirement for creating its own data management infrastructure for REM. However, metadata associated with data extracted from REM should be stored and the agency may also require the supplier to provide still images or video segments of events of interest. Similarly, while the agency has not been required to develop a review protocol for REM information or training for analysts, it has instructed the contracted supplier on the requirements for review and associated quality assurance. The supplier was able to offer considerable expertise to inform the fisheries agency's decision-making about review procedures appropriate to meeting the objectives of the programme. Similarly, the supplier's advice was critical to finalising REM system specifications.

Because the fishery has been well monitored for some time, a significant increase in the number of compliance issues detected was not anticipated. Penalties already exist in the regulatory framework for obstructing fisheries monitoring. These would apply, for example, in cases of camera lens obstruction and REM systems being deliberately powered off. The fisheries agency set out this information in the programme guide developed for vessel operators which would form part of Duty of Care agreement and adherence to this would be a condition of a fishing licence.

The programme guide also set out requirements for REM, programme objectives and context, information management (including security, privacy, and how vessel operators deliver information to the contracted supplier for review), roles and responsibilities of key programme participants, key contacts relating to the programme, and answers to frequently asked questions.

4. Implementation of the REM programme

The supplier worked with vessel operators to deploy systems aboard vessels and REM is operating as a routine part of the fishery monitoring framework. The supplier is reviewing information in accordance with the instructions received from the fisheries agency. Review findings are provided to the government fisheries agency and also communicated to vessel operators to help improve the overall efficacy of the programme. This feedback loop has been used to address minor problems. Implementation of changes required have been confirmed in imagery provided to the supplier for review, after changes were made. When issues have arisen with system operations that could not be addressed remotely, the supplier visited vessels.

An issue arose with one skipper questioning the number of dolphins his vessel was reported to have captured in a particular trawl on the basis of REM imagery. He was invited to view the imagery of that trawl at the contracted supplier's office, together with the supplier and fisheries agency staff. The REM analyst who reviewed the imagery described the review procedures and explained to the skipper how the number of dolphins recorded was reached. After watching the imagery, the skipper agreed with the findings of the analyst and no longer questioned the data recorded.

5. Review and evaluation of the REM programme

After three and six months of operation, the REM programme was reviewed. This review involved the government fishery agency, supplier, industry, and other stakeholders as appropriate. The focus of the reviews was on delivery against the programme objectives. However, all aspects of the programme were considered. The review findings were documented, such that the evolution of the programme over time can be tracked and audited. The findings were made available to industry, and other stakeholders as appropriate (and having addressed any privacy concerns and sensitive information prior to disclosure).

The main finding was that the run-on time provided for after catch sorting was completed could be reduced. This change meant that hard drives did not require such frequent replacement. This change was communicated to the supplier and industry, and the programme guide was updated to reflect the change to REM requirements. A minor finding was that on some vessels, camera lenses needed to be cleaned more frequently to ensure clear views. This was addressed with those vessels and crew directly. There was no need to revisit other implementation stages at the three or six-month reviews.

After the two reviews conducted in the short-term, the programme was scheduled for annual review on an ongoing basis.

FISHERY 2

1. Defining the REM programme

The Coastal Gillnet Fishery Association (CGFA) is interested in pursuing sustainability certification. The certification scheme provides **the policy context** for REM in this fishery. The scheme's requirements reflect what is considered an acceptable level of impact on ETP seabird populations. The **business objective** was to demonstrate that vessels in the fishery are operating sustainably (as defined by the certification scheme requirements). The **monitoring objective** for REM was to detect seabird captures. Capture data were then used to develop quantitative estimates of bycatch, enabling the business outcome for the programme to be achieved – that is, assessing the impacts of the fishery on seabirds at the population level. The main business requirements for the REM programme were to document seabird captures and fishing effort.

The CGFA established a management group for the REM programme, comprising the CGFA chair and an administrator, fishers who are also CGFA members, the REM supplier who completed the pilot programme in the fishery, and an independent technical consultant whose main role is to provide advice on the requirements of the sustainability certification scheme and how they may be met. The REM programme was voluntary from a legal perspective, and so no new regulatory provisions were needed. However, by being a member of the CGFA, fishers were required to be involved in the REM programme.

The incentive for CGFA members to participate in the REM programme is for increased market access and the potential for a price premium on fishery products if the fishery is certified as sustainable. Transitional issues were focused on how REM would be incorporated into CGFA activities longer term, if certification proceeds. More broadly, longer term arrangements would also need to include operator accountability for seabird capture rates, especially where these are unusually or unacceptably high on a particular vessel. Such specific accountabilities would contribute to the fishery retaining certification, in that operations with anomalously high seabird bycatch rates would become the focus of management intervention. Previously, if observer monitoring detected a bycatch event, it was impossible to ascertain whether this was unusual or the norm. Therefore, all fishers were affected when fleet-wide regulatory changes occurred. The impending transition to specific accountability was cited by two CGFA members as their reason for exiting the fishery. The remaining members considered that those operations were less robust, and that redistributing their catch allowances to more responsible operators was positive for the sustainability of the fishery overall.

2. Design of the REM programme

The REM supplier who completed the pilot project in the fishery provided a service proposal to the CGFA. The proposal included a detailed costing for a REM programme. With agreement from the majority of its members, the CGFA entered into a contract with this supplier. The scope of the contract included the lease of REM systems for 100 vessels, the service and maintenance of those systems, review of imagery and associated information, and reporting of findings to the Association and vessel operators. The contract also set out the agreed approach to data management, including what would happen to REM information after review. The programme management group contracted a technical expert to work with the supplier to develop data standards and specifications for the programme. These were then agreed by the CGFA and formalised as an attachment to the supplier's service contract.

The initial contract term was one year with a provision to vary under certain circumstances, including if the CGFA decided to proceed with REM on an ongoing basis. In that case, a 10% discount for the extended term would apply. The CGFA recovered the REM programme costs from members, with each member contributing in proportion to their share of the fishery's total catch, averaged over the previous three fishing years. Operators were invoiced by the CGFA for a pro-rated monthly portion of their annual contribution.

REM captured 100% fishing effort and catch sorting (with a run-on time after catch sorting was completed) on all vessels in the fishery. 50% of the imagery recorded was then selected for review. This level of review was based on monitoring levels typically required to quantitatively estimate ETP bycatch levels with reasonable confidence. The technical consultant on the programme management group advised that rarely caught species may not be detected by this level of review, and that the impact of the fishery on these may need to be explored using an alternative approach (e.g. risk assessment).

Some vessel operators who were not part of the pilot REM programme were concerned about the presence of cameras on their vessels, potentially on an ongoing basis. To avoid this concern becoming a barrier to adopting REM, the management group decided to hold a workshop involving fishers who were experienced with REM and those who were not. Experienced fishers were able to address the concerns of those who had not been involved in the pilot project. The management group committed to revisiting the concern about camera presence after the REM programme had been in place for 2 months, to ensure there were no residual issues in this regard.

The supplier developed an implementation plan for the programme, which was reviewed by the management group. Fisher feedback was sought on the draft version of this plan. The CGFA developed a Memorandum of Understanding (MOU) setting out the REM programme and the roles and responsibilities of the Association and fishers in the programme. This was signed by the Association and each member fisher.

The REM programme became a standing item on the CGFA's monthly meeting agenda. The CGFA administrator on the programme management group was designated as the key contact for fishers with queries about the programme. The administrator was also responsible for coordinating programme outreach and communications.

3. Development of systems and processes supporting REM implementation

The management group agreed on the final REM system specifications, after considering the findings of the pilot project and the scope and objectives of the new programme. The supplier was responsible for data management and sought input from the management group to address key questions relating to data management infrastructure as these arose. The management group decided to address potential compliance issues by contracting the supplier to flag these if detected during review. Compliance monitoring was not identified as an objective of the programme and therefore, issue detection was purely opportunistic. Any issues and elements of particularly good practice were identified during the REM review. Issues were ranked as minor, moderate, or major. The management group agreed that moderate and major issues would be raised with operators as soon as practicable (e.g. at the next port call), while minor issues could be raised monthly, if contact with operators did not otherwise occur sooner.

Reviewer training materials, quality assurance and the recruitment of programme support personnel were all progressed by the supplier. Reviewer training materials included imagery of captured seabirds from the pilot REM programme. These images provided REM analysts with realistic examples of what they would be looking for among imagery collected from the fishery.

A subset of management group members worked together to draft a programme guide. This was workshopped with a small group of fishers, to ensure it was clear and included all of the appropriate content. The full management group then reviewed it before it was finalised. Among other content such as programme context, data management, compliance, and points of contact, the programme guide emphasised how fishers could increase the efficiency of review (thereby reducing review time and total cost), for example, by carefully displaying captured seabirds to the camera such that the head and feet were clearly visible.

4. Implementation of the REM programme

The supplier worked with vessel operators to schedule the fitting of REM systems, and installations were completed by the management group's nominated deadline. The supplier also created a waterproof card for posting on vessels, which summarised the key operational procedures that skippers and crew must follow to optimise REM performance (e.g. daily lens cleaning, areas onboard that must be kept clear for camera views, seabird handling) and meet their agreed obligations. REM information collection and review proceeded, with findings reported to the management group monthly. Vessel-specific feedback was provided to operators monthly to highlight good practice and identify and set out solutions for minor issues. More significant issues were addressed with vessel operators on-site in port.

The management group reviewed potential incidents of non-compliance that were detected during review and decided how these would be followed up with fishers. For minor issues, feedback was included in monthly reports to vessel operators. If a more significant issue was detected, the chair of the management group met with the vessel operator to discuss the issue and set out agreed actions in response. If appropriate, these actions were then documented in an update to the operator's MOU.

In the first six months of the programme, 70% of the seabirds caught were landed by five vessels. The management group convened a workshop with these vessel operators and several other fishers, to identify risk factors in their operations which resulted in the disproportionately high bycatch. Mitigation approaches were identified and implemented. In the second six months of the programme, the occurrence of seabird bycatch events was broadly similar across the fleet.

5. Review and evaluation of the REM programme

The REM programme was reviewed after two months, to ensure implementation was completed and information was being successfully collected. The workshop also revisited the concern voiced by vessel operators during the programme design stage, about cameras being on vessels over time. Operator comfort with cameras had increased significantly in the interim. Fishers identified that the key reasons for this positive change were transparency around what happened to imagery, confidence that their privacy was respected during the review process, and the approach taken to identifying and addressing any issues that were detected (including potential compliance issues).

The management group contracted a statistician to develop estimates of seabird bycatch. The technical consultant on the group then considered these estimates with reference to seabird population information and the criteria of the target sustainability certification scheme. The consultant considered that the impacts of the fishery on seabird populations were highly likely to be sustainable, with greater confidence for the second six months of the programme after the anomalous bycatch levels on five vessels were resolved. Therefore, seabird bycatch at current levels was not expected to be a barrier to certification.

The CGFA decided to progress its plan to seek certification and continue with REM as the main tool for monitoring seabird bycatch. The REM programme management group reviewed the definition and design of the REM programme in that context. The policy context, business and monitoring objectives, and business requirements and outcomes remained unchanged.

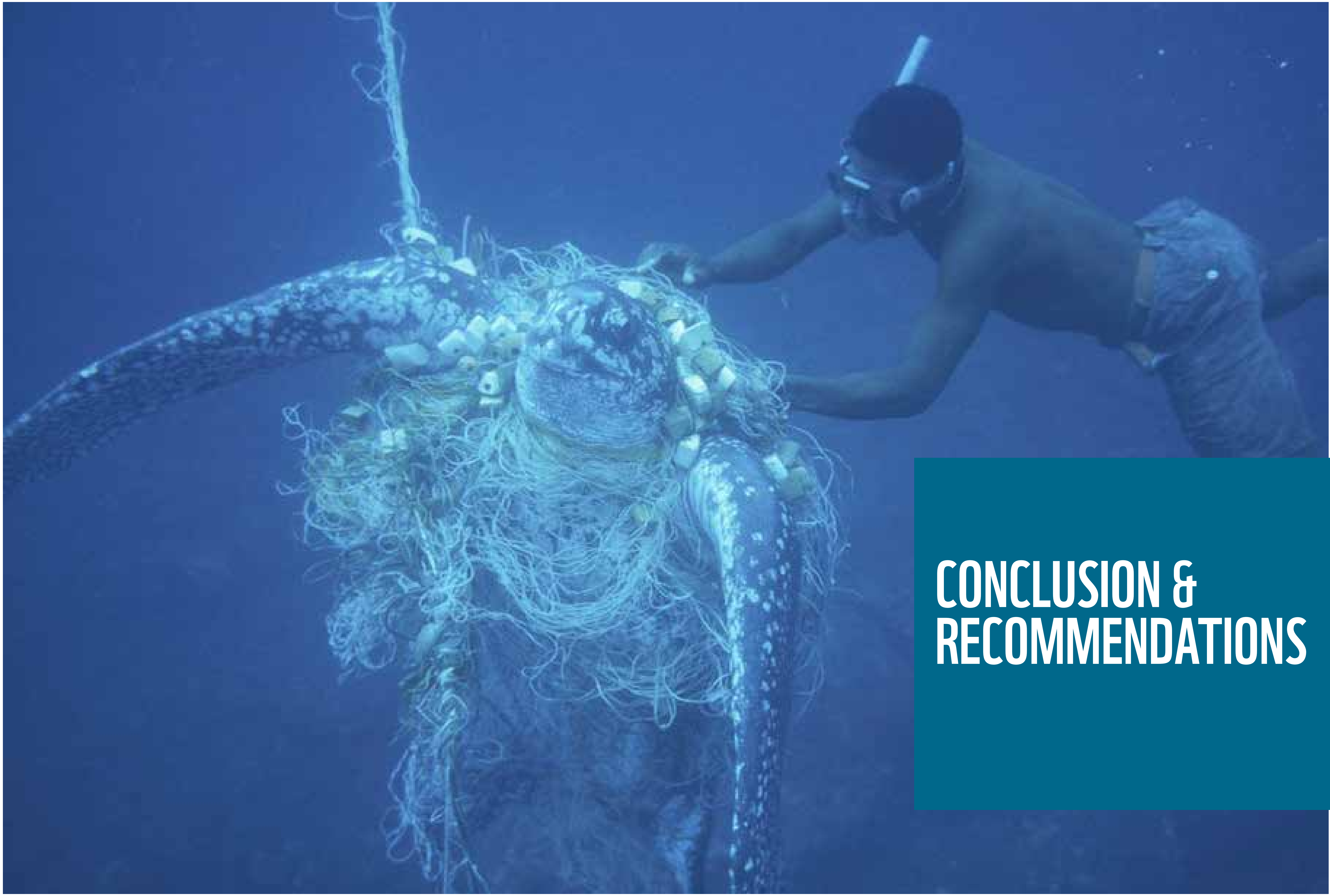
To explore whether cost savings could be made, the management group decided to retrospectively compare logbook reporting of seabird captures and captures detected from REM imagery. A REM analyst and CGFA member worked together to conduct this comparison. The purpose was to determine the comprehensiveness of logbook data and consider whether the amount of REM imagery reviewed could be reduced (thereby reducing costs).

Among most operators, the logbook reports of seabird captures were acceptably similar to captures detected by REM analysts. For a third of operators, that was not the case. Therefore, the management group determined that:

- the REM programme would continue to capture 100% of fishing effort and catch sorting on all vessels,
- the review of imagery from vessels operated by skippers whose logbooks were highly congruent with data extracted from REM would decrease to a baseline level of 30% (providing those operators with future cost savings); and
- skippers whose logbook reporting diverged unacceptably from REM findings would continue to be monitored with 50% review until reporting improved.

Reviewing the congruence of logbooks and REM findings for each vessel was added to the terms of reference for ongoing programme review, to be conducted six-monthly.

Review findings were documented and made available to CGFA members and other stakeholders as appropriate. Changes in the level of review, and how it would be set on an ongoing basis, were reflected in updates to the programme guide, and supplier contract. The REM programme continued as the fishery entered the assessment process for sustainability certification.



CONCLUSION & RECOMMENDATIONS

CONCLUSION

REM is a critical part of the future of fisheries

ETP bycatch is widespread in fisheries. In many cases (including where information is poor), this bycatch is a key threat to the persistence of ETP species.

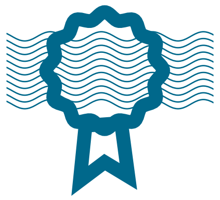
As set out above, monitoring ETP bycatch provides information that is essential for responsible fisheries management. However, in most fisheries globally, ETP bycatch is still inadequately monitored such that fishery impacts on ETP species are typically poorly known. Other methods for collecting information on ETP interactions with fisheries are not without strength. However, REM is generally the most adaptable, informative, cost effective, verifiable, scalable and unbiased monitoring method currently available**.** It is also the most amenable to implementation at scales that provide comprehensive monitoring information (Table 8). Further, the efficacy of REM has been demonstrated in many pilot projects globally, and in operational programmes where implemented (see Table 5).

With REM being widely demonstrated to be an effective monitoring tool in a range of fisheries over almost 20 years, its present use on only about 1,000 vessels [27] may appear surprising. Ongoing work to accelerate the adoption of REM involves addressing a set of well-known issues that are specific to this monitoring method (e.g. [27]), as well as increasing the requirement for or incentivising better monitoring of ETP interactions overall.

Accelerating the adoption of REM

While every fishery and jurisdiction are unique, the challenges associated with progressing REM implementation are remarkably similar across regions, nations, fishing methods, and fleets. Solutions to address priority issues that commonly arise in the development and implementation of REM programmes are set out below. Accelerating the adoption of REM requires a multi-pronged strategic approach including developing incentives, market and regulatory drivers, mainstreaming and embedding REM in fisheries operations and management, enabling funding and cost efficiencies and pre-competitive collaboration between REM specialists and providers. There are also a number of practical steps to encourage adoption and implementation of REM for monitoring ETP fisheries interactions which are described below and summarised in Table 8.

REM IS GENERALLY THE MOST ADAPTABLE, INFORMATIVE, COST EFFECTIVE, VERIFIABLE, SCALABLE AND UNBIASED MONITORING METHOD CURRENTLY AVAILABLE



ENCOURAGE SOURCING FISH FROM FISHERIES IN WHICH MONITORING PROGRAMMES ARE IN PLACE

Strategic considerations

Incentivise the adoption of REM

Effective monitoring provides information about the true nature and extent of fishing impacts. Among stakeholders, there is typically a range of views on the utility and value of this information, which can slow the implementation of monitoring. Incentivising industry to adopt REM is the single approach most likely to accelerate the implementation of this monitoring method.

For stakeholders focused on the environmental effects of fishing or sustainability, understanding the nature and extent of fishing impacts on ETP is vital and positive. It means that negative impacts and sustainability issues can be understood and addressed.

Incentivising the adoption of REM is critical for accelerating its implementation by both fishery managers and industry. There are two key drivers for incentivising REM adoption: Market demand and advantage for demonstrably legal, sustainable and traceable seafood; and top down regulation.

Establish market drivers for REM

Actively work with consumer brands and retailers to encourage sourcing fish from fisheries in which monitoring programmes are in place. In the first place this requires widespread education, that strategies that rely on catch certificates, vessel location and voluntary standards and certification do not deliver on pledges to reduce / avoid IUU in fisheries supply chains.

For market actors, such as consumer brands and retailers, to require REM, for example on high risk fisheries, would enable them to provide evidence of how they are implementing their pledges to reduce/avoid IUU in their fisheries supply chains. However, most consumer facing companies appear unwilling to move alone, without general support from the fishing industry and supply chain and for fear of competitive disadvantage. This is most likely to be addressed by influencing multi-stakeholder initiatives - such as the Global Tuna Alliance and standards setting bodies such as the Global Dialogue on Seafood Traceability, Marine Stewardship Council and less directly through benchmarks like the Global Seafood Sustainability Initiative – to strengthen their standards to require REM as a monitoring tool.

Access to markets is a powerful incentive. A good example is compliance with US MMPA Import Provisions Rule. The MMPA Import Provisions rule implements aspects of the Marine Mammal Protection Act that aim to reduce marine mammal bycatch associated with international commercial fishing operations, by requiring nations exporting fish and fish products to the United States to be held to the same standards as U.S. commercial fishing operations. The rule also establishes the criteria for evaluating a harvesting nation's regulatory program for reducing marine mammal bycatch and the procedures required to receive authorization to import fish and fish products into the United States.

Make REM a regulatory requirement

Adoption of REM will be incentivised when high levels of fishery monitoring is required, e.g. by a national regulation [27], or if specific vessels wish to demonstrate that their specified allowable bycatch rate is not exceeded (for example, in Case Study 2, and the Best Practice example of hypothetical Fishery 2), because REM is a more cost effective tool than other monitoring methods. In Europe, they would imply reform of the Common Fisheries Policy and the introduction of the Landing Obligation has highlighted the difficulties that compliance agencies face when trying to observe and quantify bycatch interactions and discarding, that occurs at sea. Enforcing the landing Obligation has proved to be extremely challenging but if REM was a requirement for a fishing vessel license or quota provision, it would allow high levels of coverage and provide an incentive for fishers to be compliant.

Establish REM as a mainstream monitoring method for ETP interactions

Embedding REM as a mainstream monitoring measure that is accepted as comparable or better than human observers is essential for accelerating uptake. The efficacy of REM has been tested and confirmed in many fisheries, where pilot and operational scale projects have been conducted [31]. The performance of human observers and REM against a range of monitoring objectives (including ETP interactions) has also been widely compared with REM demonstrating numerous advantages over human observers [27]. Therefore, accepting REM as a monitoring tool that is a routine component of the fishery data collection toolbox is overdue. If we use the example of the U.S. MMPA import provisions rule where there is a requirement to provide reasonable proof of responsible fishing and monitoring of high-risk or high-volume fisheries, this could be met by using observers but REM represents a cost effective solution to meet these standards and also avoids the safety issues associated with deploying high numbers of observers.

In international fora such as some multilateral fisheries management and species conservation organisations, REM has been considered as an effective alternative monitoring method to human observers (e.g. Agreement on the Conservation of Albatrosses and Petrels (ACAP), ICCAT, IOTC, WCPFC). Formalising the acceptance of REM as a monitoring tool by such organisations will contribute significantly to the mainstreaming of this monitoring method. Accelerating the development and adoption of data and process standards for REM, harmonising these among RFMOs as much as possible, and enforcing the implementation of required monitoring levels in RFMOs will also expedite uptake. At an overarching level, the acceptance of REM as a fisheries monitoring tool, including for ETP, would also be supported by the production of best practice guidelines by the United Nations' Food and Agriculture Organisation as part of the *FAO Technical Guidelines for Responsible Fisheries* series [198].

Establish best practice funding models and cost-efficiency

Cost and who pays are ongoing issues for REM programmes around the world, and the cost issue commonly emerges as a barrier to REM adoption. Case-specific context will determine appropriate funding models for REM, and the funding model appropriate for a pilot project will likely not be suitable when the programme is operationalised. For example, while a government agency may fund the purchase of REM hardware for a pilot project, once REM is rolled out in a fishery this would be akin to a subsidy and undesirable. Further, common psychology for most people would involve looking after REM equipment better when they have purchased it (and must replace it) themselves.

However, alternatives to upfront purchase for on-vessel hardware could include cost recovery from vessel operators by government on a specified basis, loans to purchase equipment that are repaid over time, or contracts for equipment lease with service and maintenance either built in or separate to the contract cost.

Cost efficiencies may also be incorporated into the review component of an operational programme. For example, if imagery review time is prolonged due to crew on a particular vessel not handling their catch or cleaning cameras lenses as required to optimise REM, those costs could be recovered from the vessel. This approach also rewards operators who support REM deployments with their on-vessel practices.

Growing the information base on cost efficiency of REM as a monitoring tool, and value-added scenarios as these emerge from operational deployments, is recommended to facilitate a more holistic view of the value of REM and the success rate of transitions from pilot to operational programmes.

Normalise pre-competitive collaboration where REM is under consideration as a monitoring measure

A significant amount of global expertise on REM is held by private entities, such as REM service providers. Broadly, such entities are in competition with each other and they are generally operating to make a profit. Therefore, they are likely to be unable to contribute expertise or share commercial elements of their operation without compensation. In effect, this results in an inherently competitive environment which reduces collaboration, may increase cost to REM adopters as products are created repeatedly by each supplier, and hinders the rate of progress in developing and operationalising REM. (Exceptions to this include the recent development of an open source software platform for REM analysis, supported by the US National Fish and Wildlife Foundation [199] [200]).

Creation of a pre-competitive environment for collaboration on REM is expected to accelerate progress. A pre-competitive fund could support the provision of expert advice by private entities and individuals, where REM is under consideration as a monitoring measure. For example, if a national government was planning to progress REM, a pre-competitive fund could support convening a group to provide expert advice supporting programme definition and design. After that, suppliers could then compete to implement the programme, basing offers of service on the specifications established with collective expertise. The government agency could choose their preferred provider(s) and progress implementation with greater confidence that the solution they purchase was suitable for their needs.

REM REPRESENTS A COST EFFECTIVE SOLUTION TO MEET THESE STANDARDS

THERE IS A GROWING OPPORTUNITY TO BRING TOGETHER A PORTFOLIO OF REM SUCCESS STORIES

Practical Steps to encourage adoption and implementation

Promote and facilitate the progression of pilot trials of REM to operational programmes

In reviewing the deployment of REM to date worldwide, it quickly becomes apparent that the vast majority of pilot projects have not been operationalised. Exploring why this is would be valuable, and would provide a strong basis for targeted interventions to facilitate the adoption of REM. For example, it could be that the pilot project did not meet its monitoring objectives, which should lead to an analysis of why not and what solutions might be relevant. Alternatively, it could be because there was a lack of political will, which would provide for a different set of interventions. There could be resistance among scientists if there are implications for long-term datasets or the assumptions of stock assessment models. There could also be resistance among enforcement officers keen to protect their practices and staffing levels for patrolling by air and sea and boarding vessels. If this is the case, an exploration of how to progress with REM and data management and analyses to optimise the integration of data is required. A "how to" toolkit could be created with examples of how barriers can be overcome in transitioning pilot to operational REM programmes.

Proactively address information management and privacy concerns

REM imagery creates an enduring visual record of real fishing operations. Globally, what REM records, who sees the imagery, and the form and duration of storage continue to be significant issues. Addressing these proactively is recommended, by setting out data use, data management and retention policies and timeframes. While these issues are widely recognised as important, specific examples of solutions used to address them are not widely available. For example, memoranda of understanding or data sharing agreements that have been used for REM pilots, or imagery retention and privacy policies implemented by government agencies. There appears to be benefit in making specific examples of these available, for practitioners charged with implementing new projects and programmes to draw from (e.g., as set out for Australian and New Zealand programmes [80] [201]) and these examples will help reduce the levels of concern related to data protection and privacy, that some potential new users may express

Promote the sharing of programme documentation and other information to accelerate the development and implementation of REM

Sharing REM programme documentation will promote efficiency and harmonisation of approaches, rather than the serial invention of unique approaches or unnecessary reinvention of methodologies. Materials that it would be beneficial to share among practitioners include data and process standards, training materials, review protocols, privacy and information-sharing agreements, and regulations for the implementation of REM. Globally, the EM4Fish website [202] has become the standout platform for sharing REM information.

Encourage the development and adoption of automated video review using machine learning and computer vision

This should encompass quality assurance, for example, documented performance standards for ML, because of the critical bearing that algorithms have on data quality. Like humans, algorithms also benefit from refresher training over time to ensure accuracy. This guards against drift, ensuring the algorithm continues to be effective as the fishery evolves, e.g., with new entrants, changes in fishing areas, and new species being caught [66].

Continue to build the profile of REM success stories and promote the positive benefits for fishers

As pilot programmes continue to be operationalised, there is a growing opportunity to bring together a portfolio of REM success stories and to keep this updated to allow those that are less enthusiastic to see the growing support and need for REM. These updates should include how common barriers to the implementation of REM have been addressed in the real world, and the views of fishers and other stakeholders towards REM over time (e.g. before and after implementation) to demonstrate changes in opinion. Showcasing the value of REM to stakeholders (data provision, supporting sustainability marketing claims etc) on a regular basis, should contribute to building momentum for adoption, with the sharing of lessons learned also informing progression.

Table 8. Summary of priority issues and interventions to accelerate the adoption of Remote Electronic Monitoring (REM) for monitoring interactions of endangered, threatened and protected (ETP) species with fisheries. (FAO = Food and Agriculture Organisation of the United Nations)

<table>
<tr><th>TYPE OF ISSUE</th><th colspan="4">STRATEGIC</th><th colspan="4">ADOPTION AND IMPLEMENTATION</th></tr>
<tr><td>Issue</td><td>Incentivising implementation</td><td>REM as a mainstream monitoring method</td><td>Establish best practice funding models and cost-efficiency</td><td>Pre-competitive collaboration</td><td>Progression of pilot REM projects to operational programmes</td><td>Information management and privacy</td><td>Sharing information among REM practitioners</td><td>Profiling success</td></tr>
<tr><td>Interventions</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Global</td><td>Support the growth of consumer demand and retailer leadership on legal, sustainable seafood</td><td>Support the preparation of FAO best practice technical guidelines as overarching guidance for REM</td><td>Develop best practice guidelines for funding REM and accessing cost efficiencies</td><td rowspan="3">Establish a group or network and fund to support pre-competitive collaboration to facilitate the adoption of REM</td><td>Compare pilot REM projects that have and have not progressed to operational programmes. Document reasons for both outcomes and prepare a toolkit to enable impediments to progress to be addressed.</td><td>Review approaches implemented for REM, efficacy and transferability of these, and collate real-world examples of documentation if possible</td><td>Support information sharing by the REM stakeholder community, including the use of online platforms</td><td>Support the completion of global REM reviews, such that awareness of the current state of the monitoring method is maintained</td></tr>
<tr><td>Regional</td><td rowspan="2">Support requirements for monitoring and enforcement of these by management bodies</td><td rowspan="2">Support the adoption of REM as a routine tool for ETP monitoring, including to meet mandatory monitoring requirements</td><td></td><td rowspan="2">Identify (and work to resolve) impediments to progression that apply</td><td rowspan="2">Identify and proactively document relevant context and requirements (e.g. as set by management organisation/ agency). Consider unresolved concerns and how to address, as appropriate.</td><td>Share relevant information on REM at meetings of regional fora</td><td>Profile regional REM projects and programmes at regional fora e.g. RFMOs</td></tr>
<tr><td>National</td><td>Refine best practice guidelines for application in national management and operational contexts</td><td>Support attendance by national REM practitioners at relevant regional meetings (e.g. RFMOs) to facilitate their access to information</td><td>Encourage fisheries management agencies and stakeholders to recognise and support REM project and programmes</td></tr>
<tr><td>Fleet</td><td>Identify possible fleet-specific incentives for REM adoption</td><td>Identify whether there are fleet-specific barriers to REM and how they can be addressed</td><td>Identify fleet-specific options for funding REM and opportunities for programme-specific cost efficiencies</td><td>Identify and secure expert input needed to facilitate REM adoption in the focal fleet</td><td></td><td>Identify options for fleet, and ensure these are communicated effectively and revisited regularly with concerns addressed as appropriate</td><td>Proactively connect and share information with similar fleets that have adopted REM nationally and internationally</td><td>Document REM successes and progress and recognise these (and associated key influencers)</td></tr>
</table>

RECOMMENDATIONS

While progress has been made in some fisheries, ETP bycatch remains a significant issue in most fisheries globally. Further, it is an issue that is often poorly documented, if at all, in reporting or existing monitoring programmes. REM is an important and effective tool for monitoring ETP bycatch, which has distinct advantages over other monitoring methods.

When considering REM, clarity about the monitoring objective is essential. Considering the suite of monitoring tools available, and what each has to offer in addressing the monitoring objective is also essential. REM can then be progressed to meet a specific monitoring need, ideally eventually in an operational scale programme such that benefits such as cost efficiency are maximised (Table 9).

Recommendations to ensure that REM is as an integral part of the future of fisheries are:

- Formalise the recognition of REM as a mainstream and effective monitoring method for ETP species monitoring, e.g. through technical work demonstrating its efficacy, promulgation of best practices guidelines and adoption in national legislative frameworks.
- Ensure REM is a standard method of monitoring supported by multilateral international organisations, including RFMOs, through the adoption of resolutions and management measures that enable REM to be used to meet monitoring and data provision requirements. For example, by engaging with and influencing the Joint FAO / IMO Ad Hoc Working Group on IUU fishing, individual FAO and RFMOs and their programme and project managers. Engage with ICES Strategy and Science leadership to influence their programmes on providing effective monitoring for essential data for science and advice and to develop more efficient ways of analysing, sharing and presenting big data from observation and monitoring; especially using data from remote sensing of the seas and monitoring of human activities.
- Work with major international and national seafood companies, retailers and their suppliers to use REM and to provide evidence of their effective use (i.e. audits of the system and data) to ensure that no IUU fish products enter their supply chain and to drive improvements in ETP bycatch management and human rights and crew safety standards.
- Increase the rate at which pilot projects transition to operational programmes.
- Support and enable REM to be recognised as part of a standard transparency measure recognised by global seafood company and retailer led initiatives – such as GDST, GSSI, GTA
- Develop incentives for fishermen and fishing vessel owners to roll out REM, e.g. enable market access, public recognition/ acknowledgement and other reward structures, participation in co-management programmes, access to additional quota.
- Highlight to major financial institutions which invest in large scale / high risk fisheries companies the potential of REM to secure their investment (including brand reputation and market share) and mitigate risk, through programmes like the Seafood Tracker Initiative (https://planet-tracker.org/tracker-programmes/oceans/seafood/).
- Encourage and support the development and implementation of automated video review tools that use machine learning and computer vision, to help reduce costs and increase the efficiency of undertaking video review, through funding research, building image libraries and sharing training datasets among practitioners.

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ANNEX 1

Table 1. Examples of endangered, threatened and protected (ETP) species interactions with fishing methods. Fishing mortality due to one or more methods has been identified as a key threat for one or more species in each group considered.

ETP SPECIES GROUP	FISHING METHODS	MODE OF INTERACTION	SOURCES
SEABIRDS	Pelagic longline	Caught on hooks, entangled in line	Zydelis *et al.* 2013 [109]
	Demersal longline	Caught on hooks, entangled in line	Phillips *et al.* 2016 [11]
	Trawl Gillnet Purse seine	Injury or death resulting from striking cables between the net and vessel, entrapment inside trawl net or entanglement in net mesh Entanglement in net mesh Captured in nets	Pott & Wiedenfeld 2017 [203] Suazo *et al.* 2017 [204] Clay *et al.* 2019 [12]
MARINE MAMMALS	Pelagic longline Demersal longline Trawl Gillnet Pots/Traps Purse seine	Captured on hooks, entangled in line Entangled in line Captured in nets Captured in nets Entangled in ropes (float or buoy lines), captured in pots Captured in nets	Gilman *et al.* 2006 [205] Hamer *et al.* 2012 [8] Berkenbusch *et al.* 2013 [206] Reeves *et al.* 2013 [123] Hamilton and Baker 2019 [207]
SEA TURTLES	Pelagic longline Demersal longline Gillnet Trawl Pots/traps Purse seine	Caught on hooks, entangled in line Caught on hooks (pinnipeds), entangled in longline Captured in nets Captured in nets Entanglement in vertical lines Captured in nets	Beverly & Chapman 2007 [138] Zollett 2009 [208] Wallace *et al.* 2010 [127] Casale 2011 [209] Amande *et al.* 2012 [210] Bourjea *et al.* 2014 [211]
FISH	Pelagic longline Demersal longline Trawl Gillnet Pot/trap Purse seine		
SHARKS AND RAYS	Pelagic longline Demersal longline Pot/trap Gillnet Trawl Purse seine	Caught on hooks Caught on hooks Caught in traps Caught in nets Caught in nets Caught in nets	Oliver *et al.* 2015 [10] Richards *et al.* 2018 [212]
CORALS	Demersal longline Gillnet Trawl	Caught on hooks Caught in nets Caught in nets	SIODFA 2007 [149] Blom *et al.* 2009 [146] Kumar *et al.* 2014 [147] Benedet 2016 [84] Ragnarsson *et al.* 2016 [148]

ANNEX 2

List of REM Suppliers Contacted

Many thanks to the REM suppliers listed below, who willingly provided full details of their equipment and associated costs.

Anchorlab - Denmark

Archipelago Marine Research Ltd – Canada

Ecotrust/Teemfish/Snapit (as a joint group solution) – Canada/New Zealand

Marine Instruments - Spain

Saltwater Inc. – USA

Satlink - Spain

ANNEX 3

Table 6. Stakeholder Analysis

STAKEHOLDERS	ROLES IN PROMOTING REM TO MONITOR AND MITIGATE ETP	POTENTIAL BENEFITS OF REM [213]	POTENTIAL CONCERNS
United Nations, Food and Agriculture Organisation (FAO) e.g. FAO International Symposium on Fisheries Sustainability members	The FAO produces the Code of Conduct for Responsible Fisheries and voluntary International Guidelines on By-catch Management and Reduction of Discards for States and Regional Fisheries Management Organisations (RFMOs). The 2019 Symposium considered what information and communication technologies (ICT) must be scaled and adopted; it recommended [214] • Invest in remote sensing technologies, internet access ability and sensors as ways to generate new real time and inclusive knowledge.	Implementation of voluntary recommendations.	
Regional Fisheries Management Organisations (RFMOs) There are 17 RFMOs covering different geographic areas, e.g. • Indian Ocean Tuna Commission (IOTC) • North-East Atlantic Fisheries Commission (NEAFC) • South Pacific Regional Fisheries Management Organisation (SPRFMO) • International Commission for Conservation of Atlantic Tuna (ICCAT) • Western Central Pacific Fisheries Commission (WCPFC) • Inter American Tropical Tuna Commission (IATTC)	RFMOs could apply a complementary approach of remote electronic monitoring and human observers to monitor and mitigate ETP bycatch [215]. Opportunities exist particularly in RFMO fisheries[1] [216] • large fisheries, with management plans and quotas (total allowable catch, TACs) to manage • where tenure rights exist in their fisheries, with good revenues. Invest in fisheries management systems, such as REM. For example, RFMO tuna fisheries or large forage fisheries off the Pacific coasts of Latin America, where rotating observer coverage is required. Here the driver for REM is that it is cheaper and safer than observers. Within the larger Regional Fish Management Organisations (RFMOs), two in particular have defined opportunities for engagement on deployment of REM to monitor ETP: • Western and Central Pacific Fisheries Commission (WCPFC) have an electronic reporting and monitoring working group with an agreed work programme2 • Indian Ocean Tuna Commission (IOTC) is associated with a pilot EM project being conducted in the Seychelles. IOTC also have an upcoming contract to develop EM minimum standards for IOTC fishing vessels [217].	Efficient mechanism for encouraging compliance Monitoring by catch. Improved data for management and mitigation of ETP species	Increase in workload for formulating standards and implementation. Cost of system and associated costs of increased workload. Capacity gap on the knowledge of the technology in member states. Alienation of member states that are reluctant to adopt REM.
International Council for the Exploration of the Sea (ICES)	ICES coordinates research into the marine ecosystems of the North Atlantic and provides advice by fish species and by region to a number of governments and RFMOs. It believes that remote monitoring provides detailed, interlinked data; and plan to develop efficient ways of analyzing sharing and presenting big data [154]. There is scope for greater promotion of REM and use of data flowing from it in ICES Working Groups on: • Technology Integration for Fishery-Dependent Data • Machine Learning in Marine Sciences [218] • Bycatch of Protected Species	Improved data for use in WGs Implementation of working groups recommendations.	

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European Union (EU)	The European Commission has proposed the introduction of risked-based REM requirements to improve the control of fishing activities at sea, in particular the control of the landing obligation. It introduces the requirement of full documentation of all catches and discards (Articles 1 (11) and 1(23) of the proposal). .	Improved understanding of activities at sea	
Coastal states	International law provides that coastal States have sovereign rights to manage fisheries in waters under their jurisdiction. FAO estimates that more than ninety percent of the global fish catch is taken within waters under the jurisdiction of coastal States. Coastal states set national legislation and policy targets for fisheries and protected areas. Regulators ensure fishers and producer organisations are in compliance with legislative obligations as set out in fisheries legislation. Together with the fishing industry, they can develop initiatives such as Bycatch Reduction Plans and Fully Documented Fisheries using REM. Forward-looking governments may consider financing a loss of profit for a fishery if no other mitigation measure is sufficient to reach the bycatch mitigation aims under Payment for Environmental Services (PES) schemes However, the FAO maintains that about 30% of countries have a relatively low implementation of key international instruments designed to combat illegal, unreported, and unregulated fishing [219].	Monitoring catch levels especially in fisheries with catch quotas. A mechanism to determine illegal activity that cannot be corrupted. Ability to monitor observers. Deflecting criticism that fisheries are unsustainable. Showing the public that fleets are being effectively monitored.	Loss of revenue if vessels moved to the high seas to avoid REM requirements. Hesitancy to be an early adopter. Increased workload and lack of local technical knowledge for programme implementation. Cost of the system that industry does not want to pay for. Pressure by flag states reluctant to adopt REM. Concessions that might be made to get distant water fishing nations to agree to REM.
Flag States	The flag state of a merchant vessel is the jurisdiction under whose laws the vessel is registered or licensed, and is deemed the nationality of the vessel. The flag state has the authority and responsibility to enforce regulations over vessels registered under its flag, including those relating to inspection, certification, and issuance of safety and pollution prevention documents	Deflecting criticism that pressures are unsustainable. Showing the public that fleets are being effectively monitored.	Pressure from domestic vessel operators that are opposed to REM. Additional enforcement responsibilities and expenses. Capacity gap on the knowledge of the technology. Cost of the system the industry does not want to pay for.
Catching sectors operators and Producers Organisations Producer Organisations are officially recognised bodies set up by fishery producers, usually organised at local level and recognised by the national regulator. There are more than 200 in European Union. In addition, there may be federations of producer organisations and other fisher's groups.	Producer organisations' key role is managing fisheries and marketing the fisheries products of their members. They may promote the use of information and communication technologies to work towards reducing the environmental impact on ETP of their members fishing activities. For example, the UK National Federation of Fishermen's Organisations believes that within a collaborative system of co-management REM can play a role, especially when they are invited on board vessels in order to demonstrate better compliance. However, if imposed top-down remote surveillance raises practical, legal and ethical issues that are likely to raise barriers to cooperation. The key role of Producer Organisations is to participate proactively in the creation of collaborative systems of co-management to enable effective deployment of REM.	Meeting market demand for traceability and sustainably fished product.	Risk of detecting IUU. Practical, legal and ethical issues with surveillance.
Fisheries Science Research Institutes	Responsible for scientific advice on marine life. Fisheries Science Research Institutes can help pull projects together, secure funding, develop monitoring and mitigation technologies for ETP, evaluate projects and conduct assessments for certification (e.g. Thünen Institute of Baltic Sea Fisheries [220])	Ability to efficiently collect many types of data. Greater confidence in collected data. Ability to verify data collected by human observers.	Inability to collect some kinds of data (e.g. collection of physical biological samples).

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Major Seafood companies and brands e.g. • Maja Nichiro and Nippon Suisan Kaisha (Nissui) (Japan) • Thai Union (John West, King Oscar, Petit Navire) (Thailand) • Austevoll Seafood, Leroy Seafood (Norway) • Albion (Canada) • Bakkafrost (Faroes) • Beaver Street Fisheries, Tradex Foods (US) • Pescanova, Calvo, Frinsa, Isabel (Spain) • Bolton (Rio Mare) (Italy) • Young's, Nomad (UK)	The world's top 150 Seafood companies account for an estimated $120 billion sales [221]. They have significant risks and opportunities to influence the deployment of REM to monitor and mitigate ETP including • direct relationships with, buying power and influence over the fisheries they source from • financial resources, which can be invested in fisheries that they manage or from which they source • major brands to protect from reputational risk associated with sourcing fish from fisheries involved with ETP bycatch. Most responsible seafood companies have policies on sustainable fisheries management and fisheries improvement projects that they source from, including certification schemes.	Ability to demonstrate that fishing operations are legitimate. Meeting market demand for traceability and responsibly sourced product.	Acceptability by fishing industry. Risk of detecting IUU in fisheries supply chain.
Retailers and Suppliers Major international retailers e.g. • Aldi (South) • Lidl • Ahold Delhaize • Carrefour • CostCo • Schwartz Group (Lidl) • Tesco • Walmart • Aeon Major national e.g. • Asda, Co-op, Sainsbury's, M&S, Morrisons, Waitrose (UK) • China Resources, Sun Art (China) • EDEKA, METRO (Germany) • Migros, Co-op (Switzerland) • Coles (Australia) • Kroger, Safeway (USA) • Woolworths (South Africa, Australia)	A coalition of 17 retailers and processors in the UK [222] called for improved monitoring measures, including REM, in the Fisheries Bill to be introduced on EU Exit. In Germany, 11 retailers and seafood processors have also called for the introduction of REM [223]. Preliminary research with 15 major grocery retailers indicates that all have commitments to sourcing sustainable wild caught seafood and aquaculture in their seafood supply chains and to avoiding IUU. Several specifically aim to reduce ETP bycatch but there is little indication of how this will be monitored. Retailers rely on pre-competitive multi-stakeholder standards and collaborations, such as the Marine Stewardship council (MSC), Global Sustainable Seafood Initiative (GSSI) for benchmarking of standards, and the Global Dialogue on Seafood Traceability (GDST) for traceability and the Global Tuna Alliance (GTA). The interest of supermarkets and processors indicates that vessels with REM could add market value to their catch.	Meeting market demand for traceability and sustainably fished product.	Acceptability by fishing industry Competitive disadvantage with key suppliers.

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Ratings and Certification programmes e.g. • Marine Stewardship Council (MSC) • Monterey Bay Aquarium Seafood Watch • Sustainable Fisheries Partnership • Fair Trade USA • WWF Seafood Guides	No ratings and certification programmes require the deployment of REM to monitor and mitigate ETP. MSC has been criticised over its failure to take account of the capture of non-target species, including ETP [163] The key role for certification and ratings programmes is to strengthen their (currently weak) requirements for REM to monitor ETP in Fisheries they rate or certify.	Ability to demonstrate that fisheries operations are compliant with standards.	
Multi-stakeholder platforms e.g. • Global Sustainable Seafood Initiative (GSSI) • Global Dialogue on Seafood Traceability (GDST) • Global Tuna Alliance (GTA) • Sustainable Seafood Coalition (SSC)	The Global Tuna Alliance works with RFMO member states to seek the implementation of effective harvest strategies to achieve sustainable tuna stocks under the jurisdiction of each tuna RFMO by 2020. Transparency (including bycatch data) allows improved management of fisheries and encourages improved fisheries performance. While most of the systems needed to implement transparency can be implemented independently by seafood companies, multi-stakeholder platforms enhance existing RFMO efforts.	Ability to demonstrate that fisheries operations are compliant with standards.	

i For simplicity, the term "RFMO fisheries" used in this document refers to fisheries that are managed partly or wholly by RFMOs.

ii In 2019, the Commission endorsed the objectives for electronic monitoring [225]. A draft Conservation and Management Measure for the implementation of REM is to be progressed in 2020 [226]. The WCPFC Conservation and Management Measure for sharks sets out provisions relating to what is required when REM is on a vessel comes into effect on 1 November 2020 [228].

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