Agenda Item 2.5	Review of New Information on Threats and Other Issues Relevant to Small Cetaceans Other
Information Document 2.5b	**Monitor Cetacean Bycatch: An Analysis of Different Methods Aboard Commercial Fishing Vessels**
Action Requested	Take note
Submitted by	Secretariat

Secretariat's Note

The original document is available on the ASCOBANS website here: https://www.ascobans.org/en/publication/monitoring-cetacean-bycatch-analysis-different-methods-aboard-commercial-fishing-vessels. Kindly use this link for sharing the report.

MONITORING CETACEAN BYCATCH: AN ANALYSIS OF DIFFERENT METHODS ABOARD COMMERCIAL FISHING VESSELS

ASCOBANS Technical Series No. 1

ASCOBANS

Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)

Monitoring Cetacean Bycatch: An Analysis of Different Methods Aboard Commercial Fishing Vessels

ASCOBANS Technical Series No. 1

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Executive Summary

This report reviews, describes and evaluates the different monitoring options that are available for obtaining counts of the number of cetacean bycatches that occur in European fisheries. Three methods were adjudged able to obtain these data: self-reporting by fishers, at-sea observers, and remote electronic monitoring (REM) systems with CCTV. Of these, only the data collected by at-sea observers or REM can be collected independently of the fishers and only REM allows later verification of the bycatch events as often as required. Therefore, in this report these two methods are more fully described and compared against each other in terms of ability to collect the required data and of the costs associated with running a cetacean monitoring programme. A description of the different components associated with electronic monitoring was also presented as there has often been confusion about what constitutes electronic monitoring and electronic recording and why a verification tool is necessary. Only a REM system with integrated satellite tracking, fishing activity sensors, and closed-circuit television cameras (CCTV), was considered a full remote electronic monitoring system with verification.

ASCOBANS Party states were approached to supply sampling effort and cetacean bycatch data from their dedicated cetacean bycatch monitoring programmes or if these were not undertaken, then Data Collection Framework (DCF) observer programmes. These data were compared against the average costs associated with undertaking a REM project. Very little national observer programme data and cost information were made available, but of those who supplied information, we found that the cost to run an at-sea observer programme spanned between €248 and €25,987 per observed fishing day. This large range and the limited contributors mean that using the average calculated cost per day for an observer will be inaccurate and misleading. Therefore, when considering case study examples in this report for cost comparisons, the costs calculated for the specific country in question were used, because it was considered that these would be more relevant to the case study in question than using a calculated European average cost. Sources for these cost data were referenced if they had not been supplied through the original request.

Six suppliers and manufacturers of REM systems provided details of the purchase costs, installation costs and annual running costs (including software licences) associated with their systems. This allowed the average cost per year of a 2-camera system and a 4-camera system to be calculated, assuming 5 years lifespan for the hardware, at €3,381 and €3,918, respectively. The costs associated with undertaking the video review and providing project management associated with a programme or project specifically to monitor cetacean bycatch were calculated. These cost estimates were based on certain assumptions regarding the video review rates required to monitor cetaceans, the amount of time available to undertake video review and the amount of fleet effort being monitored. This was then added to the system costs which allowed cost comparisons to be undertaken.

Overall national cost comparisons were hampered by the lack of national cost data available, so individual case study fisheries where data were available, were used to illustrate the potential cost differences between using REM and at-sea observers to monitor cetacean bycatch. These fisheries were also selected as they were considered to be high contributors to the overall bycatch of certain cetacean species. The cetacean bycatch video review costs used a review rate of 12 times normal speed, but it was expected that if additional sensitive species were also being monitored, then the review speeds would reduce. A video review speed of 4 times normal speed was used in these multi-taxa examples and costs adjusted accordingly in the case studies. The case study example fisheries used were a fictitious inshore gillnetting fishery in the UK, the French small pelagic midwater pair-trawling fishery, and a Danish inshore gillnetting fishery. All three example fisheries demonstrated that using REM provided cost savings over at-sea observers depending on the levels of monitoring required and the implementation approach used.

The implementation of a REM monitoring programme to undertake, for example, 10% of a fishing fleet's fishing activity could be done in two different ways. The programme could install REM on all fishing vessels and then review only 10% of the video data, or only 10% of the vessels installed with REM but 100% of the collected video reviewed. Both provide 10% monitoring using the video cameras, but the former method allows 100% of the positional and fishing activity sensor data to be collected for the fleet. The costs for the two implementation approaches are estimated and large differences in costs are shown between the two methods, the former being more expensive because of the need to invest heavily in REM equipment.

On the larger pelagic vessels, REM was also able to demonstrate better monitoring coverage within an individual fishing trip because it could monitor multiple areas of the deck at the same time and therefore there would be less chance of missing a bycatch interaction. To do this using only observers and no form of additional camera equipment would require several observers on duty at the same time and at least two teams of observers working in shifts, around the clock, to obtain the same 24-hour coverage as a multi camera REM system.

On small inshore vessels, there is potential for large inter-vessel variability. Having systems on as many boats as possible and then reviewing as much footage as is affordable, could improve the precision of any calculations made using the collected data. Potentially, a portable REM system that could be easily transferred between vessels could allow a rolling reference fleet approach to a REM monitoring programme, which would allow sampling effort to be spread over a larger proportion of the fleet, although reduce the number of days that can actually be monitored per vessel.

Interactions with cetaceans are generally rare events so considerable resources can be invested in monitoring fishing trips where no interaction or bycatch event occurs, in both at-sea observer programmes and REM programmes. If the REM programme was linked to a simple self-reporting mechanism, this would allow fishers to indicate when and where an event occurred, which would speed up the video review rates by allowing the analysts to concentrate on the highlighted periods. There would be a need to review a proportion (or all) of the rest of the footage to ensure that fishers are accurately self-reporting and to detect where drop out (when bycatch falls free of the net before being brought aboard) events have been missed by the crew, but this would still be more efficient than reviewing lots of trips where there are zero incidents. This proportion could increase or decrease with confidence in the self-reporting. This would in effect become a self-reporting programme with verification through REM. As REM programmes generally costs less to run, using REM to collect data from fleets where there are likely to be high zero values would allow resources (especially onboard observers) to focus on higher risk fisheries where additional biological data could also be collected.

So, although REM by itself represents a cost-effective option when high levels of fleet fishing effort monitoring is required, compared to an at-sea observer programme, it can be made even more efficient and useful through combining it with fisher self-reporting and/or onboard observers. REM cannot collect physical biological samples but visually collected data (e.g. sex or length) can be estimated if the imagery is scalable, of high quality and cameras are specifically positioned to collect this information.

A REM programme that includes fisher involvement and cooperation could also help enable these data to be collected through the orientation or placement of bycatch in the correct camera views near a visual scale. Projects could also be designed that include REM, fisher involvement and more targeted use of on board observers, so that the observers can focus on collecting the more precise biological data and samples, and continue being conduits between scientists, decision makers and industry, whilst the REM increases the monitoring coverage of the fleet.

Contents

Background

ASCOBANS

In 1992, the Convention on the Conservation of Migratory Species (CMS) established the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS). An extension to the original agreement area was introduced in 2008 and today ASCOBANS covers the Baltic, North East Atlantic, Irish and North Seas (Figure 1). A full description of the geographic boundaries can be found at the ASCOBANS website https://www.ascobans.org.

The countries involved with ASCOBANS are either "party" members or countries that are "non-party range state" members. The difference between the two is that party members have signed up to the agreement in full, whereas the non-party range state members have waters that are within the ASCOBANS area but have not signed up to the agreement but can participate in meetings and initiatives because the cetaceans of concern are present in their waters. Table 1 shows the ASCOBANS members, their status and the main sea areas they are involved in.

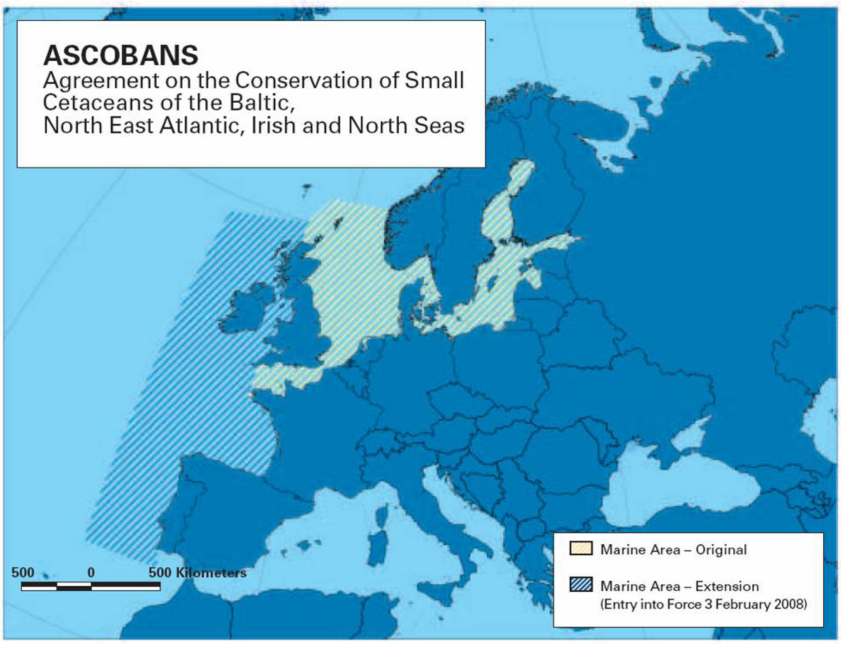

Figure 1. Map of the ASCOBANS region showing the geographic ranges of the original agreement and the extended agreement (Source: ASCOBANS website).

Table 1. List of Party and Non-Party Range State members of ASCOBANS (Source ASCOBANS website).

Country	Membership-Status	Region
Belgium	Party	North Sea
Denmark	Party	Baltic Sea and North Sea
Estonia	Non-Party Range State	Baltic Sea
Finland	Party	Baltic Sea
France	Party	NE Atlantic and North Sea
Germany	Party	Baltic Sea and North Sea

Country	Membership-Status	Region
Ireland	Non-Party Range State	NE Atlantic and Irish Sea
Latvia	Non-Party Range State	Baltic Sea
Lithuania	Party	Baltic Sea
Netherlands	Party	North Sea
Norway	Non-Party Range State	North Sea
Poland	Party	Baltic Sea
Portugal	Non-Party Range State	NE Atlantic
Russia	Non-Party Range State	Baltic Sea
Spain	Non-Party Range State	NE Atlantic
Sweden	Party	Baltic Sea and North Sea
United Kingdom	Party	NE Atlantic, Irish & North Sea

Over 80 species of cetaceans occur worldwide and 26 species of small cetaceans (odontocete species excluding the sperm whale) have been registered in the ASCOBANS agreement area (www.ascobans.org). Of these, 12 small cetacean species are regularly occurring. Table 2 lists their conservation status (according to the IUCN red species list), and the estimated population size in the ASCOBANS region where known. Population estimates come from the SCANS III (Small Cetaceans in the European Atlantic and North Seas) and ObSERVE surveys in summer 2016 (Rogan, *et al.*, 2018). SCANS III (2017) was a joint European project coordinated by the University of St Andrews covering European Atlantic waters but excluding offshore waters of Portugal and Norway. Waters south and west of Ireland were covered by the ObSERVE survey, a project contracted to University College Cork by the Irish government. Both undertook acoustic surveys, shipborne surveys and airborne surveys to obtain population estimates for cetaceans and make recommendations on future monitoring of populations and bycatch. Additional data were also included from Evans, (2020) where estimates were not previously available from SCANS III and ObSERVE. Of the 12 cetacean species encountered, five species were considered data deficient and for four of these it was not possible to obtain species estimates (SCANS III, 2017). This demonstrates the difficulties associated with cetacean research and assessing populations due to issues such as their migratory nature, scarcity of available data and the complexity of conducting research at sea over large sea areas.

In 2004, EC Regulation 812/2004 (EC, 2004) was introduced and provided European Member States with specific monitoring targets for pilot projects, scientific studies and mandatory cetacean monitoring projects in European waters, depending on the gear being used and the number of vessels in the fleet (Annex III, paragraph 2). It also specified the fleets where the use of acoustic deterrents is mandatory (Annex 1) and the technical specifications for these bycatch mitigation devices (Annex II). In 2019, Regulation 812/2004 was repealed and replaced with EU Regulation 2019/1241 on "the conservation of fisheries resources and the protection of marine ecosystems through technical measures". In Annex XIII the regulation specifies that member states should take the "necessary steps to collect scientific data on incidental catches of sensitive species" and should use these data to recommend mitigation measures, and that they should monitor and assess the efficacy of these mitigation measures. It also specifies that cetacean bycatch monitoring schemes should be established for vessels over 15m overall length for specified fisheries and areas. However, there does not appear to be any cetacean specific bycatch monitoring recommendations for vessels less than 15m overall length. It is important that the <15m vessels are included in national cetacean monitoring schemes because this size class of vessels makes up more than 90% (68,504 vessels of a total 75,405 vessels) of the European fleet in 2019 (Eurostat, 2020) and these fleets should be monitored as part of the sensitive species scientific monitoring programmes.

Obtaining data on cetacean bycatch is difficult for similar reasons as conducting population estimation

Table 2. The small cetacean species regularly found in the ASCOBANS area, with population estimates (source: Evans, 2019).

Common Name	Scientific Name	Estimated Population Size (SCANS III & ObSERVE Projects)	IUCN Threatened Species Status in the ASCOBANS area
Harbour Porpoise	*Phocoena phocoena*	493,200	Critically Endangered (Baltic Sea); Least Concern (Other)
Common Bottlenose Dolphin	*Tursiops truncatus*	115,000	Least Concern
Striped Dolphin	*Stenella coeruleoalba*	372,300+*	Least Concern
Common Dolphin	*Delphinus delphis*	481,300+*	Least Concern
White-Beaked Dolphin	*Lagenorhynchus albirostris*	39,500	Least Concern
Atlantic White-Sided Dolphin	*Lagenorhynchus acutus*	17,400	Least Concern
Risso's Dolphin	*Grampus griseus*	c. 16,000	Least Concern
Killer Whale	*Orcinus orca*	Unknown	Data Deficient
Long-Finned Pilot Whale	*Globicephala melas*	33,200	Data Deficient
Cuvier's Beaked Whale	*Ziphius cavirostris*	Unknown	Data Deficient
Northern Bottlenose Whale	*Hyperoodon ampullatus*	Unknown	Data Deficient
Sowerby's Beaked Whale	*Mesoplodon bidens*	Unknown	Data Deficient

*These estimates exclude 177,800 unidentified common/striped dolphins, which are likely to be mainly common dolphins.

surveys, but also because the data need to be collected aboard commercial fishing vessels rather than research vessels. Cetacean bycatch monitoring programmes are usually undertaken using at-sea observers and provide high quality data but can often be costly with only low levels of monitoring. Advances in technology may allow similar cetacean bycatch monitoring data to be collected more efficiently and increase fleet coverage, which may improve the precision of cetacean bycatch estimates.

Interactions with Fisheries

In some fisheries, accidental bycatch of small cetacean species can occur and is thought to result in levels of mortality that may be unsustainable in relation to the local population size. For example, the 2017 Celtic Sea harbour porpoise subpopulation bycatch mortality rates of between 2.12 - 5.57%, were greater than the advisory ASCOBANS limit of 1.7% (ICES, 2019). Cetaceans require air to breathe and any gear entanglement that occurs below the waterline will usually result in death of the individual, unless it occurs immediately prior to hauling of the gear when the fisher may have a window of opportunity to release the animal alive, although this is unlikely and will be fishing gear and fishery specific.

The main small cetacean species reported as bycatches in fisheries in the ASCOBANS area are the harbour porpoise (*P. phocoena*), common dolphin (*D. delphis*), bottlenose dolphin (*T. truncatus*), and striped dolphin (*S. coeruleoalba*), along with smaller numbers of Atlantic white-sided dolphin (*L. acutus*) (EP, 2010), white beaked dolphin (*L. albirostris*), Risso's dolphin (*G. griseus*), long-finned pilot whale (*G. melas*) and killer whale (*O. orca*) (Tindall *et al.*, 2019).

The observer programmes initiated under EC Regulation 812/2004 between 2005 and 2008 recorded a total of 132 cetaceans consisting of 81 common dolphins, 32 harbour porpoises, 6 bottlenose dolphins, 7 striped dolphins, 5 long finned pilot whales and 1 Atlantic white-sided dolphin, during 6,623 at sea observer days (EP, 2010). Numbers reported using data pooled over different time periods between 2005 and 2017 for European Member States and held in the WGBYC database were as follows: harbour porpoise (269), common dolphin (421), bottlenose dolphin (7), striped dolphin (7), Atlantic white-sided dolphin (1), white-beaked dolphin (2), and pilot whale (8), making a total of 715 cetaceans (Table 9, in ICES, 2019). However, these almost certainly represent a substantial under-estimate of the total actually bycaught, and it has also been noted that all species of marine mammals have at one time or another been recorded as caught by fishing gear in the past (Northridge, 1991); the species list and the level of bycatch can differ from year to year which illustrates that effective routine annual monitoring is required. The bycatch reported from monitoring programmes clearly is not fully representative of actual bycatch levels because, for example, over the last few years, there have been reports of hundreds of dead cetaceans being washed up on to French and Spanish beaches where some of the mortality can clearly be attributed to fishing activities (e.g. Hardach, 2018; ClientEarth, 2019; Berry, 2019; Guardian, 2018; Press and Journal, 2017; Undercurrent News, 2019 ; Express, 2017).

These events have led to scientific research into the cause of the mortality and to try to estimate the numbers of cetaceans killed, including those that may have sunk. In February and March of 2017, 793 dead cetaceans were washed ashore on the French Atlantic coast of which 666 were common dolphins (Peltier *et al.*, 2019). The researchers used reverse trajectory modelling that relied on meteorological data, oceanographic current data, drifting object patterns, dead cetacean sink rates, and the decomposition levels of the dead cetaceans to try and estimate the possible time and location of death. This was then linked to Vessel Monitoring System (VMS) data to investigate if there was any fishing activity in the area and, if so, what type of gear was used and how much fishing effort had occurred. Assuming that less than 20% of all dead dolphins float (Peltier *et al.*, 2019 used a value of 17.9%), the 793 cetaceans washed up represents only a fraction of those killed and it was estimated that 4403 cetaceans were actually killed. When linked to the VMS data, three fisheries were thought to be responsible for the majority of these mortalities: French pelagic pair trawls, French Danish seines, and Spanish demersal otter trawls (Peltier et al. 2019). Since then, the importance also of trammel (GTR) and gillnetting (GNS) in causing common dolphin bycatch over the shelf in the northern part of the Bay of Biscay has been highlighted (ICES WGBYC, 2020).

There are several types of fishing gear that are known to cause cetacean bycatch. These include drift nets, set gill and trammel nets, pelagic trawls, midwater pair trawls and some demersal trawls. Table 3 is a summary of the 2005 to 2008 cetacean bycatch and monitoring data presented to the International Council for the Exploration of the Sea (ICES) Study Group on Bycatch (SGBYC) in 2008 (EP, 2010), for set nets and pelagic trawls combined. The fleet days fished data supplied by Latvia, Spain and the UK, were incomplete and therefore the totals for the National Fleet Days Fished and the average Percentage of Fishing Days Sampled columns were unable to be provided. Although this dataset is somewhat out of date (2005 to 2008), it was found to be the most complete dataset available at the time of writing that also included overall cost estimates for collecting the bycatch data. More recent catch data from ICES working groups and the European Data Collection programmes are utilised in later tables in this report, but as a way of introducing the historic bycatch issues and for comparing rates over time, the 2005-2008 data are presented.

Overall, a total of 132 cetaceans were reported as observed bycatch during 6068 at-sea observer days (between 2005-2008), giving an average rate of 0.02 cetaceans per observed day. Of this total, three countries were responsible for the majority of reported cetacean bycatch: France, UK and Ireland, catching 124 of the 132 cetaceans during observed trips. However, some countries (for example, Spain) were not thought to routinely monitor or accurately report their bycatch levels at this time. Of these bycatch events, the majority occurred in pelagic trawl fisheries, but this was not a consistent pattern. Table 4 shows the observed cetacean bycatch by gear type for these three main contributing countries. Ireland caught more cetaceans in their set nets even though sampling effort (days observed shown in brackets) was less in set nets. France and the UK caught more cetaceans in their pelagic trawls, but the UK sampled less pelagic trawl sea days, whereas France sampled more pelagic trawl sea days. When the pelagic vessel data reported by the countries in Table 4 are examined more closely, it was found that 75 of the total 89 observed cetaceans occurred in the pelagic pair trawl metiers, 2 in the single vessel pelagic fishery and the remaining 12 observed cetaceans were not attributed to single or pair trawl (EP, 2010). This suggests that when considering which gears have higher cetacean bycatch, pelagic pair trawl is the highest contributor, but this may be linked to how sampling effort has been distributed as 1213 observer days were conducted on pelagic pair trawls, 36 days on single vessel pelagic trawls and 644 days were unattributed, with no effort specifically stated as being undertaken on single vessel pelagic trawls (EP, 2010). Table 5 presents the Table 4 cetacean catches observed as a per day monitored value, to help remove any differences caused by having different levels of sampling effort deployed across the fisheries.

Table 3. The number of cetacean bycatches in European fisheries in the ASCOBANS area, the number of days sampled by observers by year and gear type, and the number of days these observed fleets fished (adapted from EP, 2010).

Country	Year	Observed Gear	Fishing Effort (Days Fished)	Observed Days	Percentage of Fishing Days Observed	Cetacean Bycatch Observed (Unraised)
Denmark	2007	Pelagic Trawl >15m	4578	273	6	0
	2008	Gillnet REM <15m	37	37	100	1
	2008	Pelagic Trawl >15m	1007	82	8	0
Estonia	2006	Pelagic Trawl >15m	1009	8	0.8	0
	2008	Gillnet	Not Available	13	Not Available	0
Finland	2006	Pelagic Trawl >15m	275	25	9	0
	2008	Pelagic Trawl >15m	1370	43	3	0
France	2006	Gillnet	39440	91	0.2	0
	2006	Pelagic Trawl >15m	8390	276	3	4
	2007	Gillnet	38220	367	1	9
	2007	Pelagic Otter Trawl (1 boat)	280	2	0.7	0
	2007	Pelagic pair Trawl	8570	575	7	22
	2008	Gillnet	23788	475	2	10
	2008	Pelagic Pair Trawl	16096	628	4	31
Ireland	2005	Gillnet	503	78	16	5
	2005	Pelagic Trawl	972	34	3	0
	2006	Gillnet	551	51	9	7
	2006	Pelagic Trawl	629	51	8	4
	2007	Gillnet	163	10	6	0
	2007	Pelagic Trawl	1352	45	3	0
	2008	Pelagic Trawl	1781	59	3	0
Latvia	2006	Gillnet	Not Available	222	Not Available	0
	2006	Pelagic Trawl	Not Available	641	Not Available	0

Country	Year	Observed Gear	Fishing Effort (Days Fished)	Observed Days	Percentage of Fishing Days Observed	Cetacean Bycatch Observed (Unraised)
Netherlands	2004/05	Pelagic Trawl	834	98	12	3
	2006	Pelagic Trawl	685	87	13	1
	2007	Pelagic Trawl	1390	204	15	0
	2008	Gillnet <15m	1781	48	3	0
	2008	Pelagic Trawl (1 boat)	1470	220	15	1
Poland	2006	Gillnet >15m	2857	6	0.2	0
	2006	Pelagic Trawl	4130	19	0.5	0
	2007	Gillnet >15m	2288	7	0.3	0
	2007	Pelagic Trawl	6165	140	2	0
	2008	Gillnet >15m	540	32	6	0
	2008	Pelagic Trawl	1289	76	6	0
Spain	2008	Gillnet >15m	581	25	4	1
	2008	Pelagic Trawl (1 boat)	Not Available	36	Not Available	1
Sweden	2006	Pelagic Trawl	1047	36	3	0
	2007	Gillnet >15m	141	24	17	0
	2007	Pelagic Trawl	3228	160	5	0
	2008	Gillnet >15m	239	71	30	0
	2008	Pelagic Trawl	2807	34	1	0
United Kingdom	2007	Pelagic Trawl	1843	215	12	0
	2008	Gillnet	Not Available	434	Not Available	10
	2008	Pelagic Pair trawl	Not Available	10	Not Available	22
Total			**Not Available**	**6,068**	**Not Available**	**132**

Table 4. Breakdown of observed cetacean bycatch by gear for the main countries contributing to the total number caught between 2005-2008. Numbers in brackets are days observed. (adapted from EP 2010).

Country	Pelagic Trawl	Set Nets	Total Cetaceans Observed
France	56 (1481)	19 (723)	75
Ireland	4 (189)	12 (139)	16
United Kingdom	22 (149)	10 (434)	32
Total	**82**	**41**	**123**

Table 5. The main catch rates (cetaceans per observed day) for the main countries contributing to the total number caught between 2005-2008, calculated from the data in Table 4.

Country	Pelagic Trawl	Set Nets
France	0.04	0.03
Ireland	0.02	0.09
United Kingdom	0.15	0.02
Average	0.045	0.032

Spain only reported two cetaceans being bycaught during 61 observed sea days between 2005-08 in ICES Areas VIIIa, b and c (see Table 3), whereas between 2009-11 an estimated 2328 common dolphins, 454 bottlenose dolphins, 91 pilot whales, 61 harbour porpoises, 30 Risso's dolphins, and 60 baleen whales (*Mysticeti*) were reported to be bycaught per year by Spanish fishers operating in similar fishing areas, although 25% were thought to have been returned alive (ICES, 2015). These increased estimates were based on 1274 interviews with Spanish fishers conducted between 2009 and 2011 in the northern Spanish Atlantic coastal regions of Galicia, Asturias, Cantabria, and the Basque Country (ICES, 2015), whom it is assumed operate primarily in ICES Areas VIIIa, b and c. In Scotland, the Scottish Entanglement Alliance (SEA) undertook a survey of 150 creel fishermen and found that 53% of them had experienced an entanglement in the last 10 years. They responded that there had been 71 cetaceans (the majority being minke whale (43) and humpback whale (12)), 10 leatherback turtles and 49 shark entanglements, but that only 3 of these incidents had been reported to the Scottish Marine Animal Strandings Scheme (Pinn, 2019). So, there appears to be large differences between cetacean bycatch estimates depending on the source of the data and how the data are collected.

Observers and other types of monitoring programmes are important for addressing data deficiency issues (Reeves *et al.*, 2013), but using just one collection method as the only source of data can have limitations, especially when programmes may be limited by funding or rely on voluntary participation. If a fishery was experiencing high levels of bycatch, there is the potential that skippers may not allow a non-mandatory observer on board their vessel to witness this occurrence. So, it is important to have several different tools available by having a range of monitoring options to choose from, which will help reduce the negative impact that can often arise due to external influences like funding restrictions, politics, or reduced goodwill.

The aim of this report is to present the different options currently being used for observing and recording of cetacean bycatch in fisheries around the world and to consider which of these methods are the most appropriate, under different circumstances, for fisheries in the ASCOBANS area where there are known bycatch issues. Some of these monitoring methods may not yet have been used for cetacean bycatch monitoring but only in fisheries monitoring, but if it is thought that the technique could be transferred to cetacean bycatch monitoring, then it will also be considered.

Terms of Reference (ToRs)

The ToRs are to produce a report of the strengths and weaknesses (cost-benefit analysis) of the alternative methods for monitoring aboard fishing vessels with regards to cetacean bycatch in the ASCOBANS Agreement Area.

The report should consider several key issues including:

- whether a technique is adequate to answer the bycatch questions being asked and if it is deemed so, under what circumstances/situations is it the most appropriate
- levels of stakeholder involvement required and potential for achieving this
- practical aspects of use including installation requirements, security, privacy and health & safety
- sampling design/effort
- data to be collected (and the reliability of those data) and the analysis costs of obtaining the required data from the raw data (e.g. reviewing digital footage)
- analytical techniques and dealing with uncertainty.

The report should use case study fisheries (selected in consultation with ASCOBANS) with example sampling levels of 5% and 10% of a national fleet's fishing effort for the selected gear type, to compare the costs of using dedicated marine mammal observers with alternative monitoring solutions for collecting cetacean bycatch data. Factors such as health and safety, costs, and practicalities of implementation, should be considered. The full terms of reference as published are available in the Report from the ACCOBAMS/ASCOBANS Joint Bycatch Working Group (ASCOBANS, 2019).

Data Requirements

The data that need to be collected to allow scientists to make accurate cetacean bycatch assessments and subsequently allow policy makers and fishery managers to make good evidence-based management decisions, include:

- the number of cetaceans caught
- survival rate of bycaught animals
- quantity of fishing effort observed during the trip
- quantity of total fishing effort fished during the trip i.e. if some fishing operations are not monitored during the trip (perhaps due to illness, equipment failure, or safety concerns) this will allow any in-trip subsampling to be accounted for during data analysis
- location and time of fishing effort and bycatch events
- type of fishing gear used and target species
- information on any mitigation devices or measures used
- total fleet fishing effort to allow bycatch observations to be raised to national fleet level.

Depending on the monitoring techniques being used, additional useful information can also be obtained during the trip, e.g. sex and size of the cetacean bycatch, tissue/dental samples (for aging and genetic studies), other sensitive species monitoring, catches of commercial and non-commercial fish species, fishing gear parameters, meteorological data, oceanographical data, and anecdotal information from the crew.

Monitoring Techniques

There are several monitoring methods currently being used throughout the world to collect data on bycatch rates in fisheries for commercial fish species, non-commercial fish species and sensitive species (including cetaceans). Obviously, there are local variations of how these are implemented and the exact data that are required and collected, but the main principal methods are very similar. The levels of sampling between nations and fisheries are highly variable and usually dependent on local budgets, so this report will use example sampling levels of 5% and 10% of fishing effort (as specified in the terms or reference) to compare the different viable monitoring method options later in the report.

At sea (Onboard) Observers

In 2002, the Data Collection Regulation (DCR) 1639/2001 was introduced by the EU that stipulated the requirements for data collection in fisheries for all European Member States (MS), specifically the use of at sea observers to quantify discards and bycatch of fish species (EC, 2001). This regulation did not cover the bycatch of cetaceans specifically but proved useful in the design of at sea observer programmes. It was not until 2004 that cetacean monitoring was required through Regulation 812/2004. The DCR regulation was replaced by the Data Collection Framework (DCF) 199/2008 (EC, 2008), which was then subsequently replaced by Council Regulation 2017/1004 (EC, 2017). The latter of these stated that "masters of Union fishing vessels shall accept on board scientific observers and cooperate with them in order to allow them to discharge their duties while on board Union fishing vessels, as well as the use of alternative data collection methods, where appropriate, set out in the national work plan". Vessels could only refuse access if there was "an obvious lack of space on the vessel or for safety reasons in accordance with national law" (Section 3 Article 12). This meant that it was compulsory to take an observer if asked to do so, unless one of these refusal criteria was satisfied. But even if refusals occur, regulation 2017/1004 also states that each Member State should ensure that "in such cases, data shall be collected through alternative data collection methods". Vessels could therefore potentially adopt REM as this alternative method if it has been described as the alternative method in their national work plan. This measure was expected to help ensure that the data being collected were not biased by scientific observers only being allowed to collect data from certain fleets or vessels or at certain times of the year, month or day.

In 2013, the Study Group on Implementing Discard Sampling Plans (SGPIDS) stated that there are many reasons why a vessel may decline to accept an observer and that these can be classified as either a direct "hard no" or an indirect "soft no". Examples of refusal reasons that they consider a hard no, included that "the skipper does not believe that scientists do a good job and are harmful to the industry", whereas a soft no would be less strongly worded and could be a "not this time…. maybe next month" (ICES, 2013). In fisheries where there are higher refusal rates, there is more potential for bias in the collected data and a high refusal rate can often highlight a lack of cooperation and poor relationships between science and industry (ICES, 2013). But collecting the information, presenting it to industry and discussing concerns, can help highlight issues and improve cooperation which can lead to an increase in vessels agreeing to take an observer e.g. Denmark found that communicating these issues to industry increased acceptance rates from 2% to 54% (ICES,2013).

Unfortunately, there is the potential for skippers to argue that there is no space on board their vessel or that they have safety concerns around taking an additional person to sea as an excuse, and this may lead to bias. Lithuania specifically stated in their DCF reports that refusals due to safety and space concerns were the main reasons why they were not being allowed to undertake monitoring using observers (DCF, 2018; DCF, 2019). Data on refusal rates is now being collected by some Member States to help identify potential bias, the reasons for refusals, and to allow solutions to be identified where needed.

The original regulation specific to marine mammal monitoring using observers (EC812/2004) was replaced by the new Technical Measures Regulation 2019/1241 (regarding mitigation and monitoring measures) (EC, 2019). It mentions the need for cetacean bycatch monitoring programmes on vessels >15m length and also that bycatch data for sensitive species should be gathered from all fleets. The purpose of an observer that monitors cetacean bycatch is to gather data on the location and duration of the fishing activities of the vessel being sampled and record to species level all incidences of cetacean bycatch observed. Where possible, additional information on size or weight, sex, and age of any cetaceans returned or lost ("drop-outs") during hauling of the nets should also be recorded, as should whether they were alive and likely to survive the encounter, or dying, or dead.

Observer data are essential for the management of long-term sustainable fisheries on fish stocks and also provides information on the impacts of fishing pressure on the marine environment (Briand *et al.*, 2018), which includes cetacean interactions. Whether observers are deployed to monitor fish or cetaceans, the principles of the programmes are similar. Observers are tasked with collecting data on the time and location of fishing effort, the duration of the fishing effort, the quantity of fishing effort (e.g., lengths of nets, number of hauls), the quantities of fish retained and discarded, fishing gear parameters (e.g., mesh size, hanging ratios), the quantities of bycatch (e.g., birds, cetaceans), and biological data from their list of species of interest. This information could then allow any bycatch data to be raised to fleet or national level to get annual total bycatch number estimates. This is necessary because catch sampling programmes and dedicated bycatch monitoring studies usually only sample a small proportion of the fishing fleets, primarily due to budgetary constraints (ICES, 2018a), although in some fisheries around the world, e.g. Californian West coast groundfish fishery (Damrosch, 2017), or the eastern tropical Pacific tuna purse seine fisheries), observer programmes cover as much as 100% of all fishing trips and hauls on a mandatory access basis (Karp and McElderry, 1999).

In some fisheries it should be remembered that although the number of sea trips sampled may equate to 5%, the way in which the vessels operate may mean that some fishing events during the voyage will not be observed. For example, in a typical UK demersal trawl fishery the net is hauled every 3 to 6 hours throughout the 24-hour period and for up to 10 days on the longer trips (depending on the fishery). It may not be physically possible or safe for a single observer to sample every single haul without completely exhausting themselves and putting themselves and others at risk, as well as potentially contravening the 1998 Working Time Directive (amended in 2003) (WTD, 2003).

The ability to observe cetacean bycatch can be dependent on the type of fishing gear used and the viewing opportunities available to the observer. In the pelagic trawl fisheries, a large vessel can often catch a single haul that is so large that it can take almost a day to process and subsequent catches may be processed almost continuously from the moment the first catch comes on board. So, if there is only one observer on board, they will need to sample catches in set time-blocks to ensure that they have adequate rest periods. If the observer is only interested in cetacean bycatch, then the time period where the net is first hauled and catch pumped or brailed aboard, is the most likely opportunity to observe any bycatch events, and the monitoring regimes will need to be structured around these hauling events rather than routine timetabled working hours. In these types of situations, it is important for the observer not to rest and work in a uniform pattern as this will lead to the same time-frames always being observed or unobserved, which may lead to the observer missing any diurnal fluctuations in catch and bycatch rates that may be occurring. For example, if an observer starts at 06:00 and works 12 hours and then has 12 hours off, the only daily period that will be monitored is the daylight between 06:00-18:00 for the duration of the trip. Far better would be to work 10 hours and have 5 or 6 hours off, which over time, will allow all daily periods to be observed. Alternatively, additional observers can be deployed to cover all time periods, assuming that there is space on the vessel, but this will have cost implications and may reduce a programme's sampling level.

Unlike the pelagic trawlers that operate in an opportunistic way targeting large shoals as they are encountered, the demersal trawlers (also includes seine trawls and pair trawls) operate in a more structured way and once they reach their preferred fishing grounds they deploy their gear and tow for the preferred duration and then haul the net, empty the catch aboard, deploying the net again and then process the catch whilst the net is being deployed and fishing. This process then repeats until the vessel returns to shore or moves to a different fishing ground. This allows the observer to be present at all hauling and catch processing events as long as there are sufficient breaks between hauling operations, otherwise subsampling of hauls will be needed to provide rest periods. This “in-trip subsampling” will also lower the amount of fishing effort sampled during the trip. with the assumption that the data from the sampled hauls are representative of all the hauls fished during the trip. The only way to observe 100% of fishing effort on this type of voyage is to have more than one observer at sea on each vessel working in shifts to give full 24-hour coverage, but sending multiple observers to sea on one vessel will have knock on effects on the space onboard and on programme costs. A dedicated marine mammal bycatch observer will be able to observe the net being hauled, the codend being emptied, and witness any incidents of bycatch. Cetaceans seldom drop out of demersal trawls (unless an escape panel is in place) and usually need to be physically removed from the fish hopper because they are too large to travel along the normal fish processing route of conveyors or gravity fed chutes. This is usually done by tying the tail of the animal to a lifting strop and winching it back out of the hopper through the hatch and then cutting the rope to allow it to drop back into the sea. This process can easily be observed from the wheelhouse or upper decks of the vessel. However, if the observer is multi-disciplinary and also needs to process fish samples as well as record cetacean bycatch, they will need to be on the fish processing (factory) deck when the catch processing begins and then may miss any cetaceans that are lifted back out of the hopper.

Unlike trawling, the static gill (and trammel) nets are usually all deployed one after each other and then left to fish for a preferred duration, relying on the fish swimming into the nets and becoming ensnared, rather than herding them until they tire and fall back into the codend, as in trawling. In gill net fisheries, accidental catches of cetaceans can often drop out of the nets during hauling and it is important that the observer is positioned to view this should it occur.

When observers are deployed, they need to be able to observe and record the cetacean bycatch events when the animal is brought aboard along with the fishing effort and location associated with this event and sampling opportunity, especially from the small-scale fisheries. The ICES Working Group on Commercial Catches (WGCATCH) in November 2019 made recommendations regarding which data should be collected on a mandatory basis (ICES, 2020a). Observers are also ideally placed to potentially collect additional biological information from cetacean bycatch such as length, sex, specimen state when discarded body temperature, tissue/teeth samples and imagery (depending on the needs of the project/programme), when the animal is brought aboard the vessel. But they also need to be able to observe the cetacean bycatch events where the animal is not brought aboard the vessel. For example, in set net fishing, cetaceans that are entangled in the net can often be cut out by the crew whilst still in the water or they can drop out of the nets as they are being hauled aboard. From the crew's perspective, it is easier to do this as they do not need to worry about disposing of the dead cetacean or potential contamination of their fish catches. But the observer needs the opportunity to, at the very least, record the drop out event at species level. If they are busy measuring fish or working on a previously caught cetacean or on a work break, then this rare occurrence may not be reported or recorded unless done so by the skipper.

In pelagic trawl fisheries, the nets are often fitted with selectivity grids to stop large bycatch species (e.g. sharks, seals, turtles and cetaceans) from entering the actual codend. These exclusion devices do not necessarily allow cetaceans to escape alive as cetaceans tend not to follow the escape routes provided (unlike turtles, seals and sharks). This is thought to be due to "claustrophobic" tendencies keeping them from going down a potential but narrow escape route (Zeeberg et al. 2006). But if a cetacean becomes exhausted and drowns in the mouth or belly (mid-section) of the net, the dead animal may be washed out the escape route during hauling and may not be observed. Stephenson et al. (2008), reported that of the seven cetaceans interacting with an exclusion device during an underwater video project, two escaped through the grid, one escaped back out of the mouth of the net, one was washed out of the grid underwater dead, one washed out dead as the net was being hauled, and two additional dead cetaceans were missing when hauled and assumed to have washed out underwater. So, of these four dead cetaceans, only one animal would have been potentially spotted by an alert observer watching the hauling operation. The other dead cetaceans are an unaccounted mortality which would have been brought aboard and observed if the grid had not been fitted. This does not mean that exclusion devices are not working, as in this instance two cetaceans did successfully escape alive, but it does mean that on-board observers (and any other monitoring technique) need to be extra vigilant for this type of event.

It is clear that observers do have the capacity to view and record cetacean bycatch events and undertake other relevant duties on the majority of vessels. Therefore, at-sea observers will form part of the method comparison for monitoring bycatch. However, it is important to remember that the observer's ability to observe and record all cetacean bycatch events will be greatly influenced by the additional tasks they are given at sea as well as the main objectives of the monitoring programme. Most European cetacean bycatch data is provided through the DCF observer programme rather than dedicated marine mammal observers which results in downwardly biased bycatch estimates compared with those from dedicated observers deployed on the metiers that account for a significant proportion of cetacean bycatch (STECF, 2019).

Electronic Monitoring and Reporting

The term Electronic Monitoring is used to describe many types of equipment and many ways of monitoring fishing vessels or collecting fisheries related data. However, not all of these will allow the interactions between fishing gear and cetaceans to be examined. Some will only record position and speed of a vessel, whilst others can record full high definition (HD) digital video from multiple cameras, fishing effort data from dedicated sensors, catch data from self-recorded electronic logsheets, or a combination of these. Therefore, the main types of electronic monitoring equipment have been described.

VMS

Vessel monitoring systems (VMS) using satellite technology have been required on EU fishing vessels since 1st January 2004 for vessels >18m overall length and since 1st January 2005 for vessels >15m overall length, under Article 22 of Regulation 2371/2002. It states that "a fishing vessel shall have installed on board a functioning system which allows detection and identification of that vessel by remote monitoring systems" (EC, 2002). In 2013, VMS using satellite and mobile phone options was introduced for >12m vessel in length in accordance with Council Regulation (EC) No. 1224/2009 (EC, 2009) and Commission Implementing Regulation (EU) 404/2011 (EC, 2011). In the UK, there is currently an initiative to extend VMS to all fishing vessels <12m through the use of a Statutory Order, and a consultation process has recently been undertaken by Defra. This process also noted that it will not apply to other EU vessels and is unlikely to be in place before the end of 2021 (Defra, 2019).

VMS systems allow a summary of a vessel's time, date and speed to be sent via satellite or 3G/4G (depending on the manufacturer) in near real-time to a monitoring centre ashore. This information is then used to identify a vessel and its location and to make an assumption on the vessel's activity based on the speed over ground data between two points and trajectory. But it is important to understand that this activity is an "assumed" activity based on speed and knowledge of a fishery, the fishing vessels involved, and the type of model applied to the data. This is not a precise indication or evidence of the vessel's fishing activities. A study on two Norwegian trawlers found that VMS data only correctly identified 75% of the actual fishing effort, using 2-5 knots to classify fishing effort and identifying non-fishing effort was as low as 55% (Skaar *et al.*, 2011). They also found that the towing speed range of 2-5 knots was also used on 24% of non-fishing activities, so it would be easy for a fisher to argue that they were not fishing at a certain time. In contrast, Mills et al. (2007) reported a 99% success rate when investigating North Sea beam trawls. Other authors have found a range of accuracies for fishing and non-fishing activity identification and this is attributable to the classification speeds used, the types or fisheries involved, how often data are sent, the modelling techniques and software used (e.g. Marzuki *et al*., 2015; Mendo *et al.,* 2019). Some studies have investigated using VMS data to obtain information on distance fished during towing operations (i.e. trajectory lengths). Eastwood et al. (2007), found that VMS underestimated fishing distance by 54% and these underestimations are due to the straightness of towing and how often turns are made. So, in a legal case concerning fishing/non-fishing activity, VMS data alone could easily be demonstrated to be inaccurate, which will also apply to any scientific or management usage of this data.

AIS

Automatic Identification Systems (AIS) are similar to VMS in that they are able to be used to locate vessels geographically and their speed over time data can be used to infer an activity. The data transmission rates between the AIS and VMS differ, with AIS data being sent every 5 minutes whilst VMS is every 2 hours, typically. They also suffer from the same weaknesses as VMS and provide no information on catches. AIS differs from VMS in that it usually uses VHF radio signals rather than satellite signals and is therefore only functions when in line-of sight of a shore-based receiving station. However recent developments in AIS are moving towards the use of satellite. Also, AIS systems can be switched off or set so that they only receive data and do not transmit data, whilst VMS must be tamper proof, secure from false data input and unable to be switched off by the crew. It is possible for AIS information to be viewed by the general public through specific websites and therefore the data are no longer confidential, unlike VMS which is usually sent to a government shore-based tracking centre and only viewable by the receiver. The differences between the two systems is linked to why they were originally developed. AIS was primarily designed to allow vessels to identify each other at sea for safety reasons so that they can call each other by name and help avoid collisions, as well as allow last recorded position to be used in a search and rescue emergency. Fleet managers or interested members of the public can use it to track vessels during transit. VMS on the other hand is a development related to fisheries monitoring and data are usually only available to enforcement agencies. Only vessels of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size are required to have AIS for safety purposes (IMO, 2020). However, systems are available for vessels of any length and pleasure craft often have them aboard for safety reasons. Neither VMS nor AIS are suitable for monitoring cetacean bycatch by themselves but can be used as part of a more complete solution.

Fishing Activity Sensors

Fishing activity can be detected on fishing vessels using an array of sensors. For example, a gill netting vessel can have a sensor fitted in to the hydraulic system that can detect when the net hauler is being used due to the changes in oil pressure. Hydraulic sensors can also be used on towed gear fisheries where hydraulic systems are used to haul in the nets. Where vessels do not rely on hydraulic oil systems e.g. where pressurised air systems are used, movement sensors that detect the rotation of a winch or drum can be used. Sometimes, it is useful to have both types of sensors installed, so that they can substitute each other, should one be damaged or malfunction. Other sensors that have been trialled to identify when gear is being hauled aboard include noise measuring sensors to “hear” when ancillary engines are started or winches are turning, engine revolution counting sensors that can detect power surges and uses of the engines, and RFID tag technology that can be fitted to the fishing gear and detected upon resurfacing or be manually swiped.

Fishery managers need the data on fishing effort linked to time, location and vessel identity, so that they can calculate fishing effort for different regions. Sensor data collected in isolation will be of limited or no use and should be linked to GPS data and the vessel name. The sensors must also be connected to a computer or data storage device so that the collected data can be timestamped and linked to the other equipment, stored or communicated ashore.

Linking data collected from a VMS or AIS system to the activity sensors can change the inferred activity provided by AIS/VMS into physically detected activity data combined with time and position. For example, if a hydraulic sensor is fitted to a gill netting vessel’s hauler, it would allow the activity of the hauler to be logged along with the normal data associated with a VMS type tracking system i.e. position and time, to calculate speed. Because the net hauler is usually only used to recover the net (deployment being through drag and gravity) it allows the exact time and place of a net-hauling activity to be recorded. This then changes the assumed activity to an evidenced activity. Knowing when and where the fishing gear was deployed and recovered, through investigation of the activity sensor and positional data, will allow the soak time of a net to be calculated. Identifying individual nets or fleets of fishing gear that are deployed in very close proximity to each other can be difficult if only using the positional and activity sensor data, especially if the gear is prone to movement. However, fitting a radio frequency identification (RFID) tag to the net or buoy and an RFID reader sensor will allow the exact net to be identified by its unique number when the RFID tag is swiped at the time of deployment and hauling. The resulting data are then linked to GPS data, which allows it to be geo-tagged (linked to time and position) and the differences between the time and position of deployment and hauling can be used to calculate accurate gear soaking times and possibly even estimates of length of net hauled. This can then be used in any fishing effort calculations or catch per effort calculations or to verify self-reported fishing effort as declared on any fishing logbooks. However, these sensors still do not provide any independent estimates of cetacean bycatch and would still rely on the skipper self-reporting the incidental catch.

Elog

An Elog (electronic logbook) is an on-screen system where the fishers enter their catch and fishing effort at predefined time periods during a trip, or at the end of the trip, through a laptop or computer/phone application. Historically, this information was recorded on paper logsheets and these logsheets were submitted to compliance officers at the end of the trip or an agreed time frame. Elogs rely on fishers recording the data in the same way that paper logbooks do, with the main difference being that Elog data do not need to be entered into a computer system at a later date through a manual transcription process. Elog is a form of electronic reporting and not electronic monitoring and the data are only as accurate as the information that is entered on to them. Elog does not record cetacean interactions independently but only records the data that the fisher chooses to declare and share, and some fishers may be reluctant to accurately report cetacean bycatch, which may make the data unreliable. Elog can form a useful component of a full REM system but is not a stand-alone electronic monitoring solution. One cost benefit of Elog though is that the burden for digitising the data is moved from a shore-based administrator, who previously entered logbook data on to a database, to the fisher who now enters the data directly into the computer system. This saves on shore-based staff time but also reduces the opportunities for transcription or interpretation errors.

CCTV

Using closed-circuit television camera (CCTV) systems by themselves can provide video evidence of a bycatch interaction which can then be analysed ashore to identify species. It is also an essential verification tool for any self-reporting requirements. However, it needs to be linked to time, fishing effort and position, if the viewed bycatch interaction is to be used in science or management purposes or regional mortality estimates. This linked system that combines all the necessary components to collect the required data is usually referred to as a full Remote Electronic Monitoring (REM) system with CCTV.

REM with CCTV

The only reliable way of capturing a cetacean interaction at sea, in the same way that an at-sea observer would, is to have a vessel fitted with a closed-circuit television camera (CCTV) system that is linked to the vessel's position at time, and sensors to detect fishing activity. This will enable bycatch per unit effort by area to be calculated. The cameras can be used to verify that the fishing activity being detected by the sensors is correct, as well as monitor the catch handling and processing activities to view potential cetacean interactions.

The first projects in European waters that utilised electronic monitoring equipment coupled with integrated CCTV (from now on referred to as REM) occurred in 2008/2009 when the UK (England and Scotland separately), Germany and Denmark agreed to carry out pilot trials of the equipment to determine if it could be used on European fishing vessels (especially mobile gears) and in mixed fisheries (Dalskov and Kindt-Larsen, 2009; Pasco *et al.*, 2009; Course *et al.*, 2011). These were not cetacean specific projects but focused on assessing the usefulness of REM as a potential monitoring tool in typical European fisheries and to quantify all fishing effort and catches, including sensitive species, discarded and retained commercial species, and discarded non-commercial fish and shellfish species. However, REM had been used in North America for several years before this, primarily by the Canadian company Archipelago Marine Research. Their equipment, expertise and advice was utilised in these European pilot projects. These trials became linked to species specific catch quotas as incentives to become more selective (Dalskov and Kindt-Larsen, 2009; Roberts *et al.*, 2014; Needle *et al.*, 2015; Roberts *et al.*, 2015; Ulrich *et al.*, 2015), and also began to consider whether the REM equipment could be used to monitor cetacean bycatch (Kindt-Larsen *et al.*, 2012). It can also be used in scientific projects to monitor and verify the success rates of mitigation measures or other initiatives over long periods. For example, REM was used in long term gear trials in the south west of England trawled haddock fishery to compare catch data from a twin rig trawl fitted with a control codend on one side and a modified trawl on the other (Roberts and Course, 2014). REM was fitted on 11 vessels of <12m length in the Scottish inshore fleet to estimate discard rates of brown crabs, scallops, velvet crabs and lobsters, and to trial the use of REM as a verification tool for fisher self-reporting on various gear types (Course *et al.*, 2015). With the correct sensors and project design, REM could potentially be used to monitor the performance of cetacean bycatch mitigation devices.

Most REM systems comprise a GPS receiver, a hydraulic pressure sensor, winch rotation sensor, digital CCTV cameras, and a user interface (keyboard and display unit) to allow the skipper to record comments, catch or bycatch events. It should be noted that in some programmes, the REM systems are closed to external or manual input (Emery *et al.*, 2019), presumably to protect the integrity of the data. If the system is fitted with a communications system (satellite or mobile phone network) then there is no reason why the activity sensor and GPS data cannot be sent to shore on a routine basis, relatively cheaply, to allow near live monitoring of fishing activity (Course, 2015).

One of the keys to successful use of REM is in the placement of the cameras. They need to be able to see what you wish to monitor, and you have to be clear about what you want to see. There is no point having a camera placed above the sorting belt on a factory deck of a pelagic trawler if you wish to monitor the cetacean or ETP species bycatch events. These events need to be monitored at the point of decision where a crewman decides whether the animal is retained onboard or discarded back into the sea, or where it accidentally drops out of the net or is intentionally slipped from the net to avoid bringing it on board. This sounds straightforward but, in reality, needs highly skilled installation staff with a good working knowledge of that fishery and of how crew operate or how the monitoring process may be disrupted or circumvented. The installers also need to understand what the video review staff needs to be able to view in order to complete their assessment accurately.

Fisheries in the ASCOBANS area, where the highest incidences of observed cetacean bycatch occur, generally fall into two categories: larger vessel pelagic pair trawl and the set gillnet vessels (see Table 4) (EP, 2010), which are generally smaller than the pelagic vessels. Physically, the vessels involved in these fisheries are at opposite ends of the size range and will therefore require a different implementation approach when using REM as the monitoring solution. However, they still both share physical commonalities related to onboard fishing equipment (e.g. winches/haulers, catch sorting areas) and what actually needs to be monitored. In both fisheries, the REM is required to capture the location onboard where the crew interact with the cetacean bycatch, the result of the interaction, the quantity and species of the cetacean bycatch, the fishing effort deployed during the trip, the geographical location of each bycatch and fishing event, and that data are stored and/or transmitted securely so that they can be used by scientists and fishery managers with high levels of confidence.

Self-reporting

Self-reporting is a common method of gathering data for fisheries management and is used throughout the world. In its simplest form, it is a paper log sheet that is completed by the skipper and handed to the relevant authority on landing or at the end of a specified time period. For example, fishermen using traps to capture shellfish in Scottish waters have been required to fill in a weekly summary of their landed catches, called the “Fish 1” form (Course *et al.*, 2015). Historically, most fisheries data were reported using paper logbooks but recent advances in technology have allowed these data to be supplied in digital format through the use of Elog (see previous section). Logbooks require fishermen to self-declare their retained and discarded catches, their fishing effort, and the area of operation using paper records, personal computers, or on smaller vessels through the use of mobile phone applications, whilst at sea or on landing. Shortages in staffing or diversion to more immediate issues could result in long delays in entering the paper logsheet data, which could then result in delays in detecting and dealing with compliance issues and delays in making data available for scientific (and therefore management) usage. Transcribing from paper logsheets can also lead to transcription errors from data inputting or through misinterpretation of the written information. Administrative staff who may not have specific fisheries knowledge may be used for this task and where fishers have used local or fishing terms they may be misinterpreted, and data can just be misread or mistyped and so inputted incorrectly. These transcription errors can be reduced by using Elog and removing the extra step in the process, and any that do occur are the responsibility of the fisher.

There have been projects undertaken that have investigated the differences between cetacean bycatch data obtained from fisher self-reporting, onboard observers, and REM. Stephenson *et al.* (2008) undertook a comparison between observer and fisher self-reported dolphin catches between January 2004 and June 2005 in the Pilbara trawl fishery of Western Australia and reported that when observers were not present, the fishers under-reported cetacean bycatch. The fishers reported 13.3 dolphins per 1000 gear sets when the observer was onboard compared to 5.6 dolphins per 1000 when observers were absent. In another study that compared self-reported cetacean bycatch with observations from reviewing video collected using REM, the authors found that skippers reported only 25 of the 36 seen on the video and 3 of those 25 did not actually appear on the collected video near the time they were supposed to have happened (Kindt-Larsen et al. 2012). It is likely this was due to forgetting to record the event when it happened and attempting to correct the omission at a slightly later time, which at least demonstrated a willingness to actively record the information. These studies have shown that self-reporting of information related to the sensitive issue of cetacean bycatch, is generally under-reported, although Emery *et al.* (2019), also found instances of over reporting of some species due to species misidentification. These differences may be purely accidental, such as forgetting to log the interaction at the time it occurred or not observing the event due to being too busy or because the cetaceans have dropped out of the net before reaching the deck. Alternatively, they may be intentional because there is a perceived negative impact to the fisher of reporting the true number of cetacean bycatch, through negative public opinion or threat of closures.

Self-reporting nevertheless is a very cost-effective way of obtaining non-sensitive data. If the impact of reporting sensitive data could somehow be reduced or mitigated, then perhaps these data would become more accurate. Remove the “fear-factor” and there becomes no need to mis-report bycatch events and as long as the industry is willing and able to undertake this additional task, the data may reflect the actual interactions. However, verifying the accuracy of these data in any long-term programme will be essential if the data are to be used in any way other than anecdotally. Currently, self-reporting is viewed by some as “an extremely poor fisheries management tool because it is not timely and is unverifiable” (PEW, 2019) so self-reported cetacean bycatch may also be viewed with the same degree of scepticism by these same organisations. Elogs are more timely than paper logbooks but are equally unverifiable. Coupling a VMS system to an Elog system will allow a cetacean bycatch event to be recorded by time and location but it relies on the fisher to self-report the event and is therefore still unverifiable. A camera would need to be included within the system to verify these self-reported events. Therefore, self-reporting alone will not be considered further as a reliable tool for monitoring cetacean bycatch by itself although it may be referred to as a complementary tool to REM as it allows video review resources to be more closely focused to a particular event and time. For standalone self-reported data to be considered as reliable it would require a high level of trust which cannot be guaranteed, whereas verifying self-reported data using REM removes the need for this trust and instead provides evidence based data that are accessible to all stakeholders. With limited at-sea monitoring, a schism of mistrust can form where managers don’t necessarily trust what fishermen report in their logbooks, and fishers do not necessarily trust the science delivered by managers (Michelin *et al.,* 2018). On small inshore vessels, a REM system with one or two cameras, a fishing activity sensor, GPS and Elog or event logger, would allow the fishers to self-report when they have encountered a cetacean (or other rare event), and allow project managers to focus the video review effort to these times. The video footage can also be used to undertake checking to ensure that events are being self-reported and the quantity of video that is checked in this way can be based on risk and required confidence levels, or at 100% initially to help determine the levels of misreporting.

Decision: Of the monitoring options and tools discussed above, only two provide the opportunity to observe and report cetacean bycatch and interactions as they occur at sea: at-sea observers and REM with CCTV. Therefore, only these two options will be discussed further.

Comparison between bycatch monitoring methods

When considering the type of monitoring method that is most suitable for monitoring cetacean bycatch there are several considerations that must be satisfied:

1. **Accuracy:** Does the technique observe and allow the cetacean bycatch event to be counted accurately and the species to be identified?
2. **Coverage levels:** Are coverage levels high enough to eliminate or reduce potential errors when raising the data to fleet or population levels?
3. **Monitoring (Observer) effect:** Does the method alter the way fishers usually behave?
4. **Cost:** Is it affordable or cheaper than alternative methods?
5. **Additionality:** Does it have additional benefits over other methods?
6. **Stakeholder engagement:** Are the stakeholders accepting of the method and engaged with the monitoring programme?

Table 6 uses these questions and applies them to the two bycatch monitoring options of at-sea observers and REM.

Table 6. Comparing Observer monitoring and REM monitoring with the specific questions and suitability criteria to be considered.

Question	Observer Monitoring	REM
Accuracy: Does the technique observe and allow the cetacean bycatch event to be counted accurately and the species to be identified?	Yes – Observer monitoring does allow cetacean bycatch to be accurately observed, identified and recorded. There is the potential for observers to report back to managers in near real time what they are witnessing and ideally undertake immediate mitigation measures. Potential Limitations to Accuracy Observers can fall sick, be injured, lose concentration, or require specified rest times, whilst poor weather, could lead to some fishing events (or parts of fishing events) being missed. Lack of cooperation or even intimidation from the crew may lead to inaccurate data recording. The aims of the programme can influence the quality of the collected data by overloading the observer with tasks or prioritising their sampling time. For example, if the programme's priority is considered to be the collection of commercial catch data, bycatch events could be missed due to undertaking fish sampling duties away from the usual cetacean monitoring locations on board. Species identification will be accurate depending on the training and expertise of the observer and whether the handling of the bycatch allows opportunity to properly view the animal. However, if a photograph is also taken, the species can be verified at a later time ashore. Opportunity to obtain a decent image may be limited if the animal is not brought on board or rolls out of the net before an identification or photo can be taken.	Yes – REM through the use of CCTV and sensors is able to accurately record video footage linked to time and location which can be used to quantify and identify cetacean bycatch. The video can be reviewed ashore by an expert and enables any bycatch events to be detected and assigned a geographic position as well as allowing the number of cetacean bycatches for the reviewed video to be reported. Potential Limitations to Accuracy The REM may breakdown entirely or cameras could become obscured by rain, sun glare, or dirt, or sensors/independent GPS may stop working. Initial cetacean species identification accuracy will be dependent on the skills of the video reviewer (analyst) and the position and specifications of the cameras used. The size of the bycatch animal, how it is handled, and whether it is brought aboard, will also influence species identification success rates. Potential Advantages There are several advantages associated with using REM video compared to using at-sea observers. For example, in a situation where there is uncertainty over a species identification there is the option to have other analysts review the footage and come to a consensus, whereas the at-sea observer must rely solely on their own abilities with no opportunity for additional expert input, unless imagery is collected at sea for experts to review at a later date. This is especially useful when trying to identify bycatch that drop out of the net during hauling. Unlike an observer, the cameras cannot be distracted or have time off during a trip (unless they break down) so there should not be any missed events. Most REM systems are configurable and are usually set to switch on when the vessel is powered and log GPS data constantly. Cameras can then be configured to record footage based on triggers like position, distance from port, or based on the activity sensor data. If there are multiple cameras operating, they can monitor more than one location at any one time and be configured to different triggers. For observers to monitor more than one area would require additional observers or the temporary installation of video equipment, which in itself could be classed as a form of REM. The positional data is obtained from an independent GPS system and the activity sensors allow fishing effort to be automatically calculated and linked to position. Obviously, there is the potential for the cameras and related technology to break down or be accidentally (or deliberately) obscured or damaged, but these issues can be mitigated through regular cleaning and servicing, duty-of-care user agreements between programme managers and fishers, and through appropriate placement of the cameras during the installation process. Plet-Hansen et al. (2019) report that 11.4% of the video sequences selected for review collected during Danish REM trials (2010-2016) were unusable. If for some reason the cetacean bycatch data are disputed by the fisher or their representatives, digital cameras allow REM to use zoom, variable speed review, and freeze frame to get high quality imagery that can be used to evidence any claims and can be independently reviewed.

Question	Observer Monitoring	REM
Coverage levels: Are coverage levels high enough to eliminate or reduce potential errors when raising the data to fleet or population levels?	No – when raising any data to fleet or population level, there is the potential for errors to occur. Only 100% observer coverage on 100% of fishing events would eliminate error. However, it is not necessary to have these high coverage levels if the confidence levels in the subsampled data collected, and when raised to fleet, are within agreed acceptable limits. Observer programmes specifically associated with cetacean bycatch monitoring will focus their monitoring effort on those fisheries with the highest likelihood of cetacean bycatch, whilst DCF programmes will spread available resources over all required metiers. Only the UK has a dedicated observer programme that monitors cetaceans (and other sensitive species) within the ASCOBANS area. STECF (2019) state that "in general, current monitoring and reporting of cetacean and other sensitive species bycatch is inadequate and that monitoring on high risk metiers needs to be increased." STECF recommend a sampling level of 5-10 % of the total, annual fleet effort, similar to that specified in the now repealed EC812/2004. Historic sampling levels have not met this target for most relevant metiers and countries. The most up to date (at the time of writing) national sampling summaries are available in WGBYC (2019), and are summarised in Table 9 below.	Unknown The use of REM as a monitoring tool is relatively new and although multiple trials have been undertaken to determine their efficacy in capturing monitoring data, the implementation of REM in national programmes has been slow. Currently, it is used in some shellfish fisheries as a surveillance and compliance tool, e.g. Scottish scallop fishery, but only Denmark is known to have adopted REM (in 2019) as part of their national surveillance programme of bycatch of protected species. This is discussed further in the Case Studies section of the report. Potentially REM can monitor 100% of fishing effort and trips undertaken by a vessel that has been installed. Pilot trials have shown that catch information can be obtained for nearly any species from REM as long as the cameras are set up to record at the appropriate locations. The level of fleet coverage will solely depend on the cost of the REM system used and the budget available for purchase, installation and video review. So potentially all vessels in a fleet could have REM installed and have 100% of the collected video reviewed, or a randomly selected proportion e.g. 20% of a vessel's fishing effort. REM can collect sensor data, video data and geo-spatial data continuously for the whole time a vessel has a system installed. When the REM system is powered on, the GPS, time data, and activity sensors are being collected. The analysis software can be configured to automatically detect where and when fishing occurs, without increasing costs. Video footage can be recorded and stored for all trips, with the only additional cost being swapping of local hard drives. This allows accurate fishing effort and GPS data to be collected for every trip and not just the one that is reviewed by the video analyst. If budgets increase then there is also the potential to go back and review additional historically stored video data. So, coverage levels can range between 0% and 100% depending on budgets and precision required. The same could be said of observer programmes but REM is less intrusive on a vessel than an additional person when high levels of monitoring are required. Conversely, high coverage levels can also be intimidating to fishers and discourage the adoption of REM as a monitoring tool due to a perceived "big brother" effect.

Question	Observer Monitoring	REM
Monitoring (Observer) effect: Does the method alter the way fishers usually behave?	Yes – There is the potential that using observers can alter the normal behaviour of fishers, which may lead to bias in the data (Burns and Kerr, 2008; Benoit and Allard, 2009) and if observers are also undertaking enforcement roles, the data obtained can be unrepresentative of unobserved fishing effort (Mangi *et al*, 2013) The design of the sampling programme can also lead to bias if vessels are not selected randomly or if participation in the programme is voluntary. Only vessels willing to take an observer will be monitored and these may have bycatch rates that are different to the vessels that refuse to take an observer. These two sources of bias are called observer effect and deployment effect respectively, and there is also a known effect called the Hawthorne Effect that says that people may act differently as a response to simply being watched (Demarest, 2018). The type of monitoring programme can also influence the level of bias. Vessel participation in DCF monitoring programmes will be altered by current relationships between science and industry and changes in fisheries regulations will alter the levels of participation. This may not be the case for dedicated cetacean bycatch (or sensitive species focused) monitoring programmes because it is difficult to see how these sporadic and rare bycatch events can be predicted before sailing and once the observer is on board, these events will be hard to conceal.	Yes – REM does alter a fisher's behaviour and is comparable to having an observer permanently deployed aboard a vessel. However, Ulrich et al. (2015) noted that where fishers had been engaged in non-compliant behaviour aboard, they became more compliant when REM was installed because they were highly conscious of the presence of the cameras. This altered behaviour reduced with time and in some cases the fishers reverted to their original practices (Ulrich *et al.,* 2015) and others have reported that the fishers forget they are being monitored (Plet-Hansen *et al.,* 2019). Although REM associated with cetacean bycatch monitoring may not involve any enforcement role, the point is that REM rapidly becomes accepted as the new normal situation, especially if there are no repercussions for any observed infractions, so that any altered behaviour may be short term and revert to being representative of unmonitored vessels again. So, the alteration of behaviour is not just dependent on the presence of the cameras but is also dependent on the full monitoring programme processes and how detected non-compliant behaviour is dealt with, perhaps through a performance feedback process or an enforced penalty system. However, if maintaining any improved compliant behaviour is the desired outcome then it is important that fishers are aware that all vessels have REM installed, that the video is being regularly reviewed, that the new improved behaviour is incentivised or rewarded, and that non-compliant behaviour is penalised. Fishers need to be confident that they are operating on a level playing field with their competitors and this requires transparency and decisive management actions. Compliant behaviour then becomes the normal practice and the permanent observer effect is maintained. When considering cetacean bycatch, fishers have to remove the cetacean from a net somehow, be it brought aboard or removed in the water, and if cameras are well positioned then all activities, can be recorded. Obviously, a determined skipper and crew can try to alter the quality of the data captured but when deliberate attempts to circumvent the aims of the REM system are detected, it is important that there is a feedback mechanism to inform fishers that these actions have been noted. The design of the programme may also wish to consider having a pre-agreed penalty system that can be imposed through a participation "duty of care" agreement that participants are assessed against (e.g. the UK Catch Quota Trials, Roberts *et al.,* 2014). Deployment bias is removed if all vessels in the monitored fleet are equipped with REM systems because data will be available from all vessels and not just those where the observer is deployed. The video from each vessel may not be reviewed but all vessels are being monitored and can be sampled. This is particularly useful where fishers are unable to take an observer due to safety concerns or space limitations. There may still be bias introduced during the video review process if the same vessels are always selected for review, but this can be removed through random selection or careful programme design. Observer bias can become permanent on a vessel with REM and it is important that this vessel is representative of other vessels in the metier. This can be achieved by installing REM on all (or a significant proportion) of the vessels in this fishery. It is not necessary to review video from all vessels as long as fishers are aware that random selection may result in review. The presence of the cameras can also greatly improve the recording of bycatch events. In an Australian Pacific longline fishery, it was found that the installation of a REM system increased logbook self-reporting of seabird and mammal interactions, by 7 fold (Larcombe *et al*., 2016) and this improved performance allowed logbook data to be considered as a potential bycatch data source again.

Question	Observer Monitoring	REM
Cost: Is it affordable or cheaper than alternative methods?	Levels of observer coverage are usually based on three principles: regulation, budget and scientific need. Sampling levels based on regulations are usually originally based on scientific advice as well as an element of pragmatism. A monitoring level of 100% observer coverage may be desirable, but may be unacceptable to most fishers (especially in a voluntary programme), unaffordable to most governments or research institutes (and fishers if they are required to pay for observers), and unnecessary if lower levels of coverage provide statistically robust data. Without specifying exact levels of coverage, it is difficult to determine if a programme is affordable. Affordability can also be linked to penalties for not undertaking the monitoring. In other words, if the penalty cost for failure to undertake a national programme costs less than undertaking the programme, there is a financial incentive not to run a programme, and this would apply irrespective of the monitoring method used. Affordability is also relative to available budget and perceived importance of the programme to the procurer. Affordability and value for money are also dependent on whether additional duties are being undertaken during the deployment. Affordability is also a subjective topic as what may seem value for money for one, may appear expensive to another. The repealed EU Regulation 812/2004 specified sampling levels for cetacean monitoring as 5% of fishing effort in a metier for pilot projects, or a bycatch estimate with a coefficient of variation (CV) of 0.3 for fully established programmes on vessels ≥15 m. However, the Regulation has been widely recognised as not serving its purpose due to only providing limited and ill-focused coverage in terms of fishing fleets, areas and gears (Read *et al.*, 2017).	When the use of REM is discussed, concerns regarding the cost to purchase and install the equipment and review all of the video footage collected, may be raised. But costs in REM are generally lower than observer programmes to monitor the same amount of fishing effort (Kindt-Larsen *et al*., 2012; Michelin *et al*., 2018 Gilman *et al.*, 2019). However, costs will be dependent on the aims of the programme. In European waters, the reformed Common Fisheries Policy (CFP) came into force in January 2014 and outlined the new Landing Obligation, Article 15 of the Council Regulation 1380/2013 (EC, 2013). Within this and other UK Government consultation papers, it stated that REM equipment could be purchased using the European Maritime and Fisheries Fund (EMFF) to a maximum value of 90% of the equipment cost (Course, 2015) and this contribution greatly increases the affordability of the equipment to ASCOBANS Party members within the EU. If REM is used to monitor the Landing Obligation, there may be opportunity to use the collected sensor and video data to monitor for cetacean bycatch or other sensitive species. This would only require communication of the data, review software licences and video review staff costs because the hardware will already be purchased and installed. Alternatively, REM could become a part of the DCF monitoring programmes with a proportion of this funding allocated to REM. Or dedicated REM programmes to monitor sensitive species (or cetaceans only), could be established with separate dedicated funding. In addition to hardware purchase, other costs associated with REM include the installation and ongoing maintenance of the equipment, software licences, communication of the data to the analysts either by posting hard drives or sending data via mobile networks, data storage; data analysis and video review. Some of these will be dependent on the equipment supplier whilst others will be natio, and organisation specific. The level of video review undertaken will have the largest impact on costs. Most fish related projects tend to undertake a 10% random sample of fishing events and will review additional footage if required. Stanley *et al.* (2011), found this an appropriate review rate for the Canadian hook and line fishery, and this is often adopted for other REM projects. However, other video review rates may be more appropriate for different fisheries and different programme objectives. Reviewing video for cetacean bycatch events should be faster than reviewing it to identify and quantify fish discards because the events should be more obvious due to the size of the animals. However, species identification of a cetacean drop-out using REM may be more difficult than using an observer (due to possible light reflection, cetacean remaining below water surface, limited view due to camera angles) but anticipation of these events allows the cameras to be placed in a position that increases the chances of recording these events and identifying the species correctly, although may take longer than bycatch brought aboard. One way to improve efficiency may be to have the fishers self-report the cetacean interactions so that the analyst can go directly to the event. This requires a good level of engagement with stakeholders and there needs to be transparency about what the data will be used for, especially if participation may lead to detrimental management measures (e.g. temporary closure of a fishery). An element of random sampling in addition to this reported event may also be required to ensure that self-reporting is being undertaken accurately. If inconsistencies between data sets are detected, then review rates should be increased (even to 100%) and the industry should be informed of these differences. In the UK CQT, a scoring system was developed that evaluated the self-reported catch data provided by the skipper against the video review estimates as well as adherence to the Duty of Care rules of the programme. This worked well in improving the quality self-reported data (Roberts *et al.*, 2014).

Question	Observer Monitoring	REM
	Also, for most countries, obtaining this CV is unattainable due to the lack of observed bycatch in the fleets covered by the Regulation and to do so would be financially and logistically unfeasible (Read *et al.*, 2017). Regulation 1241/2019 is even less specific regarding monitoring levels.. STECF (2019) recommends rates of between 5 and 10% of fishing effort. So, estimating an overall programme cost is difficult for comparisons with other monitoring methods unless the programme objectives and coverage levels are the same. A case study approach is required that uses an estimated cost per day for monitoring and collecting cetacean bycatch data for that day, for each method being compared. To obtain this data, a data request for total cost and programme monitoring levels was sent to ASCOBANS party states (see Appendix 1). These observer programme costs are exploredfurther in this report and compared against REM costs.	So, the cost of analysis will greatly depend on how the programme is designed (e.g. review rates, vessel numbers), how well the cameras are installed to get the correct views, the reliability of the equipment, how willing the stakeholders (fishers) are to self-report incidents and maintain the equipment (if at all), and of course the size of the available budget as this will dictate actual video review rates. REM costs are explored further in this report with a comparison against observer monitoring costs.
Additionality: Does it have additional benefits over other methods?	Yes – Observer programmes do have potential additional benefits over the other monitoring methods discussed in this report. They offer an opportunity to collect additional biological data and physical samples from the catches because the observer is present. Exactly what additional data over counts of bycaught cetaceans are collected, will be determined by the programme objectives but may include overall length, sex, photographs of bycatch, biological samples for genetic and aging purposes. The observers can be used to obtain data on other sensitive species that are caught, and can log exact fishing effort deployed during a trip at location using either their own equipment or the vessel's navigational equipment. The observers may also be used to undertake watches for sightings of cetaceans further away from the vessel and fishing gear or undertake finfish	Yes – REM programmes do have potential benefits over other monitoring methods. The most obvious is related to staff safety and welfare (Course, 2017). Using REM as the monitoring tool removes the need to send an observer to sea on the vessel, unless of course physical biological sampling is required. Safety training and maintaining safety equipment can be expensive and needs to be undertaken at regular intervals. If REM replaces observers then the need for these is removed and will provide a cost saving (assuming the video review staff do not undertake other seagoing duties on other projects). Communication and project management time may also be reduced as there will be no need for frequent safety checking-in procedures with observers, or time spent trying to arrange sea trips on vessels and traveling to ports. This will also reduce travel and subsistence costs for the project. REM allows data to be collected and reviewed at a time suitable to the analyst and in a safer working environment, rather than at sea around the clock, and in all weathers. If a vessel is deemed too small to accommodate an observer or there are safety issues with the vessel or with the carrying of an observer, then REM may also be the only way that the data can be independently collected. For example, in the UK DCF monitoring programme if the vessel to be monitored is a single-handed vessel, i.e. one where there is only one crewman aboard who is also the skipper, then 2 observers must be sent. This is a safety precaution in case of a man overboard incident where it has been shown that it is almost impossible to lift an unconscious person from the sea back into the boat by oneself (pers. comm: J. Elson, 2019). This increases staff costs and also impacts on space on board the vessel. If vessels are unable to accommodate 3 people it may lead to exclusion of some vessels from the sampling population. Vessels <7m length have been excluded from the observer programme UK (English) DCF observer programme for this and safety reasons (pers. comm: J. Elson,

Question	Observer Monitoring	REM
	observer duties. Additional duties can be viewed as adding value for money, but care should be taken that observers do not become overburdened with additional duties that then distract from the primary programme objectives. This may lead to cetacean bycatch, escapee or drop-out events being missed which can then lead to an under-estimate of bycatch (ICES, 2019). Bravington & Bisack (1994) estimated that 58% of harbour porpoise entangled in the set gillnets drop out before they are brought aboard. Drop-out rates will vary depending on the study and gear used but it is important that they are included in bycatch estimates. If observers are not specifically monitoring the point at which the net is hauled to the surface and exits the water (e.g. because required to measure commercial fish species in a different location onboard), then these events could be missed. Observers can easily relocate to view different areas (compared to a camera) to witness bycatch events, but if these multiple locations are not easily accessible or visible simultaneously, then bycatch events could be missed.	2020). REM thus allows some fleet segments that may previously have been unable to be observed, to now be monitored. If an unexpected temporary staff shortage of shore-based video review analysts should occur (e.g. illness, resignation), the REM data can still be collected and stored until the analysts are available. But if an observer is unavailable the sampling opportunity may be lost unless temporary qualified staff can be found at such short notice. The recent coronavirus pandemic has led to all observer monitoring programmes being suspended (probably worldwide) to protect staff, fishers and their families. In most EU countries fishers were regarded as essential workers and fishing continued in areas where marketing the fish was still possible. If REM had been installed on vessels, the sensor and video data would continue to have been collected and could have been reviewed ashore at a later date. Temporary new working arrangements for hard drive swapping, home working and review licence sharing, may have been required but monitoring would have continued on active vessels. If review staff were unavailable, then the data could have been stored until a return to work occurred. More fishing effort can be monitored because the sensors and cameras are collecting data for 100% of the fishing activities carried out on all the sea trips undertaken by the vessel, rather than just the observed trip. This allows the effort data to be accurately and independently collected without relying on self-declarations of effort from fishers or their onboard navigation systems. The sensor and GPS data are inexpensive to transmit by mobile phone or satellite networks, so it can be viewed and used in near real time, which can then allow live tracking of vessels to enable better fleet and effort management. If REM data are able to be used in timely, science-based management decisions, then the coarse management instruments such as large-scale closures for ETP interactions can be replaced with more dynamic adaptive solutions based on granular information (e.g., catch per unit effort (CPUE), seasonality, ETP interactions, near-real-time information on ETP bycatch hotspots) (Michelin *et al.*, 2018). If this is coupled with reliable self-reporting (verified using video review), it may be useful in bycatch avoidance, in a similar way to the Cefas Spurdog By-Catch Avoidance Programme (Hetherington *et al.*, 2016). The sensor data and video footage can be used as evidence by both the monitoring programme coordinators and by the fishers. Fishers can use the data to demonstrate good practice and low bycatch rates to obtain accreditation and potentially improved prices and new markets. They can also demonstrate where they have historically fished by building up a track record for use in displacement compensation claims caused by offshore developments. Fishers may also be permitted to double check their data so that any disputes between fishers, scientists and fishery managers can be resolved through increased transparency. Allowing fishers access to their own data may also allow increased access to markets that may otherwise be closed without evidence of effective monitoring and mitigation (e.g. the USA and its requirement for importers to be held to the same standards as US commercial fishing operations under the US Marine Mammal Protection Act (MMPA) Import Provisions Rule). The presence of the REM equipment encourages compliant or positive behaviour on a long-term basis and not just for the duration of a trip. If one considers road speed cameras and a driver prone to exceeding the speed limit: when there is a long stretch of road monitored by averaging speed cameras, the driver is inclined to be compliant for the full extent of the covered road. However, if the camera is just a static (or even mobile) single unit, the driver becomes aware of the

Question	Observer Monitoring	REM
		device, slows down to pass the unit and then returns to the higher speed. If it is mandatory (or part of an accreditation scheme) to report cetacean bycatch and protected species interactions, installing REM and regular checking of the declared events and random sections of additional footage can create permanent long-term compliant or responsible behaviour, leading to more reliable and accurate self-reporting of incidental bycatch events. This in turn leads to more efficient video review as the analyst is directed to the times of interest by the self-reporting, although review of some of the remaining video is recommended to ensure reliable reporting continues and to help detect accidentally missed events.
Stakeholder engagement: Are the stakeholders accepting of the method and engaged with the monitoring programme?	Generally – Stakeholder engagement in the case of observer programmes mainly relates to fishers who are approached to accommodate an observer. Acceptance of at-sea observers varies greatly between countries, fisheries, years, seasons and projects and this can often depend on the project's objectives, the longevity of the project, and the potential uses and sensitivity of the collected data. It also depends on whether access to the vessel is on a voluntary or mandatory basis, or if incentives have been provided to accommodate an observer. There has often been an assumption that data collected during observer programmes are confidential, but this is not the case, as any data can be subpoenaed if required by a court of law. It may be treated as commercially sensitive and therefore aggregated or anonymised during analyses and publication, but if an infringement is suspected then the data can usually be demanded. This should be clearly communicated to fishers before the observer sails along with how the data are to be used. In England, Cefas require skippers to sign a letter that details why the data are being collected and how it could be used. Regarding confidentiality, the letter states "Information obtained about the activities of fishermen, either from fishermen themselves, or by Cefas staff in the course of their duties,	Variable – The use of REM as a bycatch monitoring tool is relatively new and stakeholder acceptance of the method varies between country and fishery. In countries where it is already used as a mandatory compliance monitoring tool, the use of it to monitor cetacean and sensitive species bycatch is accepted as a part of the fisheries management regulations. However, in areas where no such compliance use exists, there is understandably more suspicion and reluctance to accept REM. Stakeholder engagement of any new voluntary monitoring technique is essential to its success. If the tool is a mandatory measure then this reliance on stakeholder acceptance is lessened, but still preferred otherwise there can be a resistance to the measure and the potential for intentional disruption. Stakeholders can include fishery enforcement agencies, scientists, fishers, fish retailers/processors, and policy makers. Scientists and policy makers need to be assured that the data collected are reliable and usable in any assessments or management decisions made. Fishery enforcement officers need to know that the data have been collected securely and accurately, and that there is a clear chain of custody, if the REM has been installed for compliance purposes. The processors and retailers of fish products want to know how using the technique can improve (or maintain) market access and prices. Fishers need to know that accepting this monitoring (if voluntary) will not leave them at a competitive disadvantage to other fishers. Considering REM specifically to monitor cetacean (and sensitive species) bycatch for scientific purposes on a voluntary basis, requires scientists and policy makers to accept that REM is a valid cost-effective monitoring tool. Retailers and processors can support the tool and try to add their political weight to adoption of REM, but most importantly, fishers need to agree that REM can be used aboard their vessels. Trials have been undertaken using REM and have demonstrated that on small scale scientific projects, REM has been welcomed (or at least accepted). Participation is usually incentivised through such things as extra days at sea, money or additional quota. Whether this acceptance of REM would continue on a voluntary basis for a large-scale bycatch monitoring programme remains to be seen. If using REM is perceived as a threat to a fisher's livelihood, then it is understandable that there would be some reluctance to participate. So, transparency and careful communication of the aims of the monitoring programme and how the data will be stored and used are essential. Of course, this requires scientific and policy maker support in the first place. In fisheries where a stock is targeted by more than one country, fishers may be concerned that taking REM would lead to an unlevel economic playing field if the data collected could be used to reduce fishing opportunities. So, it is important not to confuse the aims of the programme, and detail exactly who will be able to access REM data and how they can be used. As with observer programmes, confidentiality cannot be assured, but "understandings" may be able to be established.

Question	Observer Monitoring	REM
	will be retained and used for scientific purposes only, except that such information may be released to other bodies if it is necessary for the investigation or prosecution of persons, or for any other purpose required by law". The absence of confidentiality may lead to poor stakeholder engagement, which in turn could lead to a refusal to accept observers onboard on a voluntary basis and therefore seriously curtail a monitoring programme and bias the data. However, observers can only be refused on the grounds of safety and space and member states should ensure that other monitoring methods are used if this persists (EU Reg. 2007/1004) and therefore European fisheries monitoring programmes could be classed as mandatory. Enforcing this, though, may make fishers less inclined to cooperate and may place the observer in a difficult position when they are a guest aboard the boat.	All of these concerns are valid and should be discussed with stakeholders during the design of any monitoring programme (REM or Observer), but especially for a REM programme because of its effectiveness at capturing data for all sea trips and not just on a small percentage when an observer is aboard. Retailers and processors can encourage the acceptance of REM by only buying and using fish from fishers or fisheries that can prove it has been responsibly caught and that ETP bycatch has not been beyond any agreed bycatch limits. Policy makers could make it mandatory to carry and maintain REM systems on board all vessels in certain high-risk fisheries, which would create the level playing field, allow verification of self-reported data and help remove the distrust between fishers, scientists and managers. Linking REM to an accreditation scheme may improve returns on the catch and potentially lead to new market opportunities. Incentives related to carrying REM for cetacean bycatch monitoring purposes only could include additional target catch quota allocation, inconvenience payments, access to previously excluded waters, or it could be a requirement of the fishing licence. The right to fish is a strong incentive but changes the carrying of REM from voluntary to mandatory and although this will enable equality across the fleet, it may also lead to resentment. On the other hand, a voluntary programme with high levels of engagement and commitment from the fishers can make REM programmes more cost efficient if fishers are willing to undertake some of the tasks, e.g. posting hard drives back to programme managers, feedback where improvements to the programme or camera positioning could be made, or self-report bycatch incidents to speed up video analysis.

Case Study Fisheries

The different monitoring options have been considered in isolation, and only at-sea observers and REM have been shown to allow cetacean bycatch events to be effectively monitored to species level at sea. We have briefly discussed these two monitoring options and how they meet monitoring requirements, and we have undertaken an initial discussion of how they compare to each other as monitoring tools. This can be expanded by taking case studies and using detailed costs for suppliers of equipment and national monitoring programmes to further investigate the best options for long term monitoring of cetacean bycatch.

Observer Programmes and Costs in European Waters

There are several different observer programmes operating in European waters. The Data Collection Framework (DCF) programme (under the Common Fisheries Policy) is coordinated across the European partners and is primarily focused on quantifying discarded fish from commercial fishing vessels. However, most countries also instruct their fisheries observers to collect data for bycatch of ETP species, including small cetaceans. In addition to this, countries (currently only the UK) can also undertake observer programmes specifically designed to quantify cetacean and other sensitive species bycatch, by targeting their sampling effort to the metiers where ETP bycatch is considered highest risk, but with additional data also collected from lower risk fisheries to allow fuller assessments to be made. There is very little point in wasting limited resources undertaking sampling on vessels where the known ETP bycatch rates (through experience, self-reporting and other research programmes) are extremely low or nearly zero.

Relative to human observers, REM programs are typically lower cost, and this advantage will only expand with technology advancements (Michelin *et al.*, 2018). Extensive training of the observers in personal safety at sea, monitoring and sampling techniques, and species identification (often of several hundred species) are required. It can often take months for an observer to be trained to a level where it is deemed acceptable for them to sample at sea unaccompanied. Fishers are required to undertake seagoing medical examinations and specific survival training courses as part of their legal requirement, so that should an emergency occur they are trained to deal with the situation. Observers should also be trained to the same standards as the crew regarding safety so that they have the knowledge and capacity to work with the crew and help alleviate the situation. However, the observer faces the added danger of little or no experience of the actual vessel or crew being sampled. So, training should include how to familiarise oneself onboard a new vessel and how to undertake dynamic risk assessments of the work areas. It should also be noted that for every day spent training an observer at sea, a fully trained observer is needed to accompany the trainee until such time as they are certified for solo sampling. This safety training and the medical examination also require renewal on a routine basis e.g. personal survival techniques should be refreshed every 5 years.

Observers need to be provided with suitable personal protective equipment (PPE), sampling equipment and other safety equipment. This can include lifejackets, wet weather gear (e.g. oilskins and boots), personal EPIRBs (emergency position-indicating radio beacons) and flares, communication equipment, and any other safety apparatus thought necessary. This equipment is not cheap, and some need routine servicing (e.g. lifejackets must be serviced annually), which adds additional costs and management overheads. Sampling equipment will depend very much on the focus of the study, for example for shellfish sampling, observers need accurate calibrated callipers; for fish sampling, suitable measuring boards or tapes are required; biological tissue or aging samples (otoliths or scales) require extraction and storage equipment; and for cetacean sampling, measuring tapes, biological sampling kits, body bags and anti-bacterial cleaning products to avoid contamination and infections of observers, may be needed.

Although metiers may be pre-determined, monitoring programmes often choose each individual vessel for sampling through a random selection process. This is to avoid sampling bias which may be introduced by observers only selecting certain vessels or type of trip, e.g. comfortable vessels, friendly crews, or shorter trips, or because only vessels that intend to operate in a manner that is fully compliant with current fisheries regulations agree to take an observer. Often fishing fleets can be widely dispersed geographically, or operating at considerable distance from the observer's office, so programme managers must ensure there is sufficient travel and subsistence (T&S) budget available to allow observers to travel to the randomly selected vessels and meet the sampling targets. Additional budget should also be set aside for meetings and presenting results to scientists, fishers and stakeholders.

If vessels are not required to accommodate an observer as part of their licence, and participation in the programme is voluntary, then it may lead to high refusal rates which will limit the sampling population to the vessels willing to take an observer. This can add bias to the collected data if the sampled vessels are not representative of the unsampled vessels (deployment bias). Having high refusal rates can also cost considerable staff time trying to arrange a sampling trip, make alternative arrangements, and track the refusals. More time is then required at a management level trying to engage the fishers and explain why sampling is needed.

In addition to the observer staff time, a dedicated manager/scientist will be needed for any national observer programme. There is the need to manage the programme, supervise the observers, monitor and maintain health and safety, manage the budgets, analyse the data, produce reports and scientific papers, and present the results at working groups and conferences. Of course, this will also apply to REM programmes. But usually the budgets provided by the observer programmes include all costs for the programme as a total cost, so when comparing the Observer costs with the REM costs, a managerial/scientist post should be included in the REM budget.

It is not necessary to split the overall budgets down into the different cost allocations or activities. The overall total budgets can be divided by the number of days sampled to get an average cost per sea-day sampled for the different gears and different countries. Tables 7, 8 and 9 show the cost data for the marine mammal observer programmes, the levels of sampling achieved, and the number of cetaceans encountered, for 2016, 2017 and 2018, for ASCOBANS Parties (those who were able to provide data). These data can be used to make comparisons between the coverage levels and the costs associated with REM programmes and traditional at-sea observer programmes. These data were supplied in response to a direct request for information (Appendix 1). Where it was not possible for countries to supply the data, they were sourced from published reports and other sources. Where this is the case, all sources are referenced.

The following Parties were able to provide full data sets: Poland and Belgium. The UK provided links to national annual reports that allowed the information to be interpreted and included. Finland reported that they had no cetacean or at-sea monitoring programmes, after 2016. France provided cost and effort data for a separate pelagic trawl bycatch monitoring project that was carried out in 2018/19. No other countries provided data through the specific request and so data were interpreted from the most recent ICES WGBYC reports, and reports to the EU through the Data Collection Framework (DCF). Data reported through the WGBYC are 2 years behind the publication date, i.e. the ICES WGBYC 2018 reports the 2016 observer data, etc. The DCF data are reported 1 year after they were collected ,i.e. DCF 2017 covers the 2016 observed data, etc. The UK data came from separate national reports available online at the Defra portal and are referenced under the main author, S. Northridge.

It should be noted that the DCF data from the national data sets required considerable interpretation due to the way in which the data were reported. In 2016, the Tables IIIC3 from the nationally submitted data sets were used to obtain fleet effort data and sampled days at sea data, by using the information recorded in the "Total No. of fishing trips during the Sampling year" and the "Achieved no. of sampled fishing trips at sea" data columns, respectively, and only including those sampling events that were described as "at-sea" in the column called "Sampling Frame Codes". The numbers of cetaceans caught came from the IIIC6 tables. From 2017 onwards the table formats changed and Tables 4a and 4c were used to obtain fishing effort (column "Number of fishing trips in the stratum") and sampling effort (column "Number of fishing trips sampled"), whilst table 1F was used to obtain numbers of cetacean bycatch (DCF, 2017; DCF, 2018; DCF, 2019).

There is an important distinction between the effort data used and presented in Tables 7, 8 and 9. The DCF data sources include fishing effort and sampling effort from ALL fishing gears and metiers and not just those where it is expected that cetaceans may be caught. The WGBYC data, on the other hand, only include the fishing and sampling effort from the gear types expected to catch cetaceans or where specific ETP monitoring occurs.

To obtain information on the percentage of fishing effort monitored and the cost of at-sea observer programmes, a request was sent to each country's programme manager for the total fleet fishing effort, observed effort, cost and cetacean bycatch rate data. The initial response was low due to the timing of the request coinciding with end of year reports and meetings. The request was repeated but unfortunately only Poland and Belgium supplied the data as requested. In addition, the UK provided links to national data reports that allowed their information to be used. This data is provided in Tables 7, 8 and 9.

Some countries responded that this information was available in the reports from the annual ICES Working Group on Bycatch and in the Data Collection Regulation annual reports. These data were investigated and have also been included in Tables 7, 8 and 9, but in several cases it was found to be incomplete, that it did not match data from the other sources, and that no cost information was included. In addition, the ICES WGBYC 2020 data for 2018 observer programmes was not available at the time of writing. Some countries also failed to report their data to ICES WGBYC (e.g. Germany, Lithuania) or to the DCF (e.g. France), or did not carry out any observer programmes (e.g. Finland). It was also noted that the DCF tables mostly had effort data recorded as fishing trips whilst ICES WGBYC monitoring data were in days at sea. STECF (2019) point out that "dependency on cetacean bycatch data collection through non-dedicated observers deployed through the DCF will not be adequate for robust estimation of cetacean bycatch rates" and they suggest that REM offers the greatest potential for monitoring ETP species bycatch under the DCF and on vessels <15m length.

The differences in data presentation and the lack of cost data have made comparing the monitoring programmes between the different countries extremely difficult, and it has proved impossible to obtain any ASCOBANS combined full data set. Ideally, all countries would have

Table 7. At-sea observer monitoring programme costs, sampling effort and fleet fishing effort, for the ASCOBANS Parties in 2016.

Party Member	Data Source	Monitoring Effort with an Observer Onboard	Fishing Effort by Fleet	Sampling Percentage	Number of Cetacean Bycatch Observed	Total Cost (€)	Cost per observed day (€)
Poland	As Requested	102 days	9,290 days	1.1	0	39,720	389
	DCF 20171	93 trips	71,601 trips	0.1	0	NA	NA
	WGBYC 20182	102 days	9,290 days	1.1	0	NA	NA
Belgium	As Requested	78 days	9,671 days	0.8	0	1,182,129	15,156
	DCF 2017	43 trips	3,772 trips	1.1	0	NA	NA
	WGBYC 2018	NA	NA	NA	NA	NA	NA
UK	Defra Reports[3]	374 days	36,087 days	1	14	321,1296	859
	DCF 2017	835 trips	185,878 trips	0.4	0	NA	NA
	WGBYC 2018	374 days	NA	NA	14	NA	NA
Denmark	DCF 2017	141 trips	103,897 trips	0.1	2	NA	NA
	WGBYC 2018	39 days	751 days	5.2	2	NA	NA
Finland	DCF 2017	221 days	111,432 days	0.2	0	NA	NA
	WGBYC 2018	NA	NA	NA	NA	NA	NA
France	DCF 2017	NA	NA	NA	NA	NA	NA
	WGBYC 2018	933 days	NA	NA	41	NA	NA
Germany	DCF 2017	96 trips	29,742 trips	0.3	0	NA	NA
	WGBYC 2018	NA	NA	NA	18	NA	NA
Lithuania	DCF 2017	15 trips	1,162 trips	1.3	0	NA	NA
	WGBYC 2018	NA	NA	NA	NA	NA	NA
Netherlands	DCF 2017	46 trips	17,456 trips	0.3	0	NA	NA
	WGBYC 2018	117 days	1138 days	10.3	0	NA	NA
Sweden	DCF 2017	313 trips	58,912 trips	0.5	0	NA	NA
	WGBYC 2018	93 trips	22,205 trips	0.4	0	NA	NA

NA is "Not Available/Not Supplied"

Table 8. At-sea observer monitoring programme costs, sampling effort and fleet fishing effort, for the ASCOBANS Parties in 2017.

Party Member	Data Source	Monitoring Effort with an Observer Onboard	Fishing Effort by Fleet	Sampling Percentage	Number of Cetacean Bycatch Observed	Total Cost (€)	Cost per observed day (€)
Poland	As Requested	50 days	9,209 days	0.5	0	18,925	379
	DCF 2018[7]	152 trips	35,774 trips	0.4	0	NA	NA
	WGBYC 2019[8]	76 days	NA	NA	0	NA	NA
Belgium	As Requested	72 days	8,839 days	0.8	0	1,281,503	17,799
	DCF 2018	31 trips	4,452 trips	0.7	0	NA	NA
	WGBYC 2019	NA	NA	NA	NA	NA	NA
UK	Defra Reports[4]	331 days	27,426 days	1.2	8	321,1296	970
	DCF 2018	452 trips	204,781trips	0.2	4	NA	NA
	WGBYC 2019	331 days	NA	NA	8	NA	NA
Denmark	DCF 2018	243 trips	63,359 trips	0.4	1	NA	NA
	WGBYC 2019	34 days	5375 days	0.6	1	NA	NA
Finland	DCF 2018	No sampling	NA	NA	NA	NA	NA
	WGBYC 2019	No sampling	NA	NA	NA	NA	NA
France	DCF 2018	No report	NA	NA	NA	NA	NA
	WGBYC 2019	855 days	NA	NA	80	NA	NA
Germany	DCF 2018	162 trips	31,638 trips	0.5	0	NA	NA
	WGBYC 2019	No report	NA	NA	NA	NA	NA
Lithuania	DCF 2018	25 trips	4203 trips	0.6	0	NA	NA
	WGBYC 2019	No report	NA	NA	NA	NA	NA
Netherlands	DCF 2018	28 trips	11,286 trips	0.2	0	NA	NA
	WGBYC 2019	150 days	1164	12.9	0	NA	NA
Sweden	DCF 2018	154 trips	60,845 trips	0.3	0	NA	NA
	WGBYC 2019	143 days	32,845 days	0.4	0	NA	NA

NA is “Not Available/Not Supplied”

Table 9. At-sea observer monitoring programme costs, sampling effort and fleet fishing effort, for the ASCOBANS Parties in 2018.

Party Member	Data Source	Monitoring Effort with an Observer Onboard	Fishing Effort by Fleet	Sampling Percentage	Number of Cetacean Bycatch Observed	Total Cost (€)	Cost per observed day (€)
Poland	As Requested	65 days	8,848 days	0.7	0	16,121	248
	DCF 2019[9]	78 trips	29,289 trips	0.3	0	NA	NA
Belgium	As Requested	51 days	8,548 days	0.6	0	1,325,331	25,987
	DCF 2019	24 trips	4,491 trips	0.5	NA	NA	NA
UK	Defra Reports[5]	339 days	29,659 days	1	4	284,7766	840
	DCF 2019	442 trips	192,879 trips	0.2	2	NA	NA
Denmark	DCF 2019	137 trips	64,228 trips	0.2	NA	NA	NA
Finland	DCF 2019	No sampling				NA	NA
France	DCF 2019	743 trips	119,605 trips	0.6	0	NA	NA
	WGBYC 2020	867 trips	NA	NA	24	NA	NA
Germany	DCF 2019	1211 trips	36,134 trips	0.3	0	NA	NA
Lithuania	DCF 2019	25 trips	551 trips	4.5	NA	NA	NA
Netherlands	DCF 2019	30 trips	18,789 trips	0-.2	0	NA	NA
Sweden	DCF 2019	210 trips	58,980 trips	0.4	0	NA	NA

NA is “Not Available/Not Supplied”

Data sources for Tables 7, 8 and 9:

1. DCF, 2017.
2. WGBYC 2018 (ICES, 2018b).
3. Northridge et al. (2017).
4. Northridge et al. (2018).
5. Northridge et al. (2019), costs converted to Euros using €1.1694: £1.
6. Read et al. (2017), costs converted to Euros using €1.1694: £1.
7. DCF, 2018.
8. WGBYC 2019 (ICES, 2019).
9. DCF, 2019

provided the data as requested to avoid these issues and perhaps the cost data could be made available through the EU and accessible for use, and for monitored and fishing effort data to be provided in both Trip and Days at Sea format. The data have been presented as derived from the named data sources and no attempts have been made to address anomalies, such as why some countries have reported different levels of fleet effort between the different reporting processes. It is presented as information only. It is thought that the total fleet effort data provided to WGBYC is only for those metiers where cetacean bycatch monitoring was undertaken. The DCF data tables include all metiers where fishing occurred whether they were sampled by observers at sea or not, and not just those metiers likely to encounter cetacean bycatch. The difference in how data were submitted to the DCF between 2016 and 2017 was also noted and this seems to have impacted on the quality and usefulness of the data, as very little quantitative data on bycatch were submitted, a situation also highlighted by ICES WGBYC (2019) and STECF (2019).

Using the information provided it can be seen that there is a wide span of costs associated with at-sea observer programmes between each country (see Tables 7, 8 and 9). Poland has a low cost per day of €248 in 2018, whereas the cost per observed sea day for Belgium is nearly 100 times higher at €25,987 in the same year. This large difference may be down to how each country undertakes its monitoring programme, the different legal requirements of employment between countries, or how a programme manager has calculated the days at sea (e.g. Belgium took the total fishing hours observed and fished by the fleet and divided each by 24 hours, to convert hours into days). Where a dedicated cetacean or ETP programme exists, the costs will primarily be made up of the actual sea-days dedicated to this task and the metiers likely to encounter cetaceans, e.g. gillnets and pelagic trawlers. It also means that cetacean bycatch numbers will only be raised by the effort associated with the fishing activities likely to encounter bycatch, rather than effort associated with non-relevant fishing activity. Other countries, however, may have to rely on the large national DCF programme and all its associated costs of monitoring metiers where there is unlikely to be any marine mammal bycatch (because the DCF focus is mainly on fish stocks).

The levels of bycatch recorded during these observer trips is also low with most countries reporting zero catches of cetaceans for all 3 years (e.g. Poland, Belgium) whilst others reported consistently high bycatch numbers (e.g. France reported 41 cetaceans in 2016 and 80 in 2017; and the UK reported 14 cetaceans in 2016, 8 in 2017, and 4 in 2018). Differences in the numbers reported could be due to a number of reasons. It may be that monitoring levels vary between countries, that the fishing gears being monitored don't encounter cetaceans at the time and place where they were monitored, or it could be that they never encounter cetacean bycatch irrespective of area, time or even gear. Observers may have also missed bycatch incidents due to a number of reasons that are discussed later. Countries with low or zero reported bycatch will be excluded from case studies even though bycatch could be high in some of those instances. Due to the lack of cost data available, only those countries that have provided cost data as requested or an alternative referenceable source, can be used in any case studies or discussions on costs in this report.

REM Equipment and Costs

The costs associated with a REM cetacean monitoring programme include:

- System hardware purchase/lease costs
- Installation costs
- Maintenance and servicing costs
- Data storage and communication costs
- Review software licencing costs
- Video analyst labour costs
- Staff training and safety costs
- Project management cost e.g. overheads, data analysis and reporting, attendance at meetings, staff management

REM System Hardware

The REM hardware costs are often perceived as high initially because the systems have to be purchased at the outset of any monitoring programme. But it needs to be remembered that the systems can remain deployed on vessels for several years and that this cost should be spread over the lifetime of the equipment (approximately 5 years). Alternatively, the systems could be leased so that payments are spread evenly over the programme lifespan. Leasing is generally a more expensive option to the programme overall than purchasing the equipment outright, as the leasing company must build in potential failure rates into the price and have the equipment totally paid for over a short time frame. However, a lease does usually come with the benefits of unlimited support and the opportunity to upgrade relatively easily if a newer model becomes available (Costowl.com, 2019). Not all suppliers of hardware offered a lease option so for the purposes of this report we will assume that the programme manager has opted to purchase the equipment outright and that the lifespan of the equipment is 5 years.

The main current suppliers of REM equipment and associated services were contacted (Appendix 2) and most provided details of their products and associated costs. These systems were different between the suppliers, and offered different features and functions that could not always be compared. For example, the number, quality and capability of cameras being offered can be different, or the types of activity sensors included in the price can vary. Suppliers who did not supply REM hardware but only associated project support services, e.g. video review or technical support, were excluded from this exercise. Also, some suppliers had different systems which are specifically tailored towards different

Figure 2. CCTV cameras installed on a small inshore commercial fishing vessel.

industry sectors e.g. large industrial fisheries or small inshore vessels. Therefore, to ensure fairness to the suppliers and for completeness, the systems were split into two categories (small inshore or offshore industrial) and an average system configuration was used. All suppliers and costs have been anonymised and averaged across all suppliers to create an average cost for an average system, for illustrative purposes.

The average generic system used in this report was based on the need to monitor cetacean bycatch on both large and small vessels.

On a larger offshore or industrial vessel (>15m) the system consists of:

- 4 x IP67 (see Appendix 3 for IP ratings definitions) rated digital cameras (Figure 2)
- At least one fishing activity sensor e.g. a winch rotation sensor (Figure 3), hydraulic pressure sensor (Figure 4)
- An independent GPS
- A user interface consisting of keyboard, screen and mouse (or roller ball integrated into the keyboard)
- The control box that houses the software and stores the data

This was the minimum specification judged necessary to view all locations on a larger vessel greater than 15m overall length, where potential cetacean interaction events may occur. On a smaller inshore vessel (less than 15m), the specification remained the same except that only two cameras were thought the minimum necessary to adequately monitor the potential interaction locations onboard. Obviously if the systems are installed to try and undertake other tasks, such as detect and quantify illegal fish discarding or bird warp strikes (i.e. when birds accidentally fly into the trawl towing wires), then the system will need more cameras for monitoring the appropriate locations associated with these events and potentially different types of sensors e.g. RFID tags and readers for creel or static net fisheries. But for the purposes of this report, only cetacean bycatch is the targeted subject of the monitoring programme.

Of the 14 REM related suppliers of equipment and related services approached, only one was unable to provide information by the provided deadline. There were five suppliers that only provide the installation and video analyst services associated with REM programmes, or seagoing observers to complement REM programmes and so these were removed from this costing exercise. A further two suppliers only supplied electronic equipment that comprised electronic catch reporting and/or electronic tracking but because these systems do not include video cameras, they are therefore unable to collect imagery for identifying and quantifying cetacean bycatch and so also were excluded from this costing exercise. The remaining six suppliers provided full cost details for their hardware products that could be included within this report. These suppliers were Anchorlab, Archipelago Marine Research, Marine Instruments, Saltwater, Satlink, and TeemFish/SnapIt (currently working together to provide REM solutions).

Not all suppliers were able to provide details of installation costs and therefore an average cost was calculated for both the inshore and offshore systems, from the estimates provided by those that could. Where no costs for a specification were supplied, the estimates published by the European Fisheries Control Agency were used (EFCA, 2019).
As some suppliers were based in the USA and Canada, all

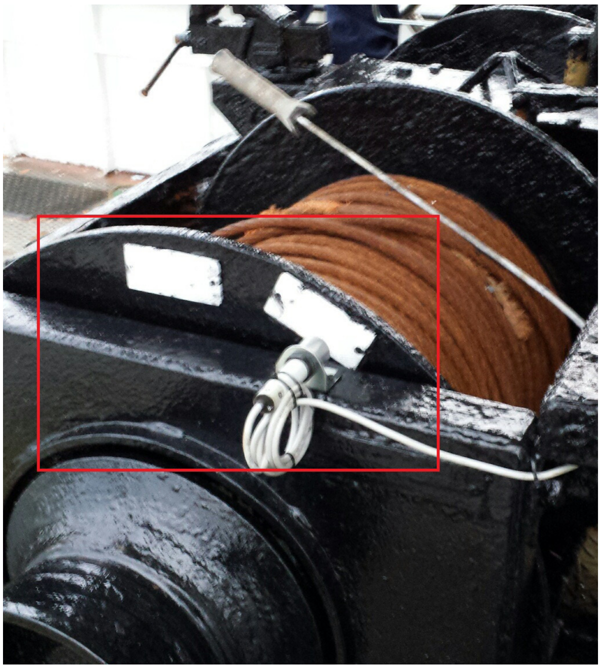

Figure 3. A winch rotation sensor for detecting fishing activities, installed on an inshore trawler.

Figure 4. A hydraulic pressure sensor installed on a fishing vessel, to detect hauling activities.

costs were converted to Euros using online conversion rates (Source www.xe.com, accessed 25/11/19). This was also used for converting any costs from British pounds. Table 10 shows the initial first year hardware purchase and installation costs as supplied by hardware providers. There is a wide price range for both the inshore 2-camera system and the offshore 4-camera system. Some of this can be explained because some suppliers have only one system available and have therefore used the same system to provide prices for both the inshore and offshore systems, with the only difference being the two additional cameras needed in the offshore system. Other suppliers have two different dedicated systems for small or large vessels and therefore there are quite wide differences between the prices for offshore or inshore systems. Also, it is worth noting that during this consultation process, several of the providers revealed that they are developing even smaller, simpler and cheaper units specifically for small inshore vessels and artisanal fisheries. If successful, these will lower the average price of an inshore system in the future. Where a software licence is compulsory for each installed vessel, it is not possible to run the system at sea without it and therefore this cost must be included as a "hardware purchase" cost. Annual licences must also be multiplied by 5 to account for the assumed 5-year lifespan of the system. This can then be divided by 5 later when working out the annual cost of the system over the system's lifetime.

In addition to hardware and installation costs, there are further hardware supplier costs associated with REM. These are not uniform across all suppliers and are therefore difficult to use when calculating an average REM hardware cost. For example, some suppliers charge a software user licence for every vessel that installs the equipment, some include the 1st year of this licence free but charge in subsequent years, some include the shipboard licence in their hardware costs, and others have developed or used software that is open source. Some of the suppliers approached also include free technical support for the first year whilst others charge for this service and some suppliers charged for monthly health checks (often via satellite communication systems), annual maintenance and servicing, whilst others did not offer this service beyond the first year. An estimate of ongoing system running costs has been estimated based on the limited information provided. Table 11 shows these additional annual running costs over the 5-year average equipment lifetime.

In addition, certain assumptions were made when calculating the costs in Tables 10 and 11, where suppliers had been unable to provide an estimate, or where costs were an average of those provided by other suppliers. These are listed below:

- Supplier 2's video review software licence fee was for up to 5 users to use on separate computers under the same licence, so the individual licence cost of €13,500 was divided by 5 people to equal €2,700 per user.
- Where suppliers did not provide a maintenance and servicing cost, the maintenance costs quoted by the European Fisheries Control Agency (EFCA, 2019) were used. A range of €400-1000 was published, so

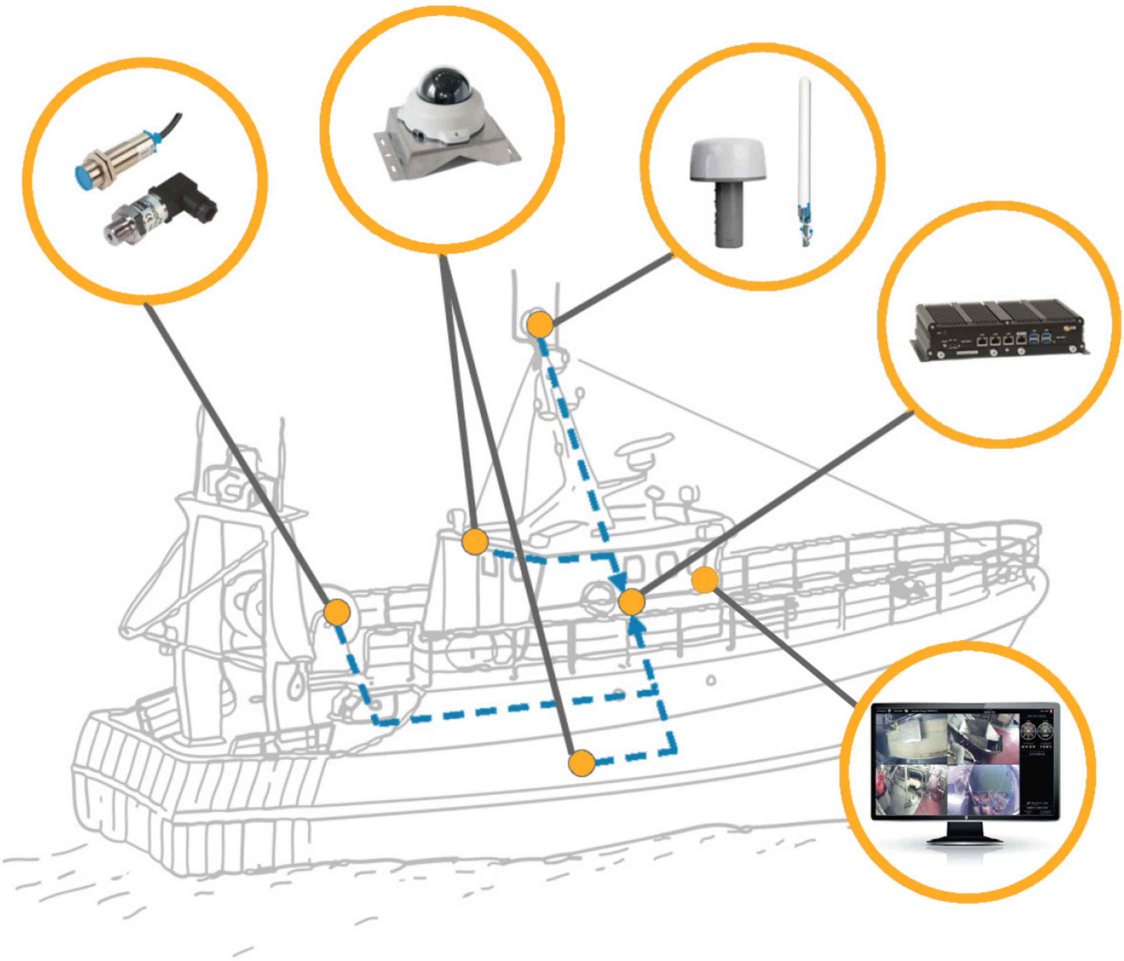

Figure 5. A diagram of a fishing vessel installed with a full electronic monitoring system (courtesy of Anchorlab, 2019).

the midpoint value of €700 was used.

- A lifespan of 5 years was assumed for all systems and additional hardware.
- All REM hardware system costs include the fishing activity sensors, GPS sensors and any cabling deemed appropriate for most 12 to 30m vessels.
- REM installation costs (Table 10) were provided by most REM suppliers, but where missing, an average cost was calculated using the data provided by other suppliers.
- One suppler (Supplier 3) was unable to provide a cost estimate for the video review software licence, so an average was calculated from the data provided by other suppliers (€2,510).
- Review software costs for Supplier 4 were free of charge through Open Source software
- Swapping hard drives and associated postage costs were estimated at €10/month.
- Each vessel requires two additional storage devices in the first year, at an estimated cost of €50 each (total of €100). The collected data can be downloaded, and the hard drives can be cleaned and redeployed to vessels after analysis is completed. The expected lifetime of these hard drives is 5 years and therefore the annual cost is €20/year.
- Remote sensor data transfer and comms assumed to be approximately €15/month, whether by satellite (EFCA, 2019) or by mobile telephone data using a sim card.

Once data have been collected by the REM system, it is possible to send the sensor and positional data via 3G/4G, satellite or WIFI to the analyst's database. However, the video data files are often very large and sending these through mobile communications is usually expensive. Also, one should question the need for having these video data available in near real time. If the footage is for compliance purposes, then there is no reason why the stored video data cannot be reviewed later, and any enforcement action carried out retrospectively based on the stored evidence. If the system is being used solely for cetacean bycatch monitoring, then the quicker it can be reviewed the more useful it will be in managing a fleet to avoid bycatch; even so it may not necessarily be needed in near real time. If the data are only to be used for quantifying cetacean bycatch rather than managing the fleet, then it can also be reviewed at a later date and there may be no need to

Table 10. Costs associated with purchasing and installing the REM equipment, as provided by REM suppliers.

REM System	Price Range (Euros)	Average Price (Euros)	Installation Cost Range (Euros)	Average Installation Cost (Euros)	Total Average Cost (Euros)
Inshore 2 Camera System Cost (Euros)	3745 to 10580	7077	817 to 1365	1091	8168
Offshore 4 Camera System Cost (Euros)	4485 to 12286	8810	1365 to 2724	2044	10854

**Note that where a mandatory individual vessel licence is required, these have been rolled into the hardware costs.*

Table 11. Additional costs (€) associated with running a REM monitoring system and reviewing the video and data collected. Some costs are annual whilst others must be spread over the lifetime of the equipment e.g. additional hard drives.

Item/ Service	Supplier 1 (€)	Supplier 2 (€)	Supplier 3 (€)	Supplier 4 (€)	Supplier 5 (€)	Supplier 6 (€)	Average Annual Cost (€)
Monthly Health Check Annual Total	0	0	1362	0	2400	600	727
Video Review Licence Per Year Per Review Analyst	3754	2700	2510	0	2100	3995	2510
Annual Service and Maintenance (EFCA, 2019)	700	700	700	700	700	700	700
Remote Sensor Data Transfer Sim Card Cost at €15/month, or by satellite (EFCA, 2019)	180	180	180	180	180	180	180
Two Additional Hard Drives at €50 each (€20/yr over 5-year lifetime)	20	20	20	20	20	20	20
Hard Drive Swapping by Collection or Courier at €10/month (€120/yr)	120	120	120	120	120	120	120
Total Annual Running Cost Including Video Review Licence	4774	3720	4892	1020	5520	5615	4257

send the video files in near real time and regular (e.g. monthly) hard drive swapping may be adequate. This will also help to keep costs down. From data provided by suppliers it has not been possible to provide exact costs for the activity sensor and positional data transfer, but previous studies have found this to be minimal. EFCA (2019), stated that sending this sensor and GPS data by 3G/4G would cost "almost nothing" and by satellite €0.5 per MB, somewhere between €50-400/year. They also report that transmission of 60 hauls worth of video data could cost as little as €180/year by 3G/4G connection, depending on resolution, frame rate, file size and data plan with the communications provider, or as much as €9,600/year, if transmitted by satellite.

The usual way to retrieve video data is to have a removable or fixed hard drive that is swapped or downloaded at the vessel periodically, and sent to the analyst. This can either be done by a technician, a local enforcement officer or even by the crew themselves, and the method preferred will be dependent on the trust between fishers and programme managers and the legal duty of care arrangements agreed at the start of the project/programme. Also, if the data are to be used for compliance purposes, there will need to be due regard of the chain of custody. The cheapest option is to have fishers, or a local compliance officer send the hard drive device to the project manager, but if this arrangement is not possible, then staff resources will need to be in place to collect these data files from the vessels.

Other costs to consider with any REM project is the quantity of data that will be collected and how it will be stored, protected, managed, analysed and reported. Data use, data disposal and privacy protection policies will all need to be provided at the commencement of the project, and staff resources will need to be in place to establish these. Analyst and technician safety and training should also be considered, with suitable resources set aside for these activities.

Another activity and cost that is often overlooked during fisheries monitoring projects is how the results and the project's progress are communicated back to the stakeholders. This is no different for a REM programme and having good and regular feedback to the fishers allows them to provide suggestions on how the project can be carried out more effectively, as well as allowing them to see the numbers of cetaceans being observed and that the collected data are being properly used. An updateable online facility that can show the anonymised bycatch and interaction results geographically on a map, could allow the fishers and other stakeholders to be able to view the most up to date results, and perhaps alter their working patterns away from higher risk areas. Regular feedback also ensures that the participating

Table 12. The total running costs per system (excluding staff time and video review software licence) associated with an average priced REM programme for a 5-year period, based on the average of the costs provided by the suppliers. The average cost per year is also shown.

Item/Service for One REM System for 5 Years	2 Camera System (€)	4 Camera System (€)
Hardware (5-year lifetime)	7077	8810
Installation (every 5 years)	1091	2044
Monthly Health Check at €727/year	3635	3635
Service and Maintenance at €700/year	3500	3500
Remote Sensor Data Transfer at €180/year	900	900
Two Additional Hard Drives at €50 each and lifetime of 5 years	100	100
Hard Drive Swapping and Transport at €10/month	600	600
Total Cost per Vessel (for a 5-year lifespan)	16,903	19,589
Annual Total Cost per Vessel Including hardware and Installation	**3381**	**3918**
Annual Running Costs per Vessel Excluding hardware and Installation	**1747**	**1747**

fishers are aware that the data are actually being reviewed and used which is essential if stakeholder buy-in is required for the project to function successfully. So again, these activities should be planned and budgeted for. For the purposes of this report, the data analysis and feedback processes have been included in the programme manager's normal duties.

When commencing a REM project, the initial costs are high because of the need to purchase hardware and install the systems on board vessels. But these costs should all be split over the lifetime of the REM system. Table 12 shows the costs for a 2-camera system and a 4-camera system, averaged across all suppliers and across a 5-year period to monitor a fleet of 15 vessels. The difference in cost between a 2-camera system and a 4-camera system is small (approx. 10% of the overall cost) and most other costs are the same, the only noticeable differences being a reduced installation cost because it will take less time to install, and the cost of the 2 extra cameras in the hardware section. Also, if EMFF funding, or similar, continues to be available for REM equipment in the future, then 90% of the hardware costs can be funded from this source (Course, 2015). The costs associated with reviewing the collected data will be discussed in the section related to staff resources because a review licence (if required) is associated with an individual or their personal computer and the staffing levels required will very much depend on the fishing technique and aims of the monitoring project/programme.

REM Staff costs

Installation and Maintenance

The installation costs have been included in Table 12, separately identified, and in Table 10 included with hardware costs. The installation process can either be carried out by contracted marine engineers or by trained project staff. It is recommended that the actual connection to the vessel's main power source should be undertaken by a suitably qualified person, for safety reasons. Even when this activity is subcontracted there is the need for analysts, project managers, and fishers to be involved in the installation process so that cameras are situated in places that allow a view of likely bycatch activity areas. Some programme managers can provide the engineers with vessel installation plans, whilst others send staff to accompany and assist the engineers and liaise with the fishers directly regarding suitable installation locations and catch handling areas. Figure 6 shows an installation plan for the Ghanaian tuna purse seine fishery project. This is used to show the engineers how and where to position the cameras to ensure that all areas on deck or in the water that have been identified as essential views are covered by the field of view. After installation is complete, a project manager should sign that the installation process has been completed in accordance with the installation plan. This is to check that the installation requirements were correctly followed and to check at a later date that the cameras have not been tampered with or moved, after the engineers have left the vessel. In addition to installation, the subcontracted engineers can also be used for routine servicing and maintenance of the hardware, or this can be undertaken by qualified staff, or may be an optional extra from the hardware suppliers (see Table 12 above).

Management and Analysis of Sensor and Video Data

The most expensive part of any REM programme is the staff time associated with the management, analysis and reporting of the sensor and video data (Dinsdale, 2013; EFCA, 2019). The staff resources associated with a particular project or programme are usually linked to the number of participating vessels, the aims of the project, which species are being monitored, the type of fishing gear being monitored, and the quality of the installation process and video data collected. Staff salary rates will vary dependent on the nation or organisation undertaking the project because of differences in local standards of living, and differences in private and public employment rates (as will also occur for observers).

There will be costs associated with the initial training of video review analysts, but these will be minimal because the training can be undertaken on real collected data and video. Also, the training can usually be provided in-house during normal working hours or, alternatively, it is often provided by the suppliers as part of the REM hardware/software package. There will be savings when compared with observers related to seagoing and safety training, as well as provision and maintenance of PPE.

To undertake the video review there is often a requirement to pay for specialist software. The suppliers we approached either provided bespoke proprietary software or have provided free open source software, and this difference means that an average cost for the software will need to be used. The licence for reviewing video (if applicable) is usually attached to an individual reviewer or reviewing computer and therefore the cost of undertaking the video review for a programme will often depend on how many staff are needed to service the desired video review rate, which is dictated by the number of vessels and aims of the project.

Some costs, for example the communication of the data to project managers, could be free (or of very minimal cost), if collecting the hard drives from the vessels was incorporated into a local fishery officer's normal duties, or if hard drives were swapped and posted by the fishers themselves on a routine basis, or if data was uploaded to a secure network via Wi-Fi when the vessel is docked. If sensor data are being sent via mobile communications such as mobile telephone networks, there will be some variation in cost which will be dependent on the network supplier, local rates, and the number of vessels involved in the project.
Storage of the data ashore or to a cloud-based system,

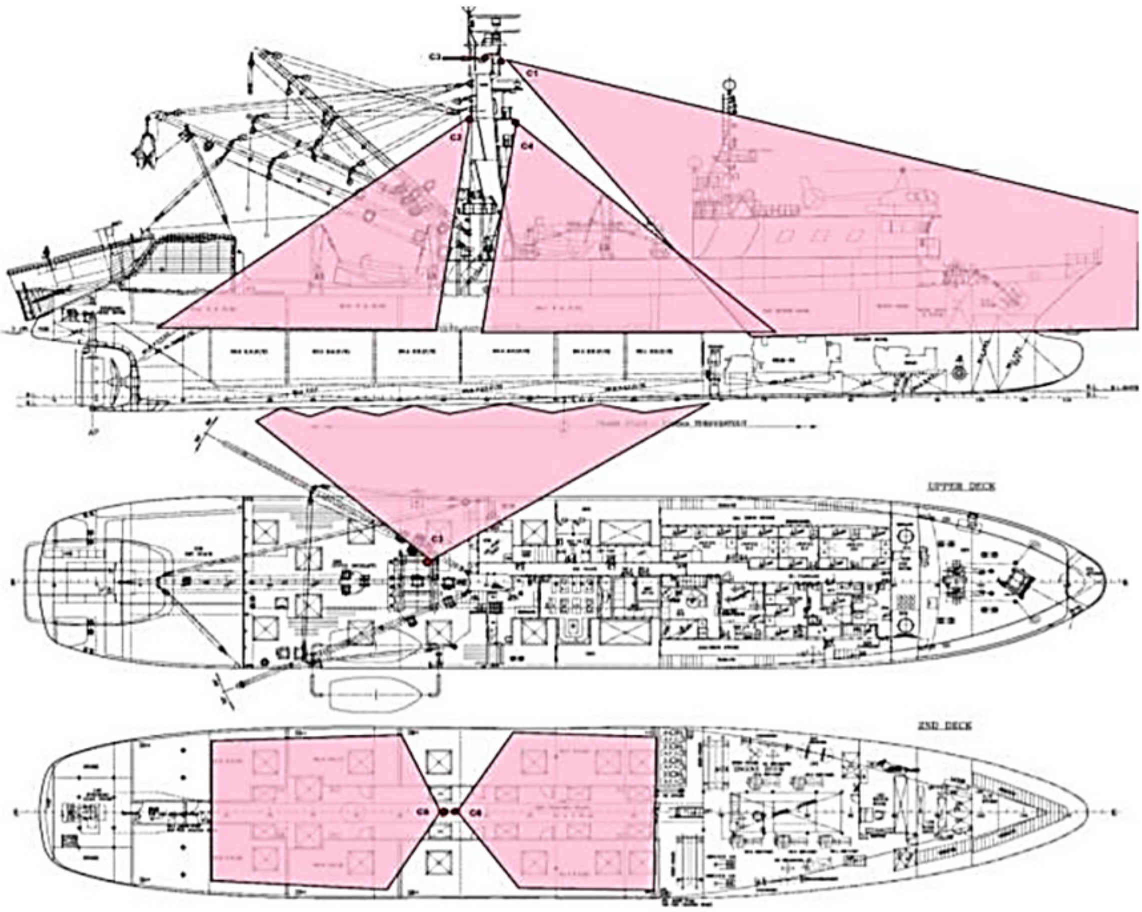

Figure 6. A vessel installation plan for a large offshore tuna purse seine vessel. The pink shaded areas show the field of view for each installed CCTV camera and how they cover the main activity areas associated with the fishing activities and catch processing (MRAG, 2017).

will also have costs associated with the management and security of the data and again these are variables depending on how the project has been set up. The sensor data files are relatively small, but could be communicated on a very frequent basis, perhaps daily or possibly even live. In this case, the data will need to be sent directly into a specifically designed database that will require management and security. Alternatively, the sensor data may only be retrieved at the same time as the hard drives and video data which will reduce the frequency of data updates (and costs) but it will still require safe and reliable storage. This is also the case for the video data.

If we assume that a hard drive is swapped every month from a programme with 15 vessels, there will be 180 hard drives being returned to the project office every year. These hard drives then need to have the data uploaded to a secure server and be cleaned for redeployment. Each vessel will need to have at least 3 hard drives available to it; one that is currently active and in use, one that has been sent to the project managers and is currently being processed or copied, and one as backup in case the current hard drive fails or in case the vessel does not return to port for long time periods and there is no opportunity to post the completed hard drive to the office. So, the management and capacity of the hard drives can also affect the overall hardware costs.

Where and for how long all the video and sensor data are stored ashore also has a cost. An individual vessel could collect up to 10TB of data per year, and large, dedicated servers will be needed if all these data have to be stored for several years. Programme designers should consider what the data are to be used for, how long they will be considered as useful, what data MUST be kept secure for scientific or evidential purposes, and at what point data need to be deleted to free up server space. There is no point keeping video data for 2 or 3 years if it has been fully analysed and unlikely to be reviewed again, or if no cetacean or ETP bycatch events were ever recorded.

The sensor data provide managers with the fishing

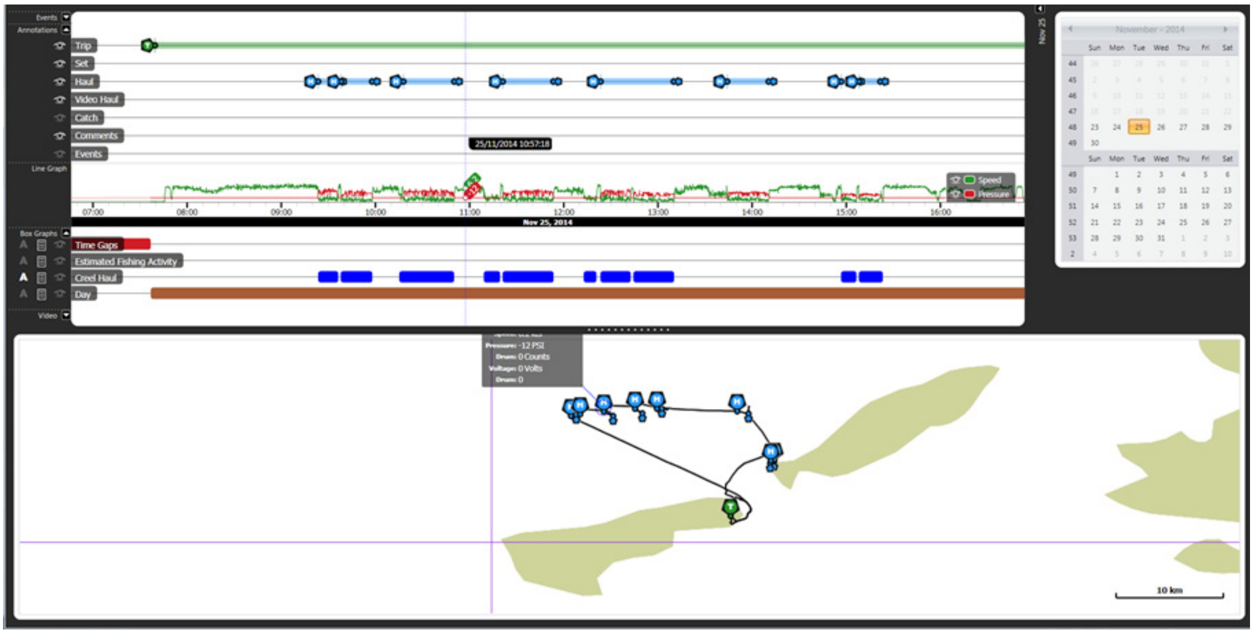

Figure 7. The track of a shellfish creel fishing vessel for a single fishing trip. The speed and hydraulic sensor readings are displayed on the line graph and are used to identify gear hauling positions (Course et al, 2015).

effort associated with a fishing trip and vessel which when linked to catch details can allow catch per unit effort (CPUE) data to be calculated. This can then be used for management purposes. These sensor data also allow the analyst to focus their review time upon the periods when gear is being hauled aboard the vessel. To illustrate, a static gear fishing vessel (set gill nets or a shellfish potting vessel) sails towards its fishing grounds, usually at higher speeds. During this transit process, the vessel's gear hauler is not engaged or active and the transit line is usually straight. When shooting the fleet of gear, the fisher will throw a marker buoy into the sea which will act as a drogue to drag the gear from the vessel and into the water. Usually there is no activity for the hauler during this process so there will be little or no rotation or hydraulic pressure sensor activity. The speed of the vessel will also be moderate and steady to allow even deployment of the gear. During hauling, the vessel's speed will be slow, and the hauler will be engaged, and the rotation/hydraulic sensor will be providing data. This information can then be used to plot exact hauling activity. Figure 7 shows a typical track from a static gear fishing vessel along with a display of the sensor data (Course *et al*., 2015) and this would be similar in appearance to a gill net track. This interpretation of the sensor data can be done manually by reviewing the values for each sensor and speed. However, some of the hardware suppliers contacted have developed embedded tools that help interpret the sensor data to accurately identify fishing activities e.g. fishing trips and gear hauling events, automatically.

Once all sensor and video data have been successfully downloaded and stored ashore, they can be reviewed by the analyst. The quantity of video that can be reviewed by a single analyst can vary greatly depending on what the analyst is being asked to monitor and quantify. In the UK catch quota trials, the two analysts were asked to quantify all discards from fish species subject to the landing obligation regulation, from 10% of the hauls fished on each trip for a fleet of 12 vessels. It was estimated that each analyst could only review footage from about six vessels per year when identifying and counting every fish discarded as they were able to review a maximum of 11% of the hauls fished (Roberts *et al*., 2013). So, approximately eight staff would be needed to review 10% of fishing effort from a fleet of 50 vessels for a fish related discard project where all fish need to be identified and accounted for.

However, if the analyst was only being asked to monitor cetacean bycatch and dropouts, say from a gillnet fishery, only the actual hauling activity will need to be reviewed (rather than all fish processing or other opportunities to circumvent the landings obligation). So, the video can be reviewed at higher speeds and therefore less staff resources will be required to review footage and the amount of staff time required can be estimated based on hours fished divided by review speed. If the fishers are also self-reporting when there is an interaction event, this will further speedup analysis as the video review analysts can go directly to the reported event (although a certain percentage of random footage should also still be reviewed to confirm the self-reporting, and ideally this should be high, even 100%, to capture rare events like cetacean bycatch monitoring).

The percentage of fishing effort being reviewed will also have implications on staffing levels and this rate is generally governed by the available budget and the time it takes to review a vessel's fishing activity. For the purposes of this report, several assumptions will need to be made regarding how many vessels or fishing events an analyst can review annually. The most relevant estimate regarding cetacean only bycatch reviewing speeds comes from the Danish gill net fisheries (Kindt-Larsen *et al.*, 2012; 12 times normal speed) and will be the one used when estimating costs. However, it should be remembered that the more you need to identify, the longer the review will take. For example, Pria *et al.* (2014), found that to review video for ETP species interactions, it took approximately 10 minutes to review 1 hour of hauling (so 6 times normal speed), whilst during the UK catch quota trials (CQTs), it often took longer than normal speed to analyse a haul with the average review time per reviewed haul being 4 hours. A haul in the case of the CQTs being identified as from when the retrieval of the net commenced to conclusion of sorting of all catch brought aboard. This was because multiple commercial fish species and discards were being identified and quantified and because the time to sort the catches was often considerable dependent on species mix, cleanliness of catch and size of catch (Roberts *et al*., 2012).

Programme managers will also be required. The level of management needed depends on what additional work they undertake and how many full-time staff are managed. These costs will be added after the number of video analysts required has been determined. It would be safe to assume that the manager would be responsible for data analysis and reporting, meeting attendance, staff safety, and general day to day programme management. It will be assumed that a full-time manager could probably supervise at least 5 full time staff. So, for every member of video review staff, 20% of the manager's salary and associated 30% overhead costs, should also be added. For illustrative purposes, a salary of €40,000 plus €12,000 overhead costs is used, i.e. a total cost of €52,000 for a manager or scientist.

Another factor that should be considered when undertaking the video review is that cetacean bycatch events are rare. Only reviewing 10% of the recorded video, as may be done on a fish discard REM project, will likely miss any interaction events. Far better would be to select a subsample of the fleet to represent the whole fleet, and then review 100% of the video collected by this reference fleet. This may introduce deployment bias and observer bias (as discussed earlier regarding subsampling a fleet), so analysis should be undertaken to ensure that the reference fleet is representative of the whole fleet and that observed data are representative of unobserved data. A potential solution may be to use a system that can be easily transferred between vessels with vessels selected randomly to carry the REM. Alternatively, the whole fleet has systems installed but not all vessels are selected for review and a risk-based approach for selecting vessels and video for review, is used.

In Table 13, the salary costs of a video review analyst are estimated at €28,000. The salary overheads are estimated at 30% of the salary cost (€8,400), to cover office space, employer contributions, access to a PC, and other associated salary costs. If a project has higher overhead and management costs, this can be raised accordingly. The recent coronavirus pandemic has driven a change in working practices and a rise in homeworking, and REM video review is an activity that could easily be undertaken in a home-based setting, thus reducing office space costs. The average annual video review analyst software licence cost is calculated at €2,510 per year. Only the periods when nets are actively being hauled need to be reviewed for gill netting.

This information will allow an estimate of required video reviewer staff time to be made. For example, if a typical gillnetting vessel spends 140 days at sea per year and on each day spends an average of 6 hours per day physically hauling nets, the total amount of fishing effort to review will be 840 hours. Using Kindt-Larsen et al's. (2012) 12 times normal speed for video review (i.e. 12 hauling hours per review hour), it would take the reviewer 70 hours to review the whole year's fishing effort for this vessel. Then if a reviewer can spend 6 hours per working day reviewing video and works for 235 days every year, the reviewer will have 1410 hours available to undertake video review which would be enough to monitor 100% of fishing effort for 20 vessels. Using this information, it is estimated that the staff time and video review software licence costs, would be €38,910 to review 20 vessels, equating to €1945 per vessel per year. When the management staff time is also added into the costs, this brings the totals to €49,310 to review 20 vessels per year, equating to €2,466 per vessel per year (Table 13).

Overall Costs and Comparisons

Using the information provided by the REM suppliers and the managers of the ASCOBANS programmes who responded (or alternative published sources as referenced), it is possible to get an average annual cost for the REM system (assuming a 5-year lifespan) and local costs of operating an observer programme in each of the ASCOBANS states. These cost estimates can then be applied to case study fisheries to determine the costs associated with:

- A marine mammal at-sea observer programme at 5% and 10% of all days spent at sea for a particular metier
- A REM cetacean bycatch monitoring programme reviewing 100% of video and sensor data captured on 5% and 10% of a fishing fleet.

The results of this comparison can help to indicate which method presents the best value for money for observing bycatch of cetaceans in a particular fishery in the ASCOBANS area. Biological sampling is excluded

Table 13. Estimated video review analyst staff and management overhead cost, plus video review software licence cost.

Item/Service	Annual Cost (€)	Number of Vessels	Annual Cost per Vessel (€)
Video Reviewer Salary	28,000	20	1400
Employer Overhead Costs (30% of Salary)	8,400	20	420
Average Annual Video Review Licence Cost per Review Analyst	2510	20	125
Management Overhead Time (20% of €52,000 (40,000 salary + 12,000 overhead) per analyst = €10,400)	10,400	20	520
Total	49,310	20	2466

from these comparisons because it is acknowledged that REM programmes cannot provide these data (other than an estimated body length) at this time, whereas at-sea observer programmes can when the cetacean is brought aboard. It is likely that image recognition and computer learning technology will eventually be able to analyse footage automatically, but this still requires developing. If the biological data were required, it would need to be part of a supplementary biological sampling programme.

Reviewing the video footage is laborious and is one of the main cost components associated with using REM for identifying and quantifying catch. Developments in Machine Learning (ML) applications that can accurately identify and flag bycatch interactions and other events of interest will reduce reviewing staff time and costs significantly.

Automatic fish recognition software has been progressing over the last 10 years due to the introduction of REM. As early as 2006, trials that utilised camera technology to sort fish by species and obtain length measurements obtained a 99.8% success rate over the seven fish species tested. They also calculated that 30,000 fish/hour could be processed using a conveyor system but with the only limitation being the need to feed the fish singularly under the camera (White *et al.,* 2006). However, French *et al.,* (2015) had less success using video collected from a standard REM system to count fish and found that the majority of video data was unusable due to how and where they had been installed aboard the vessel, the high volumes of fish and how catches were handled.

Nevertheless, the significant potential for automated fish identification is evidenced in other fisheries and studies. For example, accuracy rates of 92% were obtained when identifying four different types of rockfish from a longline fishery (Wallace, 2020). So, with good quality video footage and the right catch handling procedures implemented, high accuracy species identification and counts should be possible. Applying these developments to ETP and cetaceans specifically should be possible, and for some taxa, research has begun. A lab-based study tested approximately 200 images of seabirds and found that across all images tested, there was 93% species identification accuracy, and for some species this was 100% (Fitzgerald *et al.*, 2019).

There is no reason why software cannot be developed to identify and count cetacean bycatch. It is a question of teaching the software what to identify and this requires training datasets of imagery. To obtain these though requires video collected on ETP monitoring REM programmes, verified by an onboard observer or through expert video review. The rare nature of ETP bycatch means that a lot more hours of imagery are needed to develop a training dataset than for fish, as well as international collaboration to build up the image libraries. So, developments in ML require REM (or other data sources) to be more fully adopted to allow large quantities of training imagery in a real life setting to be collected and used. In addition, a clearly defined implementation pathway is vital to support the continued development and facilitate the widespread adoption of ML, along with sharing and storing of knowledge and outcomes (e.g. software code) (ICES, 2018c).

The observer programme cost per sea day provided through the data request resulted in only two cost estimates, of €248 and €25,987 per day monitored at sea (see Tables 7, 8 and 9). These costs vary greatly between the countries and there are serious doubts that these have been calculated correctly when supplied. Therefore, these will not be used in the following cost comparison case studies. Instead national costs will be sourced from published reports where possible.

The costs to purchase a 2-camera REM system (deemed adequate for a small inshore vessel for cetacean bycatch monitoring), range between €3,745 and €10,580, with an average value of €7,077 for five years (see Table 10). When all the additional running costs of operating a REM programme of €1,747 are included (see Table 12), the average annual cost of purchasing, installing and operating a 2-camera system REM ongoing cetacean monitoring programme is €5,128 per vessel per year (Table 12). The analyst and management staff time and video review software cost €2,466 per vessel per year (see Table 13). Therefore, the total cost to undertake video review on a typical inshore gill netting vessel would be approximately €7,594 (€5,128 + €2,466) per year per vessel for hardware (purchase, installation and running costs) and to review 100% of the sensor data and video collected. If the vessel undertook 140 days at sea per year, this would be approximately €54.24/sea-day observed.

Case Study Comparison

From the data provided by ASCOBANS Parties, the majority of cetaceans appear to be caught in gill net fisheries and midwater trawl fisheries. So, for illustrative purposes the case studies used will be from these two gear types, to try to demonstrate the cost differences and other benefits associated with the different monitoring techniques of REM and at-sea observers, at 5% and 10% coverage levels.

Case Study 1: A UK <15m Gillnet Fishery Example

Identifying the number of vessels operating in a specific gillnet fishery can be quite difficult because these inshore vessels can often target more than one species depending on the season and local regulations and will therefore switch between metiers. This is well illustrated by the UK data where the individual metier data often show the number of vessels fishing in a metier for less than 10 days on average (Northridge *et al.,* 2019). Therefore, for the purposes of this comparison we have used a fictitious metier called the "UK <15m gillnet multispecies fishery" operating in the North Sea (ICES Area IV). The fictitious effort data for this metier for 2018 was 40 vessels and reported to have undertaken 4673 sea trips and fished for 5600 days at sea. This is a completely hypothetical fishery for illustrative purposes which uses the 140 days at sea per vessel, used earlier and it is assumed that these vessels fish only using gillnets, although exact fisheries and target species may vary. Even if these vessels partake in other fisheries using non-gillnet gear, they would also still be monitored by the REM, irrespective of gear type, as long as sufficient numbers of cameras are used to cover different areas of interest or that existing cameras can be adjusted easily when required. The monitoring programme has been assumed to last for 5 years to enable REM costs to be spread over the expected 5-year lifetime of the equipment. It would become extremely complicated if these comparisons had to include equipment removal costs and periods when systems were sat ashore in storage awaiting redeployment in other fisheries.

From the UK cost data presented in Table 9, the daily cost to undertake an at-sea observer programme in 2018 was calculated at €840 per day-at-sea observed. In Table 14, the fishing effort data for the example Case Study 1 UK fishery and the cost data can be combined to show the costs associated with monitoring different percentages of the fleet's fishing effort. To monitor 5% of the days at sea using at-sea observers would cost €235,200 and to monitor 10% would cost €470,400.

To install REM on 10% of the 40 vessels (i.e. 4 vessels only) and review 100% of all fishing activities would be four vessels at €7,594 per vessel per year. This equates to €30,376 per year for 4 vessels. However, this captures video and data for four vessels for a whole year, which if they are fishing for 140 days each per year is equivalent to 560 days monitored (see Table 14). The cost to monitor 560 days using at-sea observers is €470,400 and would require at least six seagoing observers (assuming approximately 93 days at sea each per year). However, it is important that a clear distinction is made regarding these two scenarios. The observer programme monitoring days are undertaken on a random selection of ALL the vessels, whereas the REM observed days only come from 4 vessels as a reference fleet. The idea that an observer programme would deploy an observer on these 4 vessels to monitor and record data every day that they fished per year, is unrealistic. So, comparing like for like is difficult when comparing observer and REM programmes.

If the monitoring programme needs to include monitoring on all vessels, then 40 systems would need to be purchased and installed, and video review time reduced to match the observer programme monitoring rate. Equipping these 40 vessels with a REM system, and reviewing 10% of their fishing effort, would be a completely different cost, and higher for comparison than using the small reference fleet and reviewing 100% of the effort. Table 15 shows the costs associated with installing all 40 vessels with a system and the costs associated with 5%, 10% and 100% video review rates. The 100% review rate has been shown because it now becomes a viable option when all vessels are installed. After all, one would not deploy observers on all vessels and fishing days and then only ask them to collect data every 10 or 20 days.

Again, for Table 15, it is assumed that the programme lasts for 5 years, that 40 vessels undertake 140 days at sea each (5,600 in total), that each fishing day includes 6 hours of gear retrieval time, that the video analyst review rate is 12 times normal speed, and that a REM video analyst has a working year of 1,410 hours per year dedicated to video review processes.

If the whole fleet was to be monitored using REM for 100% of all effort, then two video reviewers, 0.4 of a scientist/manager and 40 REM systems (plus running costs) would be required, which would cost an estimated €303,760/year (Table 15), equivalent to €7,594/vessel/year. For an at-sea observer programme monitoring 100% of the 5,600 days at sea, the cost is calculated by multiplying the daily observer programme cost (€840/day) by the number of fleet days, so approximately €4.7million/year (see Table 15).

It is clear from these costs that undertaking REM for

Table 14. Costs associated with undertaking an at-sea observer monitoring programme or a REM programme on a UK gillnet fishery.

Method	Number of Vessels	Total Days at Sea	Cost per Day (€)	5% Days at Sea	Cost of 5% Coverage (€)	10% Days at Sea	Cost of 10% Coverage (€)
At-Sea Observer	40	5600	840	280	235,200	560	470,400
REM Video Review	40 (4 at 10%)	5600	54.24	280	15,188	560	30,376

programmes observing cetacean bycatch only, is cost effective. The rarity of the events means that the video can be reviewed at high speed and that high levels of monitoring can be achieved for relatively low costs compared to an observer programme. These rapid review rates will vary if reviews are required to monitor for other ETP species or commercial fish species. The video review cost component of a REM project solely for cetacean bycatch will be cheap compared to a REM programme required to quantify all ETP bycatch or commercial fish catches and discards. This is due to the need to identify and quantify multiple species, large quantities of catch, and in multiple catch handling or discarding locations, whilst the fish may be covered in benthic material, weed and even fish guts, on a moving conveyor or angled chute.

At-sea observers who are deployed solely to monitor cetacean bycatch would spend the majority of their time recording zero events. Obviously when they are deployed, they will be used to quantify other ETP interactions or even log fish catches or carry out dedicated cetacean spotting watches, until such time that a cetacean is bycaught, whereupon they can commence biological sampling if the animal is brought aboard dead. Of course, the REM video review analysts can also quantify birds and other ETP interactions and because these are also relatively rare events, it is likely that the review speed would reduce but still be faster than single speed (e.g. 6 times normal speed, Pria *et al.*, 2014, for ETP species; 4.6 times normal speed, Lara-Lopez *et al.*, 2012, for ETP species; 4-7 times normal speed estimated by Kindt-Larsen et al, 2012 for seabirds; at least 9.8 times normal speed by Evans and Molony, 2011, for all species caught in a gill net fishery). If bycaught cetaceans and other ETP species are handled in a pre-agreed manner so that the estimated length and sex of the cetacean can be determined during video review (using onscreen callipers, on screen vessel references sizes, or measuring tools included within the software), this can also add to the value of the REM collected data set. The large differences in cost between the two monitoring methods means that careful consideration should be given to the value of the additional information collected by at-sea observers compared to that which can (or could) be collected using REM video review. For example, if there is no difference in catch rates caused by the gender of the bycaught animal (e.g. due to migration patterns), or if data on length and gender are rarely collected by observers due to roll-out and cut away rates, then using observers is difficult to justify on a cost basis.

It is also worth considering the possibility of a joint monitoring method approach in a monitoring programme for ETP species in inshore gillnet fisheries. For example, if the biological information being collected by the observers is essential to a particular study and cannot be collected through a landing dispensation arrangement, then observers may still be required. If the majority of the vessels in the fleet are too small to accommodate an observer safely or undertake extremely long trips then REM may be the preferred choice, but with observers on the larger vessels. In programmes where the ETP monitoring forms part of a national “all” species programme such as the DCF, then perhaps a combined approach would allow the observers to focus on the fish species, collection of otoliths etc. and undertake a biological sample of ETP bycatch if it occurs, whilst REM video footage collected on the same trip is reviewed for ETP species bycatch rates ashore later by an ETP expert. Similarly, fisheries and vessels that are of low risk of ETP bycatch could have reduced observer coverage and have REM installed instead to monitor for these bycatch events.

For information purposes, the costs contained in Table 15 have been repeated for a lower video review rate of 4 times normal speed (see Table 16), as possibly more representative of REM programmes that are required to monitor all ETP species bycatch or multispecies fisheries and not just cetaceans, as specified in the ToRs for this report. This speed was used as a “worst case scenario” because previous authors had specified speeds that ranged between 4.6 times and 9.8 times normal speed for multi species and ETP monitoring using REM. It shows that the costs to monitor 10% of the fleet’s effort using REM with systems installed on all 40 vessels will change from €214,982 to €234,706 if the review rates change from 12 times normal speed to 4 times normal speed. This represents a rise of less than 10% in costs, due to the additional time required to review the video. However, if only a reference fleet of 4 vessels were installed and 100% of the video for each vessel was reviewed, it would require 4 REM systems to be purchased, installed and operated, costing €20,512 (4 x €5,128) per year and 0.6 man years to review the video,

Table 15. The estimated costs associated with installing 40 vessels with REM systems and undertaking different levels of video review (5%, 10% and 100%), when video review rates are 12 times normal speed.

Item	Cost per Year	Costs (€) and Time Associated with Installing on 40 Vessels and Reviewing 5% of Days Fished	Costs and Time Associated with Installing on 40 Vessels and Reviewing 10% of Days Fished	Costs and Time Associated with Installing on 40 Vessels and Reviewing 100% of Days Fished
Hardware and Installation on 100% of Vessels	3381	135,240	135,240	135,240
Annual Running Costs for 100% of Vessels	1747	69,880	69,880	69,880
Fishing Hours to be Monitored	-	280 days x 6 hrs/ day = 1680 hrs	560 days x 6 hrs/ day = 3360 hrs	5600 days x 6 hrs/ day = 33,600 hrs
Total Reviewing Time at 12 x Normal Speed	-	140 hrs	280hrs	2800 hrs
Number of Video Reviewers Required and Cost (€)	38,910	140/1410 = 0.1 man years =3,891	280/1410 = 0.2 man years = 7782	2800/1410 =2 man years =77,820
Management staff costs/ reviewer	10,400	1,040	2,080	20,800
Total Cost using REM		210,051	214,982	303,740*
Total Cost Using Observers (see Table 14)		235,200	470,400	4,704,000

*This value differs from earlier estimates by €20 due to decimal place rounding during calculations

at a cost of €29,586. This would bring the total cost of using a reference fleet to monitor 10% of the fleet's effort at 4 times normal speed to €50,098. When these costs for the two different REM options for delivering 10% fleet coverage (i.e. €234,706 with all vessels installed and reviewing 10% of video, or €50,098 using 10% of vessels and reviewing all of the video) are compared to the costs associated with using observers (€470,400 for 10% coverage), the change in video review rates make little difference and the possible cost savings remain large, especially if the reference fleet approach is used.

Case Study 2: The French Small Pelagic Species Bay of Biscay Midwater Trawl Fishery Example

The main French fisheries identified as responsible for recent high rates of cetacean (mainly common dolphin) bycatch in the Bay of Biscay are midwater pair-trawls, bottom trawlers and gillnets, with some additional mortality attributable to pelagic freezer and high vertical opening trawls (Peltier *et al.,* 2016). The fish targeted by these fisheries include seabass, hake, mackerel, and cuttlefish.

In 2017, it was reported that the French midwater pair trawl fishery (Figure 8) operating in the Bay of Biscay caught 63 cetaceans as bycatch during sea trips with at-sea observers. These comprised 49 common dolphins caught in the northern Bay of Biscay (ICES Area VIIIa), 8 unidentified dolphins and 1 harbour porpoise in central Bay of Biscay (Area VIIIb) and 5 pilot whales in the southern Bay of Biscay (Area VIIIc) (ICES, 2019). The French government recently organised a working group to try to determine the issues affecting monitoring in the pelagic fishery. The at-sea observers explained that the fishers were not reporting as required because they objected to the need to do this and also that they thought the online tool was not working correctly. This latter point was considered to be an invalid reason as all the fishers had been supplied with paper copies of the reporting forms to allow them to declare incidental captures irrespective of the online tool. Response rates remained low despite repeated requests by the observers (DPMA, 2019).

On 9th July 2019, a group of 22 environmental NGOs jointly called on the European Commission to adopt emergency measures to prevent the accidental deaths of dolphins, porpoises and whales (Khalife, 2019). In the Northeast Atlantic, they recommended that the EU implement seasonal closures, real time monitoring and dynamic mitigation measures on a permanent basis for gillnet and pair trawl fisheries. In response, two working groups of ICES (WGBYC and WGMME) reviewed the evidence and produced reports used as a basis for an online workshop held on Emergency Measures Bycatch (WKEMBYC) in April 2020. In general, ICES agreed with the conclusions from the NGOs, and stated that "ongoing issues existed with data availability and quality, contributing to high levels of

Table 16. The estimated costs associated with installing 40 vessels with REM systems and undertaking different levels of video review (5%, 10% and 100%), when video review rates are 4 times normal speed.

Item	Cost per Year	Costs (€) and Time Associated with Installing on 40 Vessels and Reviewing 5% of Days Fished	Costs and Time Associated with Installing on 40 Vessels and Reviewing 10% of Days Fished	Costs and Time Associated with Installing on 40 Vessels and Reviewing 100% of Days Fished
Hardware and Installation on 100% of vessels	3381	135,240	135,240	135,240
Annual Running Costs for 100% of vessels	1747	69,880	69,880	69,880
Fishing Hours to be Monitored	-	280 days x 6 hrs/ day = 1680 hrs	560 days x 6 hrs/ day = 3360 hrs	5600 days x 6 hrs/ day = 33,600 hrs
Total Reviewing Time at 4 x Normal Speed	-	420 hrs	840hrs	8400 hrs
Number of Video Reviewers Required and Cost (€)	38,910	420/1410 =0.3 man years =11,673	840/1410 = 0.6 man years = 23,346	8400/1410 =6 man years =233,460
Management staff costs/ reviewer	10,400	3,120	6,240	62,400
Total Cost using REM		219,913	234,706	500,980
Total Cost Using Observers (see Table 14)		235,200	470,400	4,704,000

uncertainty in the estimation of population abundance, distribution, bycatch, and other major threats for small cetaceans. Notably, observer coverage is well below 1% of the total effort in most fisheries" (ICES, 2020b). They recommended that enhanced monitoring be undertaken in these fisheries. ICES went on to state that "dedicated marine mammal bycatch observers or remote electronic monitoring (REM) programmes should be prioritized in metiers with identified risk of bycatch of common dolphin. Such pilot projects should be established to complement at-sea sampling programmes under EU-MAP. However, given the size of the fleets involved, ICES recognized that complete coverage by observers or REM presents logistical and financial challenges, and 100% coverage is not necessary to collect data for robust bycatch estimation".

To try to address the issues of poor data, France undertook a research project using at-sea observers on pelagic pair trawlers operating in the Bay of Biscay, between December 2018 and March 2019. The fleet comprised 28 vessels which equates to 14 fishing pair teams. The entire fleet undertook 732 days at sea during this period and a total of 205 sea days were observed. This was equal to 28% of the fleet's fishing effort during this 4-month period. The project cost a total of €250,000. This is equal to €1,220 per observed day at sea using observers (L Gauthier pers. comm. to PGH Evans, 10th March 2020; DPMA, 2019). A total of 31 common dolphins were observed bycaught during this project, with an equivalent bycatch rate of 0.15 dolphins per sea day. The cost data for this project has been used with the French pair trawl fleet data, as presented in Table 4c of the French DCF national report tables for 2018. It was decided that only the vessels that target the small pelagic species in ICES Areas VIIIa, b and c would be used in this example. It should be remembered that the number of vessels shown in Table 17 will not be the same as the total number of vessels in the whole fleet, because vessels can operate in more than one area and switch between gears, so may be represented in more than one metier. Trips and days of fished effort data will be unaffected by this. A full breakdown of the effort for these groups, as reported in the DCF tables, is shown in Table 17.

Therefore, the fleet used for this comparison example will be the small pelagic species fleet of 65 vessels that undertook 2,498 fishing trips in ICES Area VIII in 2018 and completed 2,635 days fishing. To conduct a REM monitoring project in pair team fisheries, both vessels will need to have a monitoring system installed because the catch could go to either vessel for processing. Even if the catch always went to the same vessel in the team it would still be necessary to have a REM system on each vessel to ensure that no deviation from normal practice occurs. Video review processes are likely to be slower than when static gill nets are being hauled aboard but, at the same time, less fishing events will occur each day and only the time the net is being hauled aboard or the catch being pumped/brailed aboard or put in to the fish hopper, needs to be reviewed. Therefore, we feel

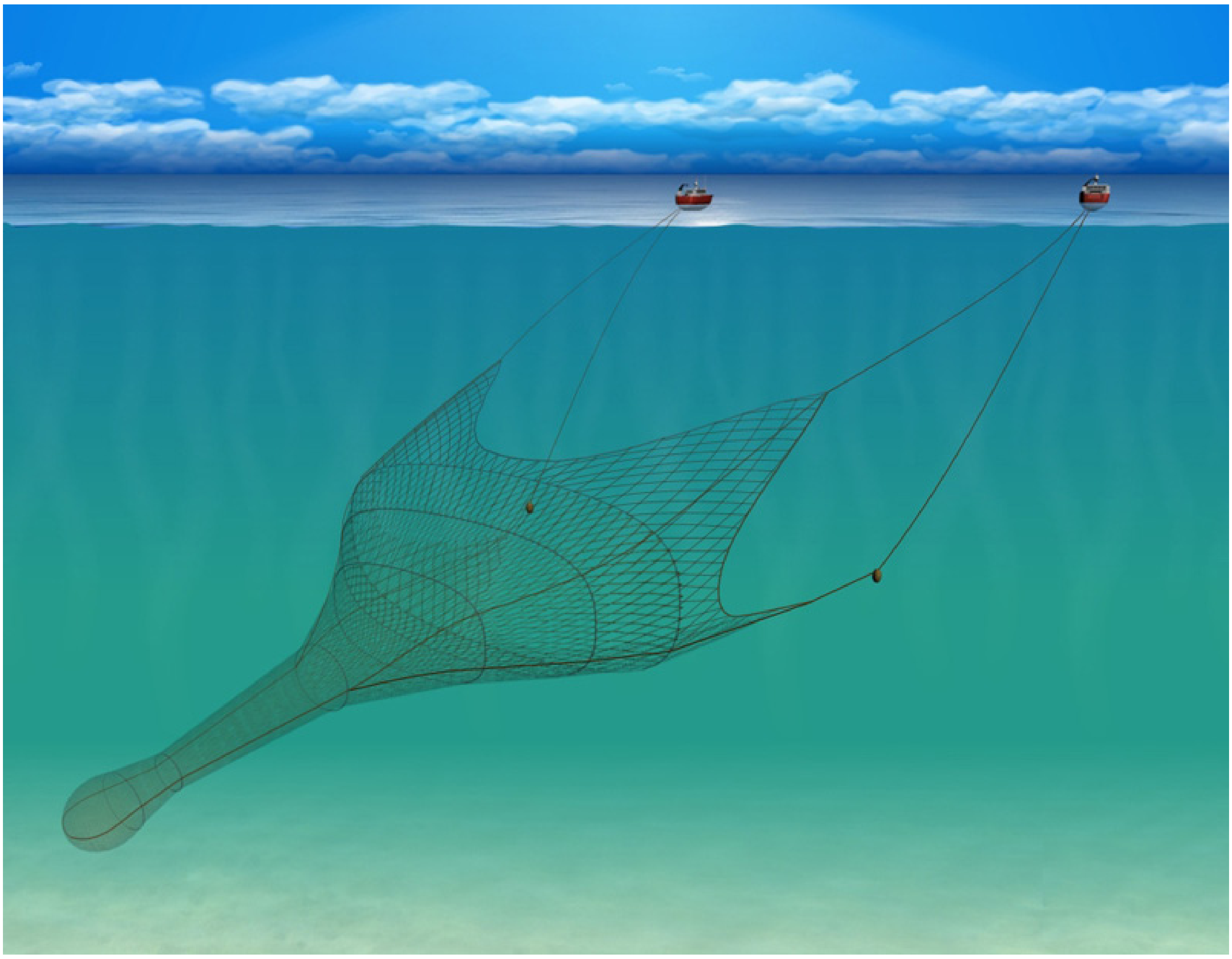

Figure 8. Illustration of a midwater pair trawling team in operation (Source: www.Cornwallgoodseafoodguide.org, accessed 5th March 2020).

that the same video and sensor data processing times (and therefore costs) used for gillnetting can be used for midwater pair trawling.

As these vessels are also larger than the inshore gill netting vessels, it is likely that any REM programme that is initiated would require somewhere between 4 and 8 cameras installed onboard to enable all potential interaction points and catch handling processes to be monitored, especially if the programme was also collecting other catch data and not just cetacean bycatch events. For example, Pastoors *et al.* (2014) used 8 cameras to monitor for fish discards on pelagic trawl projects; Scotland and Denmark used 8 cameras on their pelagic trawl trials to get better coverage of blind spots (van Helmond *et al*., 2019); England used 8 cameras during trials aboard a >100m pelagic trawl vessel to quantify bycatch and fish catches (G. Pasco, pers. comm., 28th August 2020); and the European Fisheries Control Agency (EFCA) recommend that REM systems used on >24m refrigerated sea water (RSW) pelagic trawls should use 4 cameras, and >24m freezer trawlers should use 8 cameras, for monitoring catches for compliance with the LO (EFCA, 2019).

For the purposes of this case study exercise we will use the cost to purchase, install and run a 4-camera system because it is likely that the four cameras will be enough to cover cetacean bycatch interaction locations aboard pelagic trawl vessels. The cost to purchase and install the hardware is €3,918 and the annual running costs are €1,747 (see Table 12), a total of €5,665 per vessel per year. The total hardware and running costs for the fleet will depend on the number of vessels being monitored in the fishery.

The costs to undertake the video review will depend on what percentage of video is to be reviewed, the video review rate, how many days the boats fish, and how many vessels in the fleet are being monitored. As previously mentioned, staff costs and overheads will vary greatly so the example values used in Table 13 will also be used in this case study example, giving the total staff cost of a video review analyst (and management time and overheads) of €49,310 per year per video review analyst. Each analyst works for 235 days per year and 6 hours per day are spent undertaking video review.
Table 18 shows the costs associated with using at-

Table 17. The French mid-water pair trawling fishing effort in 2018 (adapted from DCF, 2019).

ICES Area	Species Group	Number of Vessels	Number of Trips	Number of Fishing Days
VIIIa	Demersal	44	1044	1418
	Small Pelagic	42	2177	2337
	Large Pelagic	51	196	166
VIIIb	Demersal	36	434	614
	Small Pelagic	21	313	297
	Large Pelagic	42	100	150
VIIIc	Demersal	3	3	7
	Small Pelagic	2	8	1
	Large Pelagic	34	71	103
Total	Small Pelagic Metier Only	65	2498	2635

sea observers to monitor 5% and 10% of the French midwater small pelagic pair trawling fleet. This uses the daily rate calculated from the French pelagic trawl observer project of €1,220/observer day.

Table 19 shows that to monitor 5% and 10% of the fleet's effort using REM is more expensive than using observers. If REM systems were installed on all 65 vessels, the overall hardware related costs would be €368,225 (65 x €5,665) and 100% of their days at sea that need to be reviewed would amount to 2,635 days, at 12 times normal speed. Video review costs would be approximately €49,310 for all 65 vessels. A total cost of approximately €417,535 or €158/day.

This is considered to be the maximum amount as it requires every single vessel to have a system on board and for the captured data to be reviewed from all vessels on all days that the vessel is at sea, but it should be remembered that on some of these days the vessels will not be fishing. Observers must stay on board for all sea days so to undertake the same 100% level of coverage using at-sea observers would cost approximately €3.2m, using the €1,220/day observed cost, which is more than 7.5 times higher than REM costs.
For 5% of the fleet's effort, REM is more than twice as expensive (130%) and for 10% of the fleet's effort, it is 16% more expensive. However, when the review rate increases to 100% of the fleet's effort, REM becomes nearly 8 times cheaper than using observers. This is because this monitoring model of having all vessels installed with REM is an expensive approach if very little of the fishing effort is actually reviewed, especially if the vessels involved only undertake low levels of effort in the fishery.

On the other hand, if a reference fleet approach was used and only 10% of the fleet were actually installed with REM and 100% of their effort monitored, REM would be considerably cheaper than using observers because only seven systems would need to be installed and approximately 264 days of effort reviewed. The REM costs would change from €373,157 to €74,179 (7 x (3918+1747+3892+1040)), which is over 4 times cheaper than using observers (€322,080) to still monitor 10% of the fleet's effort. It would just be that the effort came from 100% of 7 different vessels' effort, instead of 10% of fishing effort from 65 (70) different vessels.

Financially, it does not make much sense to put a system on all these large vessels and then only review a small amount of the recorded data and video, because approximately two-thirds of the annual cost is incurred through the purchasing, installing and maintaining of the REM systems. If one was going to go to the expense of installing REM on the whole fleet, one might as well review as much of the video as possible. Even review rates of 50% will still cost approximately €392,880 compared to €417,535 for 100% review, although this would still be more than four times cheaper than deploying observers on 50% of the sea days (€1,610,400). Equipping all vessels also has the added advantage that no matter where the vessels are fishing and what metier they are operating, the data can still be gathered and analysed. As with the gillnetting example in Case 1, the analysis costs will be affected by what speeds the video can be reviewed at, and exactly how long the REM analyst

Table 18. The estimated costs to monitor different percentages of the French small pelagic fleet's fishing effort, using at-sea observers.

Method	Number of Vessels 2018 data	Total Days at Sea	Cost per Day (€)	5% Days at Sea	Cost of 5% Coverage (€)	10% Days at Sea	Cost of 10% Coverage (€)
At-Sea Observer	65	2635	1220	132	161,040	264	322,080

Fishing effort adapted from Table 4a and 4c of DCF 2019, fishing effort of midwater pair trawl vessels targeting small pelagic fish species in ICES areas VIIIa, b, c. Observer costs adapted from the French Pelagic pair trawl project "Bilan de l'hiver 2018-19. Captures accidentelles de petits cétacés en Atlantique" (Pers. Comms., Evans, P., 10th March 2020) and DPMA, 2019).

Table 19. The estimated costs to monitor 5%, 10% and 100% of the French small pelagic fishery using REM at 12 times normal speed video review rates.

Item	Cost per Year	Costs (€) and Time Associated with Installing on 65 Vessels and Reviewing 5% of Days Fished	Costs and Time Associated with Installing on 65 Vessels and Reviewing 10% of Days Fished	Costs and Time Associated with Installing on 65 Vessels and Reviewing 100% of Days Fished
Hardware and Installation on 100% of Vessels – 4-camera	3918	254,670	254,670	254,670
Annual Running Costs for 100% of Vessels	1747	113,555	113,555	113,555
Fishing Days to be Monitored		132 days	264 days	2635 days
Total Reviewing Time at 12x Normal Speed	-	11 days	22 days	220 days
Number of Video Reviewers Required (rounded up) and Cost (€)	38,910	11/235 =0.05 man-years = 1946	22/235 = 0.1 man-years = 3892	220/235 = 1 man-year =38,910
Management staff costs per reviewer	10,400	520	1,040	10,400
Total Cost using REM		370,691	373,157	417,535
Total Cost Using Observers (see Table 18)		161,040	322,080	3,220,800

needs to spend reviewing the retrieval operations when cetaceans (or ETP species) bycatch events will be visible.

Ideally, the whole fleet should be fitted with systems and all of the data reviewed. However, if this was not possible it could be that a form of self-reporting which targeted video review to incidents could help reduce costs. Alternatively, the programme could choose a REM system that was more portable than others with easier installation and removal processes to allow it to be swapped between vessels to try to obtain coverage on all vessels over a rolling multi-annual period. What is clear is that REM is more cost effective than at-sea observers in this fishery when high levels of coverage are needed, as the observers are required to stay on board for the duration of a trip, are limited to observing one area onboard at any one time, and are required to take rest breaks that may occur during fishing operations. By contrast, REM would allow multiple areas on the vessel to be viewed and recorded simultaneously (especially with a 4-camera system) whilst the periods when no net retrievals are occurring, can be completely avoided through interrogation of the sensor data. In this example case study, the €250,000 originally spent to deploy observers on 205 sea days over a 4-month period could have bought systems for 38 vessels (at €6,427/system (€417,535/65) with 100% video review) and allowed a whole year of fishing effort to be recorded and reviewed. This is equal to 58% of the fleet's effort compared to 8% (i.e. 25% of four months' effort) achievable using observers with the same budget.

For illustrative purposes, the costs associated with a lower video review speed of 4 times normal speed, are

Table 20. The estimated costs to monitor 5%, 10% and 100% of the French small pelagic fishery using REM at 4 times normal speed video review rates.

Item	Cost per Year	Costs (€) and Time Associated with Installing on 65 Vessels and Reviewing 5% of Days Fished	Costs and Time Associated with Installing on 65 Vessels and Reviewing 10% of Days Fished	Costs and Time Associated with Installing on 65 Vessels and Reviewing 100% of Days Fished
Hardware and Installation on 100% of Vessels – 4-camera	3918	254,670	254,670	254,670
Annual Running Costs for 100% of Vessels	1747	113,555	113,555	113,555
Fishing Days to be Monitored		132 days	264 days	2635 days
Total Reviewing Time at 4 x Normal Speed	-	33 days	66 days	660 days
Number of Video Reviewers Required (rounded up) and Cost (€)	38,910	33/235 =0.14 man-years = 5,445	66/235 = 0.28 man-years = 10,890	660/235 = 2.8 man-years =108,900
Management staff costs per reviewer	10,400	1,456	2,912	29,120
Total Cost using REM		375,126	382,027	506,245
Total Cost Using Observers (see Table 18)		161,040	322,080	3,220,800

shown in Table 20. It shows that costs increase by approximately €8,870 (2.4%) per year when using REM for 10% coverage, and becomes 19% more expensive than using observers for 10% monitoring. This is due to the costs being calculated for the fleet and per vessel based on each vessel only undertaking 40 days at sea in this metier (2,635 days in total). However, the REM systems would be onboard and able to collect data for 100% of seatrips undertaken in any metier and therefore offer greater flexibility. The costs would also reduce per day monitored. If monitoring was increased to 100% of the 2,635 days fished in this pelagic fishery, the REM would be 6 times cheaper than using observers, even at the lower video review speed of 4 times normal speed.

Case Study 3: The Danish Oresund Gillnet Fishery – An Operational REM Example

The Danish government (the projects were led by the Danish National Institute of Aquatic Resources (DTU Aqua) have been undertaking trials with REM technology since 2008, when the verification of self-reported cod (*Gadus morhua*) catches, including discards, as part of a catch quota trial (CQT) was achieved through the use of REM with CCTV (Dalskov and Kindt-Larsen, 2009). This project included several different gear types and class of vessel, with systems being installed on six otter trawlers, one Danish seine vessel, and one gill netting vessel, with a vessel size range of 14-31m (Dalskov and Kindt-Larsen, 2009). Initially, the focus was on commercial finfish species, mainly cod, but the inclusion of the small inshore gill net vessel allowed scientists to assess the technology's suitability for monitoring bycatch of ETP species, and a specific trial to monitor the bycatch of harbour porpoise was undertaken. This pilot trial was conducted for 1 year between May 2010 and May 2011 on six vessels <15m in overall length which targeted cod and plaice (*Pleuronectes platessa*) using trammel or gill nets in the North Sea, Skagerrak and Øresund areas. Each vessel was fitted with a REM system that comprised a control box with a removable hard drive, two to four CCTV cameras, a GPS system, and a hydraulic pressure sensor to detect fishing activity. Because the main aim of the project was to detect harbour porpoise bycatch, events one of the cameras was set up to capture video of the net being hauled clear of the water surface, where accidental dropouts or deliberate cut-outs could be viewed. This was a self-reporting project and the fishers were required to record all marine mammal interactions, with the REM system acting as a verification tool.

This trial successfully recorded data from 758 active fishing trips and observed 36 bycaught harbour porpoises during video review, even though the fishers only declared 25 bycaught cetaceans for the same trips. It was thought that some of the non-reported events were due to fishers being distracted on other duties at the time of the interaction and failing to see the cetacean drop out of the net, but seven cetaceans were actively disentangled by the crew (activity captured on the video)

Figure 9. A Danish gill netting vessel fitted with Electronic Monitoring equipment (courtesy of Lotte Kindt-Larsen, 18th February 2020)

although the fishers failed to report these events. The final report concluded that REM was more accurate for collecting bycatch data than using the fisher self-reported data alone. There were additional advantages of being able to monitor bycatch mitigation measures, removal of observer effect influence and possible bias, and a permanent record of the events for cross-checking and providing to the industry if requested. This project proved that REM was a suitable tool for monitoring and quantifying cetacean bycatch (Kindt-Larsen *et al*., 2012), and led to the implementation of an operational bycatch monitoring programme in the Danish commercial gillnet fleet (Figure 9).

The total cost of the marine mammal bycatch project aboard the six gillnetting vessels was calculated at €80,100. The breakdown of this cost is shown in Table 21, and included all aspects of undertaking an operational REM monitoring programme with 100% video review. Reviewing 100% of the recorded video was possible because it could be watched at up to 12 times normal speed for cetacean monitoring. Obviously if a programme is required to monitor and report other taxa, such as rare fish species, birds, or compliance issues, or litter catches, then review rates will be significantly slower and will vary depending on time of day, light conditions, weather, cleanliness of cameras, and aims of the programme. The only adjustment that perhaps should be made to enable costs to be compared to observer costs, is linked to who undertook the actual video review. In this project, students were used at an hourly rate of €16/hr whereas core DTU staff would have cost €36/hr, but it would be unlikely that students would be used as an observer in an observer programme. If DTU staff were used, the overall staff costs would be revised from €14,600 to €32,886, and the overall project cost from €80,100 to €98,363, for a total of 811 fishing days of data (Kindt-Larsen *et al*., 2012), an average of 135 days per vessel. This overall cost equated to €16,395 per vessel to collect and review all sensor data and video footage collected for one year, or €121 per fishing day observed (see Table 21). Although no differences between the results obtained by students and those obtained by research staff were detected, for the purposes of this case study example, the higher cost of using experienced research staff, rather than students, is used here. This is chosen because some countries may not have the option of recruiting cheaper students (perhaps due to local union rules), or local stakeholders may wish to see video reviewed by experienced staff for reassurance purposes, and to allow the cost to be more directly compared against the observer programme costs.

The cost of a Danish at-sea observer, under the DCF programme, was quoted as €667 per day and included salary costs, at-sea bonuses, and associated travel costs. This daily cost was calculated from the total cost of €540,667, to monitor 811 days at sea in 2011 (Kindt-Larsen *et al.*, 2012). The 2011 Danish cost data is nearly 10 years old and will be out of date but in the absence of another source, this was used. However, an attempt has been made to make this information more current by examining the Danish inflation rates since 2011 and applying these to the costs of an observer. It is acknowledged that salaries seldom rise in line with

Table 21. The costs associated with Danish marine mammal bycatch REM trials undertaken on gillnetting vessels in 2011. Two different review staff costs are shown. The higher cost in brackets is to use DTU science staff for video review, whilst the cost outside of the brackets is the cost to use a student for video review (Kindt-Larsen et al.*, 2012).*

Item	Unit Cost (€)	Quantity	Total Cost (€)
Purchase and Installation of REM Systems	10,200 per REM System	6 REM systems	61,200
Video and Sensor Data Review at Student Rate and DTU Staff Rate shown inside brackets	16 (**36**) per hour	913 hours	14,600 (**32,868**)
Technical Support and Maintenance	717 per year	6 REM systems	4,300
Running Costs	3150 per year	6 REM systems	18,900
		Total Cost	80,100 (**98,363**)

inflation but also they seldom reduce with time (unlike technology costs which do generally reduce with time); in the absence of current cost data, this approach was chosen for estimation purposes.

The national inflation rates in Denmark have typically been less than 0.8% each year since this 2012 study was completed (Source: Tradingeconomics.com; accessed 3rd March 2020), so these costs should not have increased by more than approximately 8% since 2012. For simplicity we will assume that there has been a 10% rise in the at-sea observer programme costs, then this would raise the daily cost of an observer to €734/day. For the REM costs, we will use those calculated in this report to keep the approach used in this case study consistent with the other case studies presented.

In 2018, it was reported that 66 Danish fishing vessels undertook 8,910 days of gillnet fishing in the North Sea and Skagerrak (excluding the Baltic Sea) (EC, 2020), which is an average of 135 days per year per vessel. Using the revised observer programme cost data for Denmark of €734/day (as described earlier), it was possible to estimate the costs associated with undertaking 5% and 10% monitoring of the fleet using observers (Table 22) at €326,997 and €653,994, respectively. If 100% fleet coverage was required it would cost an estimated €6.54 million to undertake an observer programme on 100% of all trips and days (8,910 days) fished in the gillnet fisheries.

When the 2-camera REM systems are installed on all 66 vessels they collect accurate positional data, fishing activity sensor data, and video data for 100% of days fished, but video review rates can be tailored to the available budget or needs of the programme. At 5% video review, the use of REM would cost €346,338 and be marginally (6%) more expensive than sending observers (total cost €326,997) to sea on 5% of the fishing days (446 days). However, when the monitoring levels are increased to 10% (891 days), using observers becomes considerably more expensive at €653,994, than using REM, at €354,228, i.e. is approximately 85% more expensive than using REM. If the monitoring rate was raised to 100% then REM would cost €496,248 (or €7,519/vessel/year) and observers would cost €6,539,940 (€99,090/vessel/year). Using observers would be over 13 times more expensive than using REM (see Table 23).

As with the UK gillnet example described earlier (Case Study 1), if the video review rate decreases due to an increase in variety of sensitive species being monitored, then overall costs of using REM will increase. Table 24 shows the estimated costs associated with a review rate of 4 times normal speed using the same 2-camera REM system. The costs of using REM increased by approximately 9% when monitoring 10% of the collected video at 4 times speed compared to 12 times speed, but is still 70% cheaper than using observers.

If a programme opts to only install REM on a reference fleet to obtain the required levels of coverage and then review 100% of the video footage collected by these vessels, then the cost differences between using observers and using REM become even larger. For example, a 10% REM reference fleet where 100% of data collected is reviewed, would cost €35,896 ((€3381+€1747) x 7) to purchase, install and operate the seven REM systems for a year. The video data review time and management time would take 79 days (0.34 of a man year) to monitor the 945 (135 days x 7 vessels) sea days at 12 times normal speed, and cost approximately €16,524. This would be a total cost of approximately €52,420 (c. €7489/vessel/year), compared to the estimated total cost of €653,994 to undertake the observer programme on 891 days (10% of fleet effort), or €354,228 to install on all 66 vessels, and review only 10% of their footage at 12 times speed. All methods review 10% of the fleet's effort, although of course installing on all vessels also allows 100% of their fishing effort and GPS data to be monitored and recorded, even though it may not all be reviewed.

The use of a reference fleet provides the highest cost

Table 22. Estimated costs associated with the Danish gill net fishery to monitor cetacean bycatch using at sea observers.

Method	Number of Vessels 2018 data	Total Days at Sea	Cost per Day[1] (€)	5% Days at Sea	Cost of 5% Coverage (€)	10% Days at Sea	Cost of 10% Coverage (€)
At-Sea Observer	66	8910	734	446	326,997	891	653,994

[1]Due to a lack of official detailed cost data for the observer programme, the costs were estimated from those provided in the 2011 REM project (Kindt-Larsen et al. 2012) and increased by 10% in an attempt to account for and cost increases due to inflation.

Table 23. The estimated costs to monitor, 5%, 10 and 100% of the Danish gillnet fisheries using a 2-camera REM system at 12 times normal speed video review rates.

Item	Cost per Year	Costs (€) and Time Associated with Installing on 66 Vessels and Reviewing 5% of Days Fished	Costs and Time Associated with Installing on 66 Vessels and Reviewing 10% of Days Fished	Costs and Time Associated with Installing on 66 Vessels and Reviewing 100% of Days Fished
Hardware and Installation on 100% of Vessels – 2-camera	3381	223,146	223,146	223,146
Annual Running Costs for 100% of Vessels	1747	115,302	115,302	115,302
Fishing Days to be Monitored		446 days	891 days	8910 days
Total Reviewing Time at 12x Normal Speed	-	37 days	74 days	740 days
Number of Video Reviewers Required (rounded up) and Cost (€)	38,910	37/235 = 0.16 man-years = 6,226	74/235 = 0.32 man-years = 12,452	740/235 = 3.2 man-years = 124,520
Management staff costs per reviewer	10,400	1,664	3,328	33,280
Total Cost using REM		346,338	354,228	496,248
Total Cost Using Observers (see Table 22)		326,997	653,994	6,539,940

savings but may provide the least random or least representative data. As previously discussed, the reference fleet needs to be representative of the non-monitored vessels, otherwise bias will be introduced, and the data will not represent what the non-monitored fleet are doing. Sensor and GPS data can be analysed almost automatically by most REM providers' software and this can be compared relatively easily against VMS recorded to at least determine if the reference fleet and non-reference fleet have similar fishing patterns. However, if the same budget that was available to a 5% observer programme (€326,997) was also available to the REM programme using a reference fleet where each vessel costs €7,519/year, then it would allow 43 vessels to be installed with REM, and 100% of their data reviewed at 12 times normal speed, equivalent to over 65% coverage of the fleet.

Table 24. The estimated costs to monitor, 5%, 10 and 100% of the Danish gillnet fisheries using a 2-camera REM system at 4 times normal speed video review rates.

Item	Cost per Year	Costs (€) and Time Associated with Installing on 66 Vessels and Reviewing 5% of Days Fished	Costs and Time Associated with Installing on 66 Vessels and Reviewing 10% of Days Fished	Costs and Time Associated with Installing on 66 Vessels and Reviewing 100% of Days Fished
Hardware and Installation on 100% of Vessels – 2-camera	3381	223,146	223,146	223,146
Annual Running Costs for 100% of Vessels	1747	115,302	115,302	115,302
Fishing Days to be Monitored		446 days	891 days	8910 days
Total Reviewing Time at 4x Normal Speed	-	112 days	224 days	2228 days
Number of Video Reviewers Required (rounded up) and Cost (€)	38,910	112/235 = 0.48 man-years = 18,677	224/235 = 0.95 man-years = 37,354	2228/235 = 9.5 man-years = 373,536
Management staff costs per reviewer	10,400	4,992	9,984	99,840
Total Cost using REM		362,117	385,786	811,824
Total Cost Using Observers (see Table 22)		326,997	653,994	6,539,940

Conclusions

When considering the most appropriate tool for monitoring a fishery, it is important to consider which data you need to collect and how often the events of interest are likely to occur. For example, if it is a very common event but also important that biological information and samples are collected during the project, then it is appropriate that there is a physical researcher presence aboard the vessel. Or alternatively that there is industry engagement and cooperation to allow fishers to collect these samples on behalf of the project. If it is important to get accurate data independent of the fishing industry, perhaps because they could be affected by the result, then it is necessary to remove the fishers from the sampling process completely and have the data collected by independent means, such as an at-sea observer or REM.

This report has reviewed the various monitoring options available to scientists and detailed the difference between electronic recording and electronic monitoring, and also described the different components that make up a full REM system.

The terms of reference for this report specified that the focus of the report should be on monitoring cetacean bycatch. It was concluded that there are currently only three viable options available for collecting cetacean bycatch data. These are self-reporting by fishers (via Elog or paper records), deploying at-sea observers, or monitoring using REM with CCTV.

Fisher self-reporting does allow data to be collected extremely cheaply but it cannot easily be verified and has been reported to be inaccurate and prone to under-reporting. This applies whether the self-reporting is undertaken using paper logbooks or electronic logbooks (Elogs), especially for catches that must be discarded at sea e.g. protected species. REM allows all declared bycatch incidents to be verified by reviewing the collected video. The fishing time where no declared cetacean or ETP/sensitive species bycatch has been made can also be checked to ensure that incidents of bycatch have not gone unreported. This can be done by reviewing all collected video at high speeds or through a random subsample of the video data.

At-sea observers are able to collect accurate bycatch data and also undertake biological sampling of any cetaceans that they encounter, but they are limited to only being able to record what they physically see. They cannot monitor more than one location on board at any one time. If there is more than one area on board the vessel where bycaught cetaceans can be detected or discarded simultaneously, additional observers will be required to ensure full coverage of all areas. If vessels are pair trawling, then the catch may be landed by either vessel, so an observer will be needed on each vessel to ensure full monitoring. This means that two observers are required to monitor one net, effectively doubling the costs. Of course, REM would also require a system to be installed on each vessel but only footage from one system would need to be reviewed to monitor that hauling operation. During rest periods, observers will not be able to monitor fishing operations and may miss bycatch events.

Few countries undertake dedicated protected species monitoring programmes and observers are generally deployed under the DCF observer programme to meet the EU-MAP obligations. The focus of the DCF programme is primarily to monitor and quantify the discarded and retained commercial fish catches, but there is also a requirement to undertake monitoring and sampling of ETP species. Observers can become overwhelmed with monitoring tasks at sea and if they are busy sampling fish below deck on a sorting conveyor, they may miss bycatch events happening at the surface of the water.

The current coronavirus pandemic has highlighted an additional vulnerability associated with using observers. If they cannot be deployed due to an unexpected event (e.g. pandemic, political decisions leading to poor relationships between fishers and scientists, observer illness or other reasons), then they cannot collect data. REM on the other hand will continue collecting GPS, fishing activity sensor and video data, remotely and automatically. These data can then be reviewed ashore at a later date. The levels of monitoring will not be reduced or stopped altogether if using REM, assuming that the system can be easily maintained and remains functioning (and monitored) and local arrangements (perhaps with the fishers) are made to swap out hard drives as required. Solely using observers will lead to long periods of data with no monitoring and data gaps in time series as is now happening with observer programmes.

REM has been shown in various projects to be able to collect data on the vessel's location at any time through the use of GPS, its fishing activity through the use of sensors that are triggered by hauling events and the interpretation of speed and track data, and the catch and gear handling processes, including bycatch events through the recording of video imagery by CCTV. By having multiple cameras, it is possible to cover all possible areas where cetacean interactions can occur, simultaneously. Reviewing the collected video data can be undertaken independently of the fishing industry or of any others who may have a vested interest in a particular outcome, to ensure that all parties accept the results. Also, because there is recorded video evidence of the event, it can be used to allay any doubts through corroboration, by having multiple experts review the footage in a disputed incident or to check species identification.

When REM was first introduced as a monitoring option, the main argument being raised against it was cost as it was perceived to be an expensive alternative to at-sea observer programmes. But this perception was usually based on a short-term view of monitoring and a lack of understanding of what the costs involved were. The focus was always on the cost to initially buy the equipment and install it, rather than considering how those costs are spread over the lifetime of the programme. To buy a system initially can cost approximately €10,000 or slightly more, depending on the supplier, but the equipment will work and remain monitoring for several years, often in excess of 5 years. Skilled video review staff are required to ensure the information collected is accurately interpreted but instead of being placed in one of the harshest and most dangerous working environments possible for the full duration of a fishing trip, they are based in a safer office or home environment. This also removes the need to provide staff with expensive PPE and safety training that has to be maintained and renewed on a regular basis, if they are never required to go to sea.

When monitoring for cetaceans only, REM analysts are able to review a hauling operation at up to 12 times normal speed, meaning that they can complete data analysis on multiple trips in a very short time. The review rates will depend on what is actually being monitored, and will be slower if video is being reviewed for all sensitive species and not just cetaceans. Literature suggests that the video review rates for all ETP species monitoring would range between 4 and 9.8 times normal speed, so a cost comparison between 12 times speed and 4 times speed was presented for each of the case studies. It showed that the slower rate did increase the costs associated with REM but only marginally (less than 9%) at 10% monitoring levels of the fleet.

The fishing activity sensors also allow this reviewing effort to be directed only to the times when the vessel is hauling, unlike an observer who is present on board for the whole trip and all activities. This process could be streamlined further if a form of self-reporting (with some means of random checking) by the fishers was built in to the project, as reviewers could check these incidents first and then perhaps review a percentage of the remaining footage to ensure all incidents are being accurately reported. This review rate will depend on how reliable the self-reported data is considered to be. In some fisheries, it may be appropriate to review 100% of the footage at high speeds initially which can be reduced, as each fisher's self-reporting reaches agreed thresholds. To enable this improved reporting requires good communications to ensure that any anomalies are not considered as criticism, but to also allow the fishers to realise that their data are being checked and that their participation and performance in the programme is important.

Video review can be focused on the periods of interest by using self-reported data, but it could also be focused by using machine learning to automatically identify the times where suspected interactions occur. There would still need to be an element of quality control review of other non-identified fishing activity but developing software that reduces video review requirements in this way would significantly reduce catches and make using REM a more efficient monitoring option.

By using different case study fisheries, we were able to compare the costs associated with undertaking cetacean monitoring using observers or by use of REM. These were a hypothetical inshore gillnet fishery in the UK, the French small pelagic pair trawling fishery operating in the Bay of Biscay, and a Danish gillnetting fishery. In all cases it was more cost effective to use REM than at-sea observers if high levels of fleet coverage were required. This was the case even when the video review rates were reduced to 4 times normal speed to allow all ETP species to be monitored. The highest savings were found in fisheries where there were low numbers of vessels undertaking high numbers of days at sea, e.g. the two gillnet examples.

In the pelagic fishery case study, REM cost more to use for a 10% level of fishing effort coverage but only if REM had been installed on all 65 vessels and only 10% of the collected video reviewed. A better option in this fishery would be to undertake a reference fleet approach. It was shown that the cost to operate and review 100% video (at 12x normal speed) on one of these vessels for a year would be approximately €6,424 (€417,535/65 vessels, and to undertake 10% observer coverage would be €322,080. If the observer budget was diverted to REM, it would allow 50 of the 65 vessels in this fleet to have REM installed and 100% of their fishing effort and video monitored, compared to the 10% using observers.

REM with CCTV is a cost effective and appropriate tool for monitoring the number of cetaceans or ETP species caught during fishing operations. The main limitation of REM is that it cannot collect biological samples from bycaught animals. Some of these data are possible to estimate. For example, some of the REM systems have inbuilt length estimation tools that use known on-screen image reference points to measure catches and gear e.g., the length of a fishing beam used in the Scottish scallop fishery. Other projects have asked the fishers to measure fish discards below a camera (Course *et al.,* 2011) to obtain length frequency distributions of a known number of fish (cod), and then applied this to the total number of discard cod counted being discarded. If a REM programme is designed so that fishers are trained and tasked with collecting biological data or are provided with dispensations (and incentives) to bring samples ashore, then this limitation could be reduced or overcome. Developments in smaller portable REM units may also allow systems to be swapped relatively simply between vessels, so that there is no need to install permanent REM on all vessels.

This report has been presented in a way that allows the different monitoring methods to be evaluated as separate tools in relation to costs. But this does not mean that only one monitoring tool should be used or that the cheapest tool is the most appropriate in every fishery or monitoring scenario. The choice of monitoring method is dependent on what the aims of the programme are, what the available budget is, how improving quantity of data (levels of coverage) will improve the confidence limits and utility of the data, how accepting are the stakeholders of the monitoring methods used, and how the programme is implemented (mandatory or voluntary). Perhaps combining both tools is the best approach. REM could be combined with an element of self-reporting where fishers report all ETP bycatch events on all vessels and in all fisheries. Then observers are deployed on a subsample of the fleet to collect commercial catch data, discard data, fishing effort data, ETP bycatch data, and biological samples. REM monitoring for ETP species, combined with a DCF style observer monitoring programme may allow high levels of fishing effort monitoring for fisheries where collecting these data using dedicated ETP observers or DCF observers is problematic and expensive.

Recommendations

Below is a list of possible recommendations and future developments related to the use of REM as a monitoring tool for ETP bycatch.

- The development of a portable "lite" REM system may allow for the inexpensive reference fleet approach to be adopted with the potential to switch the REM system on to different vessels for limited periods of time, e.g. 2 months. Vessels could be selected through a random selection process. This will allow fleet monitoring levels to be increased without the need to install systems on all vessels, and will also help reduce any bias associated with vessel selection. This development will only occur if suppliers of REM are confident that there is a market for the developed product, but this development will be reliant on scientists and programme managers accepting REM as a monitoring tool and with demand driving the development process.

- Machine learning software has the potential to develop algorithms that can identify species, and gender, and measure bycatch from imagery collected from REM. Several companies and research projects are exploring this technology but, so far, no reliable software has been brought to market for multiple species and fisheries. The potential to reduce video review time to an automated process will speed up the adoption of REM as a monitoring tool, but again these developments will not occur unless there is a significant demand and acceptance of REM in the first place. This will need programme managers, scientists and other stakeholders to put pressure on policy makers to implement REM as a monitoring tool. In some countries and fisheries, this acceptance has already occurred (e.g. USA, Canada, New Zealand, Ghana), but there seems to be a reluctance in Europe to embrace REM and initiate a full large-scale monitoring programme.

- ETP monitoring programme managers should consider trialling REM on some fleet segments and experiment with using the equipment and how the data will feed into their population or bycatch estimation models. It will allow protocols for data collection and data use to be established. It will help introduce REM as a normal monitoring tool to the fishers and help develop codes of practice between fishers, scientists, and policy makers.

- REM could be mandated in the same way that DCF observers are mandated, i.e. if approached to carry REM (observer) then it must be carried unless safety and space make it inappropriate to do so. This would be especially useful on small vessels where observers are unable to sample because of lack of space or because of a programme's internal safety policy.

- The submission of data to the appropriate working groups e.g. WGBYC, needs to be significantly improved using appropriate formats. The lack of reliable fishing effort and cost data has made comparing monitoring methods extremely difficult, and both ICES and STECF have been critical of the data. The data can also be up to two years old before it is published, whereas REM may allow information to be available quicker due to some of the automated processes.

- To improve the fishing fleet data, the carrying of electronic equipment specifically to monitor fleet fishing effort should be mandatory for all commercially registered vessels. This should allow position, time and fishing activity (through the use of sensors or algorithms that identify activity based on GPS generated speed and direction) to be identified automatically and relayed to fishery managers/ scientists in near real time. Some vessels may not have a reliable power supply and so be unable to operate a full REM system but recent developments in solar tracking devices will allow tracking and assumed fishing activity to be estimated.

- The implementation of REM should be considered in a verified self-reporting project to determine if fishers are willing and able to provide reliable ETP bycatch data. Incentives should be considered, and reassurances provided to help reduce the "fear factor" associated with reporting these events. Good communication will be essential.

- Some suppliers offer "open source" software options for video review and other purposes, and this removes the need to pay for software licensing and should provide cost savings to REM programmes. Developments in this "free" software option may make REM more affordable for some fisheries but there needs to be research and development funds available to properly explore this as an option. However, it may also disadvantage those companies that have invested large amounts of capital in software development and perhaps market forces will dictate how software development progresses.

- Observer programme managers and observers need reassurance that REM is not a threat to their livelihoods. REM is another data gathering or self-reporting verification tool. REM does not have to be seen as a replacement for observers. It should be considered as a complementary monitoring tool that gathers large quantities of overview information rather than the detailed biological data gathered by observers. The video that is collected by REM must be reviewed, and observers are also ideal for undertaking this role too.

- REM is a powerful tool and until one has used it properly and seen what it can do, it cannot be fully appreciated, so trial it as part of your monitoring programmes. It is always compared against observers with respect to the data that can be collected by REM or an Observer, but it should be thought of as a different tool for different data collection needs, and for overcoming any observer programme's logistical issues or bias encountered.

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Appendix 1

Requested data from ASCOBANS party states and their responses.

An email requests for "contact details for the managers responsible for marine mammal observer programmes in your country in the ASCOBANS Area" was sent on 25th November 2019 by the ASCOBANS secretariat. A request for information was sent by the author on 3rd December 2019. Then again on 24th January 2020, a data request table (Table 25) completed with example data to demonstrate how it should be completed, was also sent to all national observer programme managers. The responses to these requests are shown in Table 26. Unfortunately, very little data or responses were received and so on the 19th February 2020 the decision was made to continue without the missing data and to try and obtain information via other sources, such as WGBYC and DCF.

Table 25. The data request table sent to party states, with example fictitious data, to show how the table should be completed.

Country XXXX			
Year	2016	Currency	
Total Cost of Observer Programme/s (Euros)	500000	Euros	
Metier/Gear	**Number of Days Monitoring with an Observer Onboard**	**Total Number of Days Fished by Fleet**	**Number of Bycatch or Drop Out Cetaceans Observed**
GNS	50	1083	5
OTM	60	8207	2
PTM	70	3000	0
OTB	100	4000	0
LLD	10	80	0
Country XXXX			
Year	2017	Currency	
Total Cost of Observer Programme/s (Euros)	550000	Euros	
Metier/Gear	**Number of Days Monitoring with an Observer Onboard**	**Total Number of Days Fished by Fleet**	**Number of Cetacean Bycatch Observed**
GNS	150	2000	2
OTM	70	8000	0
Country XXXX			
Year	2018	Currency	
Total Cost of Observer Programme/s (Euros)	300000	Euros	

Country XXXX			
Metier/Gear	**Number of Days Monitoring with an Observer Onboard**	**Total Number of Days Fished by Fleet**	**Number of Cetacean Bycatch Observed**
GNS	100	1000	1
OTM	60	4000	1
OTB	5	5000	0

Table 26. National programme managers responses to the cost and sampling effort data requests made specifically for this report.

Country	National Expert Response to the Specific Data Requests
Poland	Provided data as per request.
UK	UK was unable to provide the information due to work commitments but recommended that the annual reports that were submitted to Defra and WGBYC reports should be used instead.
France	Initially too busy but provided Case Study data via personal communications with ASCOBANS (Peter Evans), but not complete data as per request.
Belgium	Provided data as per request but there may be issues due to effort data being converted from hours to days, by dividing by 24.
Netherlands	No response to original request but data was subsequently provided that stated that a 5-year pilot project using REM has been undertaken with 14 small scale gillnet vessels at a total cost of €700,000.
Denmark	Would investigate and respond when less busy, but unfortunately no data was available.
Finland	No response.
Germany	Did not have a programme manager and so no contact details provided to contact.
Lithuania	No response.

Appendix 2

List of REM suppliers contacted who were able to provide detailed cost and system specifications. An additional provider was contacted but did not respond.

- 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

Appendix 3

Guide to the different levels of IP rating on equipment

Table 27. IP Ratings Table (Source: www.mpl.ch/info/IPratings.html)

I.P.	First digit: Ingress of solid objects	Second digit: Ingress of liquids
0	No protection	No protection
1	Protected against solid objects over 50mm e.g. hands, large tools.	Protected against vertically falling drops of water or condensation.
2	Protected against solid objects over 12.5mm e.g. hands, large tools.	Protected against falling drops of water, if the case is disposed up to 15 from vertical.
3	Protected against solid objects over 2.5mm e.g. wire, small tools.	Protected against sprays of water from any direction, even if the case is disposed up to 60 from vertical.
4	Protected against solid objects over 1.0mm e.g. wires.	Protected against splash water from any direction.
5	Limited protection against dust ingress. (no harmful deposit)	Protected against low pressure water jets from any direction. Limited ingress permitted.
6	Totally protected against dust ingress.	Protected against high pressure water jets from any direction. Limited ingress permitted.
7	N/A	Protected against short periods of immersion in water.
8	N/A	Protected against long, durable periods of immersion in water.
9k	N/A	Protected against close-range high pressure, high temperature spray downs.

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