Review of optimal levels of observer coverage in fishery monitoring

Consultant Report

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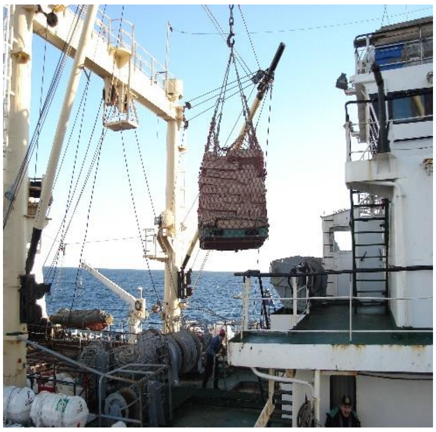
Marine Stewardship Council



Review of optimal levels of observer coverage in fishery monitoring

Marine Stewardship Council

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MRAG

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Table of Contents

List of Tables

List of Figures

Acronyms

CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CV	Coefficient of Variation
EEZ	Exclusive Economic Zone
EM	Electronic Monitoring
ER	Electronic Recording
ELB	Electronic Logbook
ETP	Endangered, Threatened or Protected
FAD	Fish Aggregation Device
FAO	Food and Agriculture Organisation
FIFD	Falkland Islands Fisheries Department
GARFO	Greater Atlantic Regional Fisheries Office
GoM	Gulf of Mexico
HMS	Highly Migratory Species
HO	Human Observation
ICCAT	International Commission for the Conservation of Atlantic Tunas
IPOA-IUU	2001 International Plan of Action to Prevent, Deter, and Eliminate IUU Fishing
LL	Longline
NGO	Non-Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
POP	Pelagic Observer Program
REM	Remote Electronic monitoring
RFMO	Regional Fisheries Management Organisation
SD	Standard Deviation
SEFSC	Southeast Fisheries Science Centre
SLED	Seal Exclusion Device
tRFMO	Tuna Regional Fisheries Management Organisation
TAC	Total Allowable Catch
WCPFC	Western and Central Pacific Fisheries Commission

1. Introduction

This report can be considered as a follow up to a previous report commissioned by the MSC '*Review of good practice in monitoring, control and surveillance and observer programmes'*. It focusses on observer programmes themselves and is a review of evidence on optimal levels of fishery monitoring, including the scientific basis for different coverage levels and global differences in best practice. According to the terms of reference (ToR) the report has been divided into two main sections, outlined below.

1 Literature search for studies into the optimal levels of observer coverage (human or electronic).

> A) Compile a list of research undertaken on optimal levels of fisheries observer coverage, considering both the academic and fisheries management literature; this should focus on research undertaken in the last decade, although earlier studies may be included if they remain relevant.
>
> B) Provide a brief description for each study, including its aims and main findings.
>
> C) Identify any regional or fishery-specific differences in what is considered to be an optimal level of observer coverage and briefly discuss possible reasons.

2. Discuss the scientific basis for different observer coverage levels with respect to management objectives around the quality of monitoring information.

> A) Using examples, summarise how setting levels of observer coverage may be used to achieve a certain level of precision in estimates (of catch, bycatch, etc).
>
> B) Conclude the strength of the relationship between the level of observer coverage and the precision of estimates.

2. Previous Studies

The following section summarises the main studies considered relevant to observer coverage. In line with the ToR it has reviewed the most recent reports, although older studies that are still relevant and have also been included. A general discussion of observer coverage rates is followed by a brief review of studies into the subject.

The design of at sea observer programmes, including the coverage rates, will largely depend on the management objectives of the fishery. These were broadly defined at a 2003 NMFS fisheries observer coverage workshop (NMFS 2004b) as:

- catch/effort monitoring for in-season management and/or stock assessment;
- bycatch monitoring for in-season management and/or stock assessment;
- protected species monitoring;
- technical monitoring for better understanding of fishing effort and catch per unit effort; and
- compliance monitoring.

More recently there has been a drive to monitor crew welfare and general safety on fishing vessels. Although not classified as observers per se they are undertaking a similar role as compliance observers, checking that certain standards are being met and advising officers on vessels how to meet these standards where required. This has recently been introduced in the Falkland Islands squid jigger illex fleet, five Jigger Safety Advisors (JSAs) are required to monitor the fleet of ~105 vessels. Although not discussed in any detail here it is likely that this role will become more prominent in the future given the increasing social concerns highlighted in some fisheries

At-sea observer programs are normally accepted as reliable and accurate sources of data collection needed to meet the objectives outline above. For example, a program providing data for protected species bycatch will require a high level of coverage whereas data estimating total catch of target fish will require much lower levels of coverage (Brooke 2014).

The most accurate and reliable data will come from fisheries with 100% observer coverage and include total catch accounting as well as quantification and characterization of endangered species interactions. For example, all CCAMLR fisheries require 100% coverage of all their fisheries (of vessels, but not effort), and observation effort includes target, bycatch as well as ETP species.

However, due to financial and logistical constraints, 100% coverage is usually not feasible and often also not always necessary. Many observer programmes, particularly those required by Regional Fishery Management Organisations (RFMOs), aim for 5% coverage and even then rarely achieve this level. For instance the uptake on the IOTC programme[1] , which shows than many Member States currently submit no observer data despite accounting for the majority of catches (although these are mainly though artisanal fisheries with limited capacity). Observer placements are often made on an opportunistic basis, not all vessels are willing to accept an observer, some vessels may be unable to accommodate an observer (an extra 'non-fisherman' body) and some may be too small and considered to be unsafe. Additionally, suitably trained observers may not be available for deployment in the region (Lawson 2006). Taking into account political, social and economic considerations recruitment and training of often depends on local circumstances. Fishery observer programs may not be a priority in the region due to lack of funds, political and fishery support, and access to proper equipment (FAO).

[1] https://www.iotc.org/documents/SC/23/07E

Generally, an observer coverage rate of 5% is thought to be enough to identify areas and seasons in which bycatch occurs, detect common bycatch species that has a low variance and estimate total catch of target fish. Fisheries at low risk of encountering endangered or protected species, causing habitat damage, or those that are not involved in a catch share program may only require 5% or less to achieve the desired certainty in the data collected. In the case of shore-based fisheries, activity takes place on land or within view of land, fishing gear is extremely selective and often there is dockside monitoring or similar.

Fisheries will require more than 5% observer coverage when estimating ETP species bycatch, when a bycatch species is a statistically rare event, when bycatch limitations restrict target species harvest or when monitoring for regulatory compliance is a priority (Brooke 2014). The amount of coverage will also depend on varying risk factors such as the area in which the fishery is operating, the gear used, and the mitigation efforts used.. The definitive study on this remains Babcock and Piktch 2003 which states that the amount of coverage needed to achieve the desired level of precision of bycatch estimates for ETP species would be a minimum of 50%.

In order to extrapolate more common bycatch rates to the whole fishery, coverage should be a minimum 20% of the total fishing effort (Babcock and Pikitch 2003; Wolfaardt 2015; Black et al. 2008). Assuming an unbiased sample of the fishery, observer coverage at 20% reduces the coefficient of variation of common bycatch species (accounting for 35% or more of the catch) estimates to nearly 10% of the actual catch level. When observer coverage is less than 20%, the coefficient of variation increases exponentially. Conversely, as coverage increases above 20% the coefficient of variation decreases in smaller increments as coverage approaches 100% indicating little is gained with more coverage (Wolfaardt 2015; Black et al. 2008; Debski, Pierre and Knowles 2016). To achieve a similar level of accuracy, rare species (bycatch less than 0.1% of catch) would require more than 50% observer coverage (Babcock and Pikitch 2003; Debski, Pierre and Knowles. 2016). These rates are dependent on the variability and distribution of catch and bycatch within the fishery. More variable catches require a higher level of coverage (>50%) in order to accurately estimate species (target and bycatch) caught. More details of this are found in Section 2

RFMOs also require a certain level of coverage. As discussed the five tuna RFMOs (tRFMOs) require a level of 5% of fishing effort, although this is rarely achieved. CCAMLR[2] requires and achieves 100% coverage of all vessels in all fisheries, in some cases requiring two observers per vessel in areas considered to be exploratory. A comprehensive review of observer requirements and coverage for 16 RFMOs and CCAMLR was undertaken by Ewell *et al.* (2020), while precise coverage levels were not given it did provide a general overview of the current situation. Although not all the criteria are relevant to this particular study it does give an overview of some of the important issues, these have been updated where appropriate and summarised in Table 1.

Table 2 goes on to summarise some of the key literature reviewed with regards to coverage, giving the reference, area it applies to and the aims, findings and conclusions. Table 3 and Table 4 look at current programmes and studies utilising REM technology.

[2] CCAMLR is not an RFMO but a conservation organisation that allows ration use of resources.

Table 1 Summary of RFMO observer requirements (adapted from Ewell *et al.* (2020))

RFMO	Regional Policy?	Data Public?	Summary reports available?	Right to access logs?	Different flag state?	Observers for some gear/ areas/species?	100% of fishing vessels?	100% of carrier
CCAMLR	Y	N	N	Y	N[a]	Y	Y	N
CCBSP	Y	N	N	Y	N	Y	Y	N
CCSBT	Y	N	N	N	N	Y[b]	N	Y
GFCM	Y	N	N	N	N	N	N	Y
IATTC	Y	N	Y[c]	Y	N	Y[d]	N	Y
ICCAT	Y	N	Y[e]	Y	N	Y[f]	N	Y
IOTC	Y	N	Y[g]	Y	N	Y[h]	N	Y
IPHC	Y	N	N	N	N	Y[i]	N	N
NAFO	Y	N	N	Y	N	Y	Y	N
NASCO	N	N	N	N	N	N	N	N
NEAFC	Y	N	N	N	N	Y[j]	N	N
NPAFC	N	N	N	N	N	N	N	N
PSC	N	N	N	N	N	N	N	N
SEAFO	Y	N	N	Y	N	Y	Y	n/a
SIOFA	Y	N	N	N	N	Y[k]	N	N
SPRFMO	Y	N	N	Y	N	Y[l]	N	N
WCPFC	Y	N	Y	Y	N	Y[m]	N	N

[a](CCAMLR has required 100% coverage using international observers on toothfish and icefish vessels and since the 2020/21 season 100%for krill. Flag states are allowed to use national observers on krill vessels as CCAMLR observers)

[b] (10% of all fishing vessels)

[c] (contracting parties)

[d] (5% for longline vessels, 100% for purse seines and in Antigua area)

[e] (only transshipments)

[f] (20% bluefin tuna longlines, 100% bluefin tuna purse seines, cages, towing vessels and farms, 5% Mediterranean swordfish longliners)

[g] (only transshipments)

[h] (5% of all fishing vessels)

[i] (~20 vessels)

[j] (exploratory bottom fishing)

[k] (100% bottom trawls, 20% other bottom fishing gear)

[l] (10% sea days for jack mackerel, 5% sea days or 5 full time at sea observers for jumbo flying squid, 100% AFMA fisheries within SPRFMO)

[m] (5% for longline vessels, 100% for purse seine vessels)

Table 2 Summary of studies into observer coverage.

Study	Fishery	Description, aims and findings
Babcock and Pikitch (2003)	All, but US specific	Looked at the level of coverage required to adequately estimate bycatch. It concluded that levels of coverage should be at least 20% for common species and 50% for rare species, assuming no financial restraints and an unbiased section of the fishery is sampled. In areas where low levels of mortality may jeopardise ETP species recovery it advocates 100% coverage, although this may be seasonal, for example during times of year when right whales are calving. It differentiates between accuracy – 'how close the expected value of the estimate is to the actual value' and precision – 'how close a series of independent estimates are to each other'. Through a number of simulations, the study looked at the sampling fraction required to get 90% of the estimates within 10% of the true value.
Brooke (2014)	US fisheries	Gave a review of the NOAA observer programme since the 2070's and how the emphasis on sampling programmes has changed from monitoring the bycatch of marine mammals by foreign fishing vessels and the general harvest of US resources, to meeting the broader needs of the conservation of marine resources in general. The sampling strategy has moved towards a more fully documented, science based strategy for fisheries management. It highlighted the fact that funding is key factor in developing coverage levels and that these costs will increase as management strategies increase in complexity and real time data requirements, for example for sector and catch share systems.
Dietrich et. al. 2004	US Longline	Report of a workshop held at the International Fisheries Observer Conference that looked at the collection of data of protected species. The workshop focussed more on the types of data that should be collected rather than levels of observer coverage and in in particular how to effectively assess the effects on turtle bycatch. Mention was made of putting mitigation measures in place in the Pacific fishery to reduce incidental capture and subsequently increasing coverage rates from 4% to 12% to monitor the effectiveness of the measures and whether they were being implemented. It was estimated turtle catch dropped from 1,500 to 100 per year. Coverage rates in the Atlantic were between 2.5 and 5%, however the report is dated, using pre-2004 data and coverage levels have changed since then.
Finkbeiner et. al. 2011	US fisheries	Gave estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007 and highlighted the lack of coverage in some fisheries making the estimates highly unreliable. It summarised levels of coverage in a number of US fisheries as defined by the NMFS as 'None', 'Baseline', 'Pilot', 'Developing' or 'Mature' (NMFS 2004). While the figures are based on 2004 data the principle for defining the programmes along these lines can still be applied. It was noted the Hawaiian longline programme introduced a number of management measures, including 100% observer coverage, on shallow-set longlines (most associated with turtle bycatch) had reduced turtle bycatch 'substantially'.
NMFS 2004a	US fisheries	Looked at standardising bycatch monitoring programmes and the factors that will affect the levels of precision and accuracy of the estimations. Goals were defined by the coefficient of variation (CV) of each estimate and recommended

Study	Fishery	Description, aims and findings
		that a CV of 20-30% should be the goal for estimating both catch of protected species and other bycatch. The level of observation to achieve these goals will depend on the fishery characteristics. It acknowledged that this may exceed some statutory requirements, or that they may be revised downwards if bycatch limits are not the particular management aim of the fishery. It went on to define the evolution of observer programmes from 'None' (0%), 'Baseline' (0.5-1%), 'Pilot' (0.5-2%), 'Developing' (sampling to meet recommended precision goals), 'Mature' (optimal sampling allocation, periodically reviewed). Also assessed the vulnerability, by fishery, to bycatch species (fish, marine mammals, other ETP species) in terms of high, medium or low to recommend the level of coverage to meet the requirements of the fishery.
NMFS 2004b	US fisheries	Workshop report summarising coverage levels issues and needs and the process required that could lead to the establishment of programme specific levels. It stated how levels of coverage and objectives should be defined by the management goals of the fishery being monitored. These were outlined as catch/effort monitoring for in season management/stock assessment, bycatch monitoring for in season management/stock assessment, ETP species monitoring, technical monitoring (performance of fishing gear) and compliance monitoring. It highlighted the fact that anything less than 100% vessel coverage can lead to observer bias, particularly if schemes are voluntary or vessels choose which trips should be observed and deliberately choose areas where bycatch is low. Even with 100% vessel coverage there may still be bias unless 100% of activities are covered, with vessels recording no catches on unobserved hauls. It reviewed a number of coverage levels on various fisheries, with most fisheries achieving <10%, although these data were from 2003 or earlier so will likely have changed.
Furlong and Martin 2000	General	Examined the effectiveness of onboard observers with compliance and enforcement, in particular what conditions is partial coverage optimal and, if so, how can the optimal level of coverage be gauged for a fishery. While on shore monitoring can be more cost effective (in that it can provide inspections of several vessels per day), it cannot pick up violations such as discarding of fishery closures. The presence of observers on board a vessel will, in theory, deter illegal activity leading to a more productive stock and a higher resource rent. The optimal level of coverage will therefore occur when the marginal cost of employing an observer is equal to the marginal benefit (in terms of increasing yield).
Ewell et. al. 2020	All RFMOs	Broadly reviewed at sea compliance monitoring and observer programmes in place within 16 RFMOs and CCAMLR. As well as looking at observer safety it examined the type of data collected by observers, levels of coverage and the take up of Remote Electronic Monitoring (REM) by each RFMO. RFMOs are 'scored' on a number of criteria in these categories on a simple yes/no basis and while slightly out of date (data collected in January 2019), ICCAT were rated the highest in terms of general criteria results. It states the importance of having a uniform coverage policy across RFMOs , referencing Babcock et. al., 2003 figures of 20% for 'accurate' assessments of common bycatch species and 50% for rarer species. As

Study	Fishery	Description, aims and findings
		with NMFS 2004b it concludes that anything less than 100% coverage, whether human or through REM, will lead to observer bias, particularly where the take up of observers are voluntary.
Pennington and Helle (2011)	Norwegian purse seine fleet (herring, mackerel and blue whiting)	Although the paper refers to vessel self-sampling rather than observer programmes it does have some relevance in that it looks at the most effective survey design to get a true representation of the length frequency distribution of the target species. It concluded that the precision of the estimated mean weights (from the estimated length distributions of the catch) was affected more by the number of boats sampled in the reference fleet rather than number of samples taken and the number of fish in each sample. The result is the number of fish sampled from each selected catch was reduced by more than 50%.
Itano, Heberer and Owens (2019)	PS - WCPO	Provided a comparison on the use of different observation methods in order to determine the most effective method of monitoring and catch sampling. It concluded that REM should not replace human observation (HO), Instead it should enhance it, assimilating more of the repetitive tasks allowing HO to focus on priority duties. HO and EM should be complementary so their combined efforts can provide higher quality and more robust monitoring information. HO results gave a closer match to actual catch figures than REM, especially for species of special concern. Greater discrepancies and over estimates existed in the REM dataset which needed onboard verification. It referenced the fact that in 2015, only ~0.04% of video REM data were used to determine the proportion of purse seine catch sampled at sea (Hampton and Williams, 2015) .
Kraan, Uhlmann, Steenbergen, Van Helmond and Van Hoof (2013)	Netherlands fisheries	This study provided a literature review of Dutch self-sampling programmes, comparing and discussing how self-sampling by fishermen can be used to provide low-cost and expansive data collection. The study put forward suggestions to overcome the shortfalls in self-sampling and how the methodology and approach can be developed in devising self-sampling as cooperative research, this includes through better engagement with industry and more communication which can improve self-sampled data reliability and be seen as an overall investment in fisheries sustainability.
Luck, *et al* (2020)	Irish Static net fisheries.	Used a general liner mixed effects model (GLMM) to estimate megafauna bycatch rates in data poor static net fisheries. A case study for other maritime nations with limited bycatch observer data to fill data gaps in protected species management, specifically, where unobserved small-scale inshore fisheries represent a substantial proportion of fishing effort, and more likely to come into contact with inshore-based marine megafauna. Estimates were based on an observer

Study	Fishery	Description, aims and findings
		effort and self-reporting of skippers of 1.3% of total reported static fishing net vessel effort within the Irish EEZ between 2010 and 2018. In a reference to Benoît and Allard (2009) it stated the assumption that unobserved fishing activity can be inferred from the observed can be a flawed due to possible changes in fishers' behaviour when an observer is on board.
Morrell (2019)	US Atlantic/Gulf of Mexico/Caribbean pelagic longline fishery.	Presented an analysis into the observer effect and logbook reporting accuracy. Under the Pelagic Observer programme (POP), set up by the Southeast Fisheries Science Centre (SECFC), there has been a minimum requirement of 8% coverage on commercial pelagic longline vessels since 1992. This coverage level was introduced to produce a statistically reliable sample of Highly Migratory Species (HMS) such as swordfish and yellowfin tuna. It concluded that there was a general consistency in logbook and observer reported data for target species but that there was a non or under-reporting of bycatch and lesser-valued species. The presence of observers increased the reporting accuracy of non-target, low value and bycatch species. REM has also been used to increase self-reporting accuracy on unobserved trips.
NGO Tuna forum (2019)	All RFMO managed Tuna fisheries.	Press release from thirteen leading environmental Non-Governmental Organizations (NGOs) advocating that all tuna Regional Fisheries Management Organizations (tRFMOs) have 100% observer coverage, human and/or electronic, on industrial tuna fishing vessels. They stated that 100% observer coverage will provide the means to mitigate the conservation and compliance issues that put tuna stocks, ocean ecosystems, and tuna supply chains at risk.
Wolfaardt (2016)	All RFMOs longline bird bycatch.	Reviewed the optimum level of coverage for monitoring bird bycatch in pelagic longline fisheries managed by tRFMOs. It concluded that a higher level of coverage would be needed to quantify the level of seabird bycatch as opposed to whether seabird bycatch is occurring. The exact level of observer coverage will depend on several factors such as the frequency of bycatch events, the variability of by-catch rates, and the desired coefficient of variation of by-catch estimates. This makes it difficult to recommend a single optimum level of observer coverage that will cover all fisheries and taxa. Although 5% observer coverage is sufficient to identify simply where and when bycatch is occurring, **a**nalysis of the bycatch data collected will reveal a lack of precision and it is important that efforts continue to encourage an increase in the level of coverage, and the accuracy and precision of estimates, to be increased.
Lawson (2006)	As reported in Wolfaardt (2016)	Lawson (2006) has showed that in general the co-efficient of variation of by-catch estimates decreases rapidly as the coverage rate increases to 20% and then decreases slowly to zero when reaching 100% coverage. Therefore, in order to extrapolate observed by-catch rates to the whole fishery, the level of observer coverage should ideally be 20% of the fishing effort.

Study	Fishery	Description, aims and findings
Agnew et al. (2010)	Conventional krill trawl vessels in South Georgia (CCAMLR Subarea 48.3).	Aimed to determine the relationship between observer coverage and the accuracy of length frequency and bycatch observations and how to subsequently design a sampling strategy to ensure data collected are sufficiently statistically robust. The results established that: • There are substantial gains in the precision of estimates with increases in the proportion of vessels sampled up to about 50% of vessels. • There are substantial gains in the precision of estimates with increases in the proportion of hauls sampled up to about 20% of hauls. Caution should be applied for rarer events, such as larval fish by-catch and endangered species. These will require a higher sampling rate >50% for intra-vessel sampling i.e. hauls. It should be noted that the paper was written prior to the mandatory requirement within CCAMLR for observer coverage on krill vessels. Coverage was phased in and as of the 2020/21 season all vessels are required to carry an observer.
Benoît and Alland (2009)	Gulf of St. Lawrence (Canada) groundfish and shrimp fisheries	There were three principal objectives: • To test for deployment effects and examine certain factors potentially related to non-random deployments among sampling units. • To estimate the impact of deployment effects on the accuracy and precision of discard estimates. • To test for observer effects using and approach that controls for spatial, seasonal and vessel specific variation in fishing performance – changes in fishing behaviour when observers are present. Results showed there was a significant lack of randomness in the deployment of observers to fishing trips in most fisheries with vessels tending to go to areas with lower bycatch when carrying an observer. There may therefore be significant effects of non-random deployment. Biases should be small to nil when observer coverage is 100%, although high costs would likely prevent this.
Debski et al. (2016)	International pelagic longline fisheries	Provided guidance on levels of coverage appropriate for developing seabird bycatch estimates in pelagic longline fisheries and the extent to which observer data reflects true levels of mortality. Coverage required by RFMOs is not usually more than 5%, at this level, data will only identify that incidents occur but no statistical inferences can be drawn from this level of coverage.

Study	Fishery	Description, aims and findings
		It concluded: • To establish reasonably precise estimates of seabird by-catch, coverage of > 20% is required, increasing to >70% to detect rare species or species that rarely interact. • Coverage of 5% is wholly inadequate to quantify seabird bycatch. • Cryptic mortalities add to events and require higher coverage. • The extent of coverage needed to generate robust bycatch estimates varies with the characteristics of the fishery being monitored, species of interest and bycatch patterns. • Coverage should be representative; consideration of factors (season, inter-vessel differences, timing of sets and location/area of fishing).
Bradley et al. 2019	All fisheries	Reviewed the application of fishery dependent data technology in multiple fisheries sectors globally and the most recent developments and emerging technologies with the aim of increasing coverage and reducing costs. It can also facilitate traceability of catch for fisheries certification programmes. It summarises all the current REM trials being conducted globally and highlights the fact that British Columbia's hook and line groundfish fishery has required 100% REM since 2006.

3. Monitoring Rates for REM Systems

Monitoring rates for fisheries that currently carry REM systems can vary widely, as with HO this will depend on the objective of the programme. Footage is either used to census all, or review a proportion (which can then be extrapolated or raised), of fishing effort to estimate catch composition and/or to audit a proportion of fishing effort to verify fishing logbooks. In cases where the audit approach is used 10% monitoring of has generally been considered adequate to pass an audit for verifying fisher reported data (Mangi *et al*., 2015). The census approach, where 100% of fishing effort is monitored, is generally used for programmes where the focus is on interactions with seabirds and marine mammals. The approach taken varies depending upon a number of factors, primarily the overall monitoring objectives but also such factors as whether the programme is a pilot or a full rollout in a particular fishery. Whether a programme is voluntary or mandatory also significantly affects the coverage.

Given that REM is a relatively new technology there are not that many areas where it has been used as a monitoring tool across an entire fleet or fishery for a significant amount of time rather it is being deployed as part of a pilot, with voluntary participation of a small number of vessels, for a particular fishery (Michelin *et al*., 2018).

Canada, and subsequently the USA and Australia have been the pioneering countries in REM and as such these are where mature mandatory REM programmes exist with the audit model employed in all of these cases.

The limitations of pilot schemes include short time series of coverage, small numbers of vessels involved relative to the entire fleet and also the voluntary nature of these programmes.

The following table details studies that have been conducted in these areas.

Table 3 Summary of studies detailing REM coverage in fully monitored fisheries.

Study	Fishery	Description, aims and findings
Stanley et. al., 2011	British Columbia Groundfish	REM imagery from a 10% random sample of fishing events were reviewed and compared with the logbook records of counts for the same quota species onshore following completion of the trip. This showed that it could meet the operational and management requirements of the fishery. This fishery operates in a mixed fishery area with other choke species present which are also subject to quota. Operationally, test scores were consistently high, with values of 9 or 10 being achieved in 80% of the comparisons between REM and fisher reported data, with a score of 10 indicating a difference of less than two individuals. More importantly, the catch estimates (including discards) were sufficiently precise and unbiased for management and operational needs. Compared with the census, the audit approach is less costly. The former would cost at least 50% more. The audit system is also more robust and flexible, as well as being more intuitive and transparent to the harvesters.
Stanley et. al., 2015	BC Groundfish	Catches in the groundfish hook and line fishery in British Columbian Canada's west coast have been monitored since 2006 with an interrelated suite of technical components. These include, but are not limited to, full (100%) independent dockside monitoring, full video capture of fishing events and vessel monitoring at sea, 10% partial review of the video imagery from each trip, and full coverage of fisher logbooks.
Emery et. al 2019	Australian eastern tuna & billfish, gillnet hook & trap & southern and eastern scalefish.	An integrated REM system was introduced in several fisheries by the Australian Fisheries Management Authority (AFMA) as a replacement for at-sea observers from 1 July 2015. Under the current program, AFMA uses the integrated REM system to validate fisher-reported logbook information with an audit target of 10% of sets (defined here as the haul of catch from a single set) from each vessel (100% of all gillnet sets for protected species interactions in the Australian Sea Lion Management Zones). The 100% monitoring rate of this fishery is to confirm the veracity of the mandatory self-reporting of all interactions by fishers. This audit includes an analysis of catch composition, discards and interactions with protected species. Audits are conducted by specialised video reviewers onshore following the completion of trips.
Larcombe et al (2016)	Australian Eastern Tuna & Billfish	The objectives of this paper were to describe the REM system used in the Australian Eastern Tuna and Billfish Fishery and how it operated when it was first introduced. The aims of the programme were to monitor interactions with EPT species and monitor compliance with various required mitigation measures In addition it looked it the discarding of quoted species and the accuracy of recording bycatch species. This study provided early evidence that the introduction of the REM system in the Australian ETBF modified fisher behaviour and improved logbook reporting. This is most evident in the reporting of discarded catch where logbook reporting rates have increased substantially under REM. REM was deployed on 100% of vessels operating in this fishery with 10% of fishing operations being audited onshore by video reviewers following trip completion.

Table 4 Summary of studies detailing REM coverage in pilot programmes

Study	Fishery(ies)	Description, aims and findings
Sheidat et al (2018)	Dutch bottom set gillnet	Assessed the bycatch of harbour porpoise (*Phocoena phocoena*) in the Dutch commercial bottom-set gillnet fishery trialling REM between June 2013 and March 2017. Not all of the days that the REM systems were on-board of the participating vessels could be analysed. The reasons for this were primarily due to technical problems of the system and insufficient video quality. There was also a cut-off point to the number of REM days that could be analysed within the time frame and funding of the project.. During the study period the sampling coverage of the total fishing effort was 11.07% (900 REM analysed fishing days of 8133 of the complete fleet fishing days). For single-walled gillnets (GNS) it was 9.80% (760 REM analysed fishing days of 7756 of the complete fleet fishing days) and for trammel nets (GTR) it was 37.14% (140 REM analysed fishing days of 377 of the complete fleet fishing days).
Glemerec et al (2020)	Danish gillnet.	Assessed the rate of seabird bycatch using REM. Bycatch of birds occurred in 13.3% of the fishing trips recorded with REM and in 3.5% of the hauls. A few mass bycatch events may have influenced the mean bycatch rate estimates. In 95% of the trips where bycatch was observed, no more than six birds per trip were captured, while in the remaining 5%, up to 57 birds per trip were caught. These 5% represented only 14 out of 2118 (<1%) trips, but accounted for 40% of the total incidental catch of seabirds observed during the study. A solution to overcome the problem of accuracy of bycatch rate estimates is to increase the monitoring effort, although there will be associated costs. Problematically, bird bycatch events are rare and not randomly distributed. In this study, 40% of the casualties were recorded in <0.2% of the hauls so examining a sample of the complete dataset would likely result in inaccurate estimates.
Tremblay-Boyer, L.; Abraham, E.R. (2020)	New Zealand snapper and bluenose longline.	An REM pilot was introduced in order to reduce the uncertainty in the data of fisher reported bycatch of seabirds, particularly black petrels. This pilot was instigated on a segment of the fleet with 100% review of all fishing operations from these vessels being conducted. It was found that the rate of fisher-reported seabird captures increased from 0.0044 birds per thousand hooks before the trial to 0.0089 birds per thousand hooks during the trial for the vessels that participated. Key candidate model structures showed a positive effect of onboard cameras on the reporting of seabird capture rates: the model estimated that fisher reporting of seabird captures in the pilot programme fleet was around twice as high when vessels had onboard cameras than when they were without cameras. There was a 99.9% probability that the fisher-reporting rate increased during the trial for the analysis extended to the whole fleet.

Study	Fishery(ies)	Description, aims and findings
Kindt-Larsen et al., (2012)	Danish gillnet	When monitoring for rare and highly visible events, such as the catch of cetaceans, all footage was reviewed when played at a higher rate (10–12 times faster than real time).
Course et al. (2011)	UK North Sea demersal trawl.	Monitoring catches of commercial species aboard demersal trawlers was generally found to be time-consuming and in response to the large quantity of data most trials developed strategies where a random 10%–20% of the camera footage was validated against (self) recorded catch data in logbooks.
van Helmond et al. (2015)	Dutch North Sea demersal mixed trawl	Evaluated the efficacy of REM for cod (*Gadus morhua*) catches on vessels in a mixed bottom-trawl fishery and tested the hypothesis that cod catches are difficult to detect with video monitoring, specifically in catches with large volumes of bycatch. In 2011, a catch quota pilot study started for cod in the Dutch bottom-trawl fishery in which REM was used as an audit system to review the consistency of reported cod catches. Eleven vessels joined the pilot voluntarily. From the trips that could be reviewed, ~ 10% of the hauls were randomly selected for analysis. Based on the results of this study, it was concluded that distinguishing small numbers of cod in catches of small-meshed gears is difficult. Still, the results appeared encouraging for using REM for control purposes: the system was only inaccurate when the number of cod in the catch is low.
Needle et al. (2015)	Scottish North Sea Demersal Trawl	Seven vessels participated in a voluntary trial in 2008. 20% of trips were randomly sampled (hard drives were used to record data during the trip, normally one hard drive per trip), and a randomly selected 20% of the hauls on these trips were analysed by MS Science staff for discards of six key species: cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*), hake (*Merluccius merluccius*), and monkfish (*Lophius piscatorius* and *Lophius budegassa*). As a minimum, counts were collated for these species. Selection of both trips and hauls to be sampled was random - such post hoc random sampling of fishing activity is a unique benefit of REM-based monitoring.

The below provides a summary of REM pilots that have been conducted in Europe highlighting the selection procedure of video data, the species/events monitored and also the data source that the REM analysis was compared with subsequently to ascertain the veracity of the REM given that they were all pilot programmes.

Table 6 Summary of European REM pilots (van Helmond et al, 2019).

Pilot/Fishery	Selection procedure of video data	Species/Events Monitored	Data source for subsequent comparison with REM analysis
German North Sea mixed trawl	Random-selected sequences.	Landings and discards of cod.	Official logbook.
Dutch North Sea cod	Random selection 10% of hauls with sufficient image quality.	Landings and discards of cod.	Self-recorded catch by haul.
Dutch trial on harbour porpoise bycatch	Census of video data played 8-10 times faster.	Harbour porpoise.	Self-recorded catch by haul.
Dutch Pelagic freezer trawl	Census of video data played from frame by frame to up to 16 times faster.	Discards.	Not applicable for this pilot.
Dutch Sole	Random selection of 5% of hauls.	Landings and discards of sole.	Self-recorded catch by haul.
Scottish mixed trawl	Random selection of 20% of hauls.	Discards of cod, haddock, saithe, hake and monkfish.	Observer data.
English otter trawls & gillnet, North Sea	Random selection of 10% of hauls.	Discards of cod, sole, megrim, hake and monkfish.	Self-recorded catch by haul.
English beam trawl, Western Channel	Random selection of 5% of hauls.	Discards of sole, megrim, monkfish and plaice.	Self-recorded catch by haul.
English <10m	Random selection of one haul per trip.	Landings and discards of all species.	Self-recorded catch by haul.
English Western Haddock	Random selection of 10% of hauls.	Landings and discards of haddock.	Observer data & Self-recorded catch by haul.
Minimizing discards in Danish Fisheries	56% of hauls reviewed.	Discards of cod, hake, haddock, whiting, saithe and Norwegian lobster.	Self-recorded catch by haul.
Danish gillnet	Census of video data played 10-12 times faster.	Harbour porpoise.	Supplementary logbook.
Swedish gillnet	Census of video data.	Bird and marine mammal interactions.	Fishing logbook.

4. Differences by fishery and region

There are no universal set rates for observer coverage by fishery or area although there have been guidelines set out in various studies, most notably Babcock *et al.* (2003) who recommended 20% coverage for common species and 50% for rare species (see Table 2).

CCAMLR underwent a risk review of the areas under their management to define the levels of coverage (Waugh, Baker *et al*. 2008), where each CCAMLR Subarea or Division was given a particular risk level from 1-5. These were based on the risk of an encounter with seabirds, in particular those that have a high IUCN status (vulnerable or above). The ratings ranged from (1) low, (2) average to low, (3) average, (4) average to high and (5) high. Recommended observer coverage of hauling effort on longliners, (along with other management measures) was set according the risk rating of a particular area, outlined below:

Table 5 CCAMLR recommended observer coverage according to risk rating.

Risk Rating	Recommended observer coverage
1	20% hooks hauled
	50% hooks set
2	25% hooks hauled
	75% hooks set
3	40% hooks hauled
	95% hooks set
4	45% hooks hauled
	95% hooks set
5	50% hooks hauled
	100% hooks set

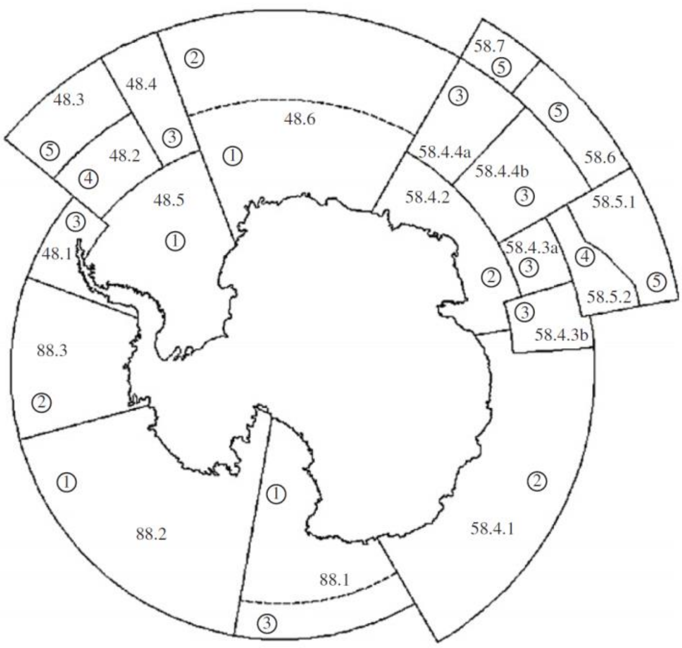


Figure 1 CCAMLR areas by risk (Source Waugh *et al.* 2008)

While these coverage levels have not been strictly applied within CCAMLR the principal is good and should apply across all fisheries. A similar approach has been taken by the NOAA when evaluating bycatch estimations (NOAA 2004a), here if defined the developmental stages of observer programmes, outlined in Table 6.

Table 6 Categories of observer programme as defined by NMFS 2004a

Observer programme level	Definition
None	No *systematic* program exists for bycatch data collection – coverage 0%.
Baseline	An initial effort including at-sea monitoring to assess whether a systematic program is needed to estimate bycatch is completed – coverage 0.5-1%.
Pilot	An at-sea monitoring program that obtains information from relevant strata (time, area, gear) for design of a systematic program to estimate bycatch with the ability to calculate variance estimates has been done - coverage 0.5-2%.
Developing	A program in which an established stratification design has been implemented and alternative allocation schemes are being evaluated to optimize sample allocations by strata to achieve the recommended goals of precision of bycatch estimates for the major species of concern.
Mature	A program in which some form of an optimal sampling allocation scheme has been implemented. The program is flexible enough to achieve the recommended goals of precision of bycatch estimates for the major species of concern considering changes in the fishery over time.

It went on to look at how programmes could become 'enhanced' depending on the vulnerability of the type of bycatch (high, moderate or low). They were defined as (1) fishery resources (excluding protected species), (2) marine mammals and (3) other ETP species. While this was looking at how programmes could become enhanced (i.e. move up a programme level), this analysis could be applied across fisheries to determine coverage by area and fishery.

Table 7 Examples of fisheries and their associated risk levels (based on NMFS 2004a).

Fishery	Target species	Gears	Program level	Vulnerability by type of bycatch		
				Fish	Marine Mammals	Other protected species
New England Large Mesh Otter Trawl	Gadoids, flatfish, monkfish	Otter trawl	Developing	Moderate	Low	Low
New England Small Mesh Otter Trawl	Gadoids, herring, small pelagics, dogfish	Otter trawl	Developing	Moderate	Low	Low
New England Gillnet	Gadoids, flatfish, dogfish	Demersal gillnet	Developing	Moderate	High	Moderate
New England Demersal Longline	Gadoids, dogfish	Longline	Baseline	Moderate	Low	Low
Gulf of Maine Shrimp Trawl	Northern shrimp	Otter trawl	Baseline	Moderate	Low	Low
Georges Bank Scallop Dredge	Sea scallop	Mechanical dredge	Developing	Moderate	Low	High
Mid-Atlantic Large Mesh Otter Trawl	Summer flounder, black sea bass, scup	Otter trawl	Developing	Moderate	Low	Moderate
Mid-Atlantic Small Mesh Otter Trawl	Squid, mackerel, butterfish	Otter trawl	Pilot	Moderate	High	Moderate
Mid-Atlantic Longline	Tilefish	Longline	Baseline	Moderate	Low	Low
Mid-Atlantic Gillnet	Monkfish, dogfish	Gillnet	Developing	Moderate	High	High

5. Coverage levels with respect to management objectives

There have been a number of studies into the optimal levels of observer and electronic coverage, as reviewed in Section 1 and coverage rates are regularly reviewed by RFMOs and fisheries managers against the objectives of their programmes. However, it is important to recognise that there are a number of different ways in which coverage can defined:

Trips – the number of vessel trips that carry an observer.

Days – The number of sea days that are covered by observers.

Effort – The amount of fishing effort that should be covered by observers. This in turn can be defined at different levels as hauls, trawls, hooks.

Catch – The proportion of catch that should be sampled.

In a previous best practice guideline (MRAG (2006) levels of coverage were divided into four broad categories: no coverage; occasional coverage (<2%), partial coverage (20-30% of trips, 10-20% of hauls) and total coverage (100% of vessels, 30-70% hauls) and the relative advantages and disadvantages of each examined. These are summarised in Table 8.

Table 8 Observer coverage, advantages and disadvantages

Coverage	Advantages	Disadvantages	Circumstances when rate is appropriate	Reason	Fishery example
No coverage	• No cost • Money saved can be applied to other approaches to monitoring, for example port sampling.	• No observer data • No on-board compliance monitoring • Not equitable compared to other components of the fleet	• Fishery has little to no interactions with ETP species and very little habitat and ecosystem impacts.	The footprint of the fishery does not overlap where protected species forage nor does it use gear known to interact with them.	Small-scale beach seine fishery operating in river mouths
Occasional coverage (eg <5 % coverage of trips and/or hauls, or specific research programmes	• Cheap to implement • Provides qualitative information on issues of concern • May provide good estimates of particular parameters in directed research efforts • Easily acceptable to fleet	• Cannot provide robust estimates of fleet-wide parameters. • Unlikely to give precise estimates of ETP species catch.	• Homogenous fisheries • Extremely selective gear • Little to no interactions with ETP species and very little habitat and ecosystem impacts. • Low variability in bycatch, if any.	Level of coverage can provide sufficient information to support stock assessments (data on selectivity, fish size, age structure).	Shore-based fisheries operating on land or within view of land.

Coverage	Advantages	Disadvantages	Circumstances when rate is appropriate	Reason	Fishery example
Partial coverage (e.g. observers covering 20% or 30% of all trips, and 10-20% of all hauls)	• Cheaper than 100% coverage • More feasible for smaller vessels • May provide sufficient coverage for routine scientific sampling	• Propensity for differences in vessel behavior between observed and non-observed days • Data may be biased for various reasons: including non-random observer deployments and differences in behavior between observed and non-observed vessels • May not provide enough spatial or temporal coverage for special scientific programs (e.g. otoliths, stomach contents sampling for ecosystem studies) • Implementation may be uneven across the fleet and lead to resentment of inequity	• Low variability in bycatch. • Bycatch commonly found (35% of catch) • Some seabird bycatch • Gear/habitat interaction	• Commonly caught species requiring 90% of cases be within 10% of the true value requires 30-40% coverage. • 25% coverage is considered adequate to detect increases in seabird bycatch	• U.S. Pacific groundfish trawl fishery (common species bycatch). The fishery commonly catches dover sole and sablefish in the deep-water DTS complex when untargeted.

Coverage	Advantages	Disadvantages	Circumstances when rate is appropriate	Reason	Fishery example
50% to total coverage (i.e. observers on 100% of vessels all the time, monitoring between 30 and 70% of all hauls)	• Good cover for compliance monitoring • Equitable across the fleet • Possible to collect large amounts of data	• May not provide 100% coverage of fishing effort, if not all fishing activity is observed. • True 100% coverage of fishing effort may require more than one observer on each vessel. • Expensive • May not be feasible to put observers on all vessels (issues of space, cost etc. for small vessels) • May not be necessary for purely scientific programs • Difficult to get fleet acceptance	• Rare species bycatch in the fishery (0.1% of catch) • High variability in bycatch • Assess efficacy of mitigation measures. • Threatened or endangered species interactions. • Interactions with a species that occur infrequently. • Bycatch limitations restrict target species harvest. • Assess efficacy of mitigation measures	• When bycatch is a rare event, observer coverage required to achieve bycatch estimates within 10% of the CV in 90% of the cases is greater than 50%. • Endangered species interactions. • Low levels of mortality could jeopardize the recovery of a threatened or endangered species. • Bycatch limitations restrict target species harvest, therefore an incentive exists to underreport bycatch	• South eastern Atlantic coastal gillnet fisheries are known to interact with Atlantic coastal bottlenose dolphins. The species is listed under the MMPA as depleted and has been observed caught in all gillnet mesh sizes • U.S. Pacific groundfish trawl fishery (rare species bycatch). Bocaccio is a severely depleted species, managed under a rebuilding plan. It is captured more rarely in the shallow-water trawl but by regulation must be discarded. • Eastern tropical Pacific tuna purse seine fisheries are managed with individual vessel quotas on dolphin bycatch. • During certain times of the year the Atlantic shark gillnet fishery may encounter right whales when they are calving (Brooke 2014).

A combination of coverage rates can also often be used, for example a longline fishery may require different rates for monitoring line setting, line hauling, target species sampling and bycatch sampling. As discussed these will vary according to the area fished, associated risk (to ETP species) and the management strategy of the fishery. Exactly how various parts of the catch are classified should be defined. Babcock and Piktch (2003) use the definition outlined by Hall 1996, where everything caught is included as 'Capture', this was then divided between 'catch' and 'bycatch'. For the purpose of this report however we have suggested the classifications as set out in Figure 2, where everything that is caught is included as 'catch' (as this is closer to most logbook definitions). This is then divided into target and bycatch and further divided into a number of sub-categories.

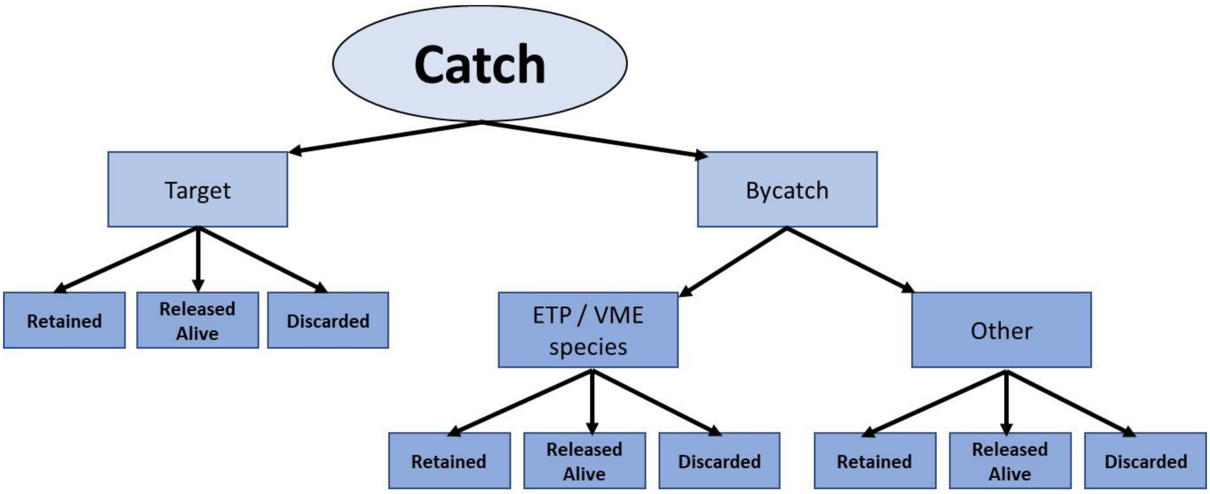


Figure 2 Categorisation of vessel catch

When referring to observer programmes it is important to understand exactly what part of the process they are monitoring, although in most cases it may be all.

Babcock and Piktch (2003) ran a series of simulations to look at the level of observation that would be required to get within 10% (for 90% of events) of the true value of what would be classified as bycatch in Figure 2. The results of this are shown in Table 9, Table 10 and Table 11. Table 9 gives a broad estimate on observer coverage on 'real' fisheries and types of bycatch, Table 10, is more specific to the proportion of bycatch in the total catch and Table 11 compares the size of fishery, smaller fisheries requiring a higher sampling fraction but a lower sample size.

Table 9 Sampling fraction required to reach desired level of bycatch accuracy (Source: Babcock and Piktch (2003))

Fishery	Bycatch sp.	Target sp.	Denominator variable	Sampling fraction to get 90% within 10%
Pacific groundfish	Sablefish	Dover sole, sablefish, thornyheads	Towing hours	30%-40%
Pacific groundfish	Dover sole	Dover sole, sablefish, thornyheads	Towing hours	30%-40%
Pacific groundfish	Bocaccio	Flatfish	Towing hours	>50%
Atlantic coastal gillnet	Bottlenose dolphin	Monkfish, striped bass, black drum, croaker, spiny dogfish	Total catch of target species	>50%

Table 10 Effect of the rarity of the bycatch species on the required sampling fraction. The fisheries all have 1,000 trips / year and only differ in the rarity of the bycatch species.

Total bycatch as percent of total catch plus bycatch	0.1	0.7	6	35.4
Percent coverage to get within 10% of the correct value in at least 90% of simulations	>50	28	18	17

Table 11 Comparison between sampling fraction and sample size. The fisheries vary only in the number of trips.

Number of trips in fishery	10,000	1,000	100
Percent coverage to get within 10% of the correct value in at least 90% of simulations	3.6	28	>50
Sample size to get 90% within 10%	360	280	50-100

More recently Debski et al. (2016) looked at the optimal level of coverage for ETP species. They examined levels of observer coverage in a number of different fisheries and concluded that while 100% coverage obviously provides complete information on catch composition, in most longline fisheries this is never achieved or sought. To establish a reasonable precise estimate of seabird bycatch, a coverage level of 20% (of hooks observed) is required, although levels of over 2.5 times that would be required to detect captures of species that are rare or rarely interact with fishing gear. Specifically, if a seabird is infrequently captured but caught in large numbers when it is caught then higher levels of coverage will be required to obtain a specified level of precision. Conversely a species often captured but in low numbers per event will require less coverage for the same level of precision. They went on to identify a number of factors that will affect the adequacy of all catch monitoring undertaken by observers these are summarised in Table 12.

Table 12 Key factors that influence the accuracy and precision of seabird bycatch estimates based on observer data collected from pelagic longline fisheries (Source: Debski et al. 2016)

Factor	Type of variation				
	Target fish species	Day / night	Annual / seasonal	Spatial	Vessel to vessel
Fishing effort	X		X	X	X
Seabird abundance	X		X	X	
Seabird behaviour	X	X	X	X	
Vessel	X		X		X
Vessel behaviour	X	X	X	X	X
Mitigation use	X	X			X

They provided a number of recommendations with regards to levels of observer coverage in the pelagic longline fishery:

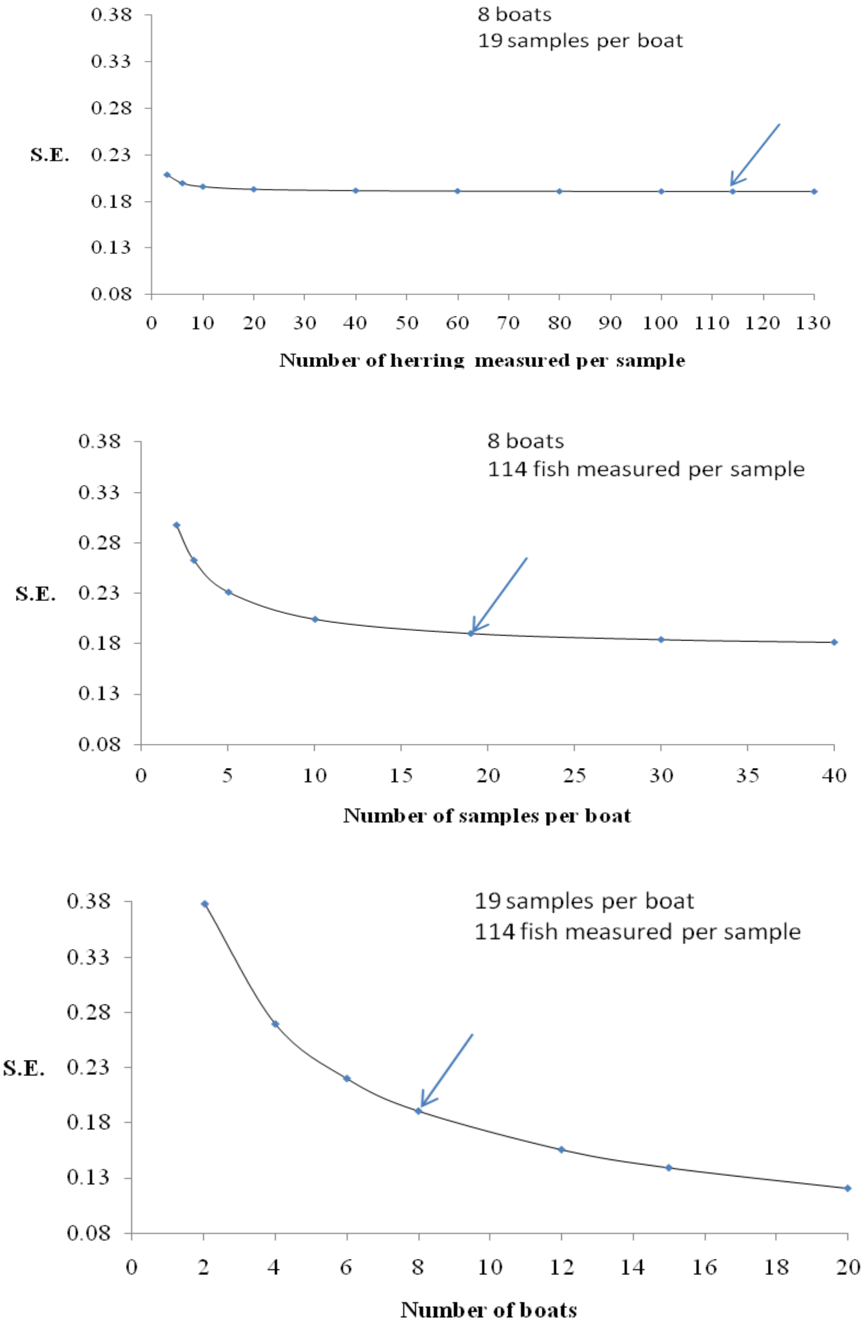
- the extent of observer coverage needed to generate robust bycatch estimates varies with the characteristics of the fishery being monitored, species of interest, and bycatch patterns;
- observer coverage levels of 5% may be adequate to collect information identifying some bycatch risks and issues but is likely insufficient for effectively quantifying seabird bycatch;
- in general, to robustly estimate bycatch levels of more frequently caught species, observer coverage levels of 20% or more may be necessary, whereas to estimate bycatch of species caught infrequently, coverage levels of 50% to almost 100% may be necessary;
- observer coverage should aim to be maximally representative, taking into consideration factors such as seasonality of fishing, between-vessel variation within a fishery, timing of sets, and location of fishing activities; and,
- even with high levels of observer coverage there can be unobserved bycatch (i.e. “cryptic” mortality), and this can form a high proportion of total bycatch and can vary substantially between fisheries.

When looking at the target species, a study in 2010 (Pennington and Helle (2011)) looked at the factors that would affect the precision of the mean measured lengths when compared to the actual lengths of the catch. It was part of a vessel self-sampling programme on the Norwegian purse seine fleet, rather than using observer data but the results are still relevant. It looked at three basic factors:

- The number of the species per sample per vessel
- The number of samples taken per vessel
- The number of vessels from which samples were taken

The results from this are shown in Table 13, where the biggest change (reduction) in the standard error occurs when the sampling occurs across a number of different vessels and the number of samples taken per trip. The number of fish taken per sample has little effect. This is in line with the findings from Agnew & Grove (2010), who determined that number of vessels was more relevant than sample size when considering precision of estimates.

Table 13 Hypothetical changes in the standard error in estimating mean length of Norwegian spring-spawning herring.



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