Conservation Services Programme
Project INT2017-02:

Using electronic monitoring imagery to characterise protected species interactions with commercial fisheries: A primer and review

https://www.st.nmfs.noaa.gov/advanced-technology/electronic-monitoring/index

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Executive summary

Monitoring commercial fisheries provides essential information to enable effective fisheries management. Traditionally, human observers have provided the majority of fisheries monitoring services, with other methods used including position monitoring (e.g. using Vessel Monitoring Systems), at-sea boarding and aerial surveillance. While monitoring using human observers can work well in some cases, challenges such as occupational safety, space constraints on smaller vessels, representativeness of data collected, and cost, have catalysed the exploration of other methods. In this context, electronic monitoring (EM) using on-vessel cameras has developed through extensive trial, pilot and operational programmes in the last 15 years. Amongst other objectives, EM has been used to monitor interactions between threatened, endangered and protected species (TEPS) and commercial fisheries.

To investigate the types of these interactions that EM has been used to explore and training given to analysts to detect and describe those interactions, an extensive review was undertaken. The review encompassed grey literature, published reports, social media, and websites of practitioners, companies, agencies, and multilateral bodies known to use or promote EM. Experts were also consulted directly to collect information on work that is underway but not yet publicly available.

The majority of EM programmes to date that have focused on TEPS interactions were trials or pilots, with a smaller number of operational programmes underway. Information reviewed showed that EM has been widely tested and proven effective in monitoring captures of a range of TEPS in fishing gears. When EM imagery captures these interactions, species identification is possible in most cases. Life status can also be determined where animals are vigorous, especially when brought on deck prior to release. Detection of unusual or unexplained behaviour, that may result from crews wishing to avoid a TEPS capture being recorded by EM, is also possible. EM has been explored (but found less effective) for monitoring seabird interactions with trawl warps and third wires.

Other effective applications of EM that are relevant to the impacts of fishing on TEPS include monitoring handling of these species after capture, deployment of mitigation devices (e.g. tori lines, pingers, turtle exclusion devices), and detecting the presence of fish waste discharge within camera views. Collecting robust quantitative information on the abundance of TEPS around fishing gear is difficult using EM.

Species identification using EM imagery has been approached by practitioners using a number of methods, e.g. employing analysts who are trained and have worked as at-sea observers or who have received observer training (but not gone to sea), using field guides, species lists, and images of species of interest. Because animals seen in EM imagery may be wet, incomplete, covered in fish slime or scales, or not visible from an angle that optimises identification, using imagery from EM (or sources as close to this as possible, e.g. observer photos) to train analysts on species identification is encouraged. Documenting how identifications were made is important to add rigour to the EM dataset. Characteristics such as body size, morphology, colour, and distinctive markings are all important in this regard.

In many reports and published papers, the training provided to EM analysts is not described. However, because EM analysts are the source of data, the training process has a strong bearing on data quality and therefore end-user confidence in datasets produced. In studies where training is described, it routinely incorporates elements such as core instruction, self-tests and practice runs after which feedback is provided, and a formal assessment that documents analyst competence. When a particular level of competence is reached in the formal assessment, this provides an assurance of a commensurate level of data quality.

The development of automated review methods for EM imagery is accelerating. However, currently, automated review is not in place as part of routine EM for any species. The majority of work on automated EM imagery review to date has focused on fish. Four projects dedicated to automated review of imagery recording TEPS interactions were identified during this review. Automation will change, rather than eliminate, the role of humans in EM review. For example, automated review algorithms must be written, trained, and tested, and the need for processes that provide assurance of data quality remain.

The detection of interactions between TEPS and fishing gear occurs after a number of other steps in the EM process chain. For example, monitoring objectives and business requirements must be clearly defined, EM cameras must be deployed in appropriate positions on-vessel, system specifications (e.g. frame rate) must be optimised to record interactions, and crew activities onboard must occur such that imagery capture is not compromised. Once imagery is captured, the review process provides for the extraction of data on TEPS interactions from EM imagery. EM imagery review may be undertaken as a census or a sample approach, depending on objectives, and time and resourcing available. Business requirements must link to the data elements analysts are instructed to extract from imagery during review. As part of a rigorous monitoring process, data extraction must be repeatable and auditable. The need for standards for data collection from EM, review processes, and quality assurance of review is well recognised. However, the development of standards to underpin EM is in its early days.

To support the continued exploration and adoption of EM to monitor TEPS interactions with New Zealand commercial fisheries, it is recommended that:

- Data standards are developed and documented to specify the information that EM analysts are tasked with extracting from imagery,
- Quality assurance standards are developed for EM review,
- Training materials and programmes are prepared to enable EM analysts to populate data fields and to document their findings,
- The development of training materials is initiated where requirements are already understood,
- Photos and videos taken by fisheries observers are catalogued and stored for use as part of EM training materials, and potentially to contribute to the development of machine learning over time,
- New Zealand remains abreast of the regional development of EM process and data standards to enhance progression of NZ-specific work and to harmonise that with international precedent as appropriate, and,
- Practitioners in New Zealand and internationally are encouraged to make available EM process and data standards, review protocols and training materials.

Contents

Introduction

Monitoring commercial fisheries provides essential information to support fisheries management. Globally, human observers are responsible for conducting most fisheries monitoring, with other tools including dockside monitoring and aerial and at-sea patrols (Flewwelling et al. 2002). In New Zealand, human fisheries observers have been the mainstay of government monitoring of commercial fisheries since the 1990s. The role of government fisheries observers is articulated in the Fisheries Act 1996. Remote monitoring of some vessels has also occurred, for example using Vessel Monitoring Systems (New Zealand Government 1993, 2017).

Human observer placements can be a very effective approach to collecting fisheries information, especially in large-vessel fisheries. Efficiently implementing human observer coverage on smaller vessels is challenging for a variety of reasons, e.g. dynamic fishing schedules that can change at short notice, space constraints on vessels, lack of willingness amongst operators to carry observers, and high proportions of observers' time spent onshore relative to sea days achieved (e.g. Calahan et al. 2010; MPI 2016). Further, due to the observer effect[1], the quality of information collected from observer placements can be compromised, particularly where these placements do not occur on a routine basis.

Globally, challenges with effectively achieving representative observer coverage, the costs of deploying human observers on vessels, safety concerns for observers at sea, and ever-increasing technological capabilities, have catalysed the investigation of remote electronic monitoring methods using on-vessel cameras (e.g. Evans and Molony 2011; Piasente et al. 2012b; Lowman et al. 2013; Hosken et al. 2016b; NOAA 2016; Sylvia et al. 2016; SPC and FFA 2017). Electronic monitoring (camera) systems have been deployed extensively in pilot and trial programmes in the last 15 years, across a variety of fisheries and fishing methods (e.g. set net/gillnet, pot, purse seine, trap, trawl, and surface and bottom longline (Pria et al. 2008; McElderry et al. 2007, 2008, 2010, 2011; Evans and Molony 2011; Piasente et al. 2012a, b; Ruiz et al. 2013; Buckelew et al. 2015; Hold et al. 2015)). Preliminary programmes have progressed to operational monitoring programmes in some fisheries (e.g. gillnet, longline, purse seine and trawl fisheries (Stanley et al. 2014; AFMA 2015; NOAA 2016; Wallis and Barrington 2017; G. Marcos, pers. comm.)).

The efficacy of camera-based electronic monitoring (EM) in addressing a range of fisheries monitoring objectives is well established (GSGislason and Associates 2007; NOAA 2016; Denit et al. 2016). Elements of protected species monitoring that EM has been used to investigate include captures of these species on or in fishing gear (e.g. on hooks and in nets), interactions with components of fishing gear that do not hold catch (e.g. seabird strikes on trawl warps and third wires) and monitoring the deployment of mitigation measures (Ames et al. 2005; McElderry et al. 2004b, 2010, 2011; Kindt-Larsen et al. 2012; Wallis and Barrington 2017).

The quality of information collected from monitoring programmes is dependent on many factors, including the specification of clear monitoring objectives, effective use of fit-for-purpose tools and technologies, on-vessel processes, and resourcing to deliver appropriate levels of staff capacity and

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[1] The observer effect is when vessel operators change their fishing behaviour in the presence of an observer (Babcock et al. 2003; Singer 2014; Piasente et al. 2012b).

capability. Training is a key factor influencing staff capability, and therefore the quality of data acquired from EM programmes.

This report provides a review of:

- The types of interactions between commercial fishing operations and threatened, endangered and protected species detected by EM,
- Training given to EM analysts to detect and describe those interactions in imagery, and,
- Recommended next steps to support effective review of EM imagery of protected species interactions, that is collected from New Zealand fisheries.

Selected elements of the EM process that optimise the collection of imagery for protected species monitoring are also explored.

Methods

Review of available information

Global online search tools were used to locate available information on EM studies and programmes. Published, grey and conference literature were all included in the search process. Search tools used included:

- Google Scholar
- WorldWideScience.org
- ResearchGate
- ScienceDirect
- OpenGrey
- Fish, Fisheries and Aquatic Biodiversity Worldwide database
- JSTOR
- BioOne
- US National SeaGrant Library
- Proceedings.com
- Science.Gov, and,
- New Zealand Fisheries Management Research Database.

Initially, broad searches were conducted using the phrases “electronic monitoring”, “video monitoring” and “e-monitoring”. Given the irrelevance of the majority of search returns (e.g. electronic monitoring of criminals in the judicial context, rather than fisheries monitoring), wildcard search terms were introduced to focus results. Using wildcards such as fish*, bycatch*, observ*, trawl*, longlin*, train*, and review* usefully constrained search results to records that included a greater proportion of relevant items.

In addition to open searches, targeted searches of online venues known to contain information on electronic monitoring were undertaken. These included Regional Fisheries Management Organisations, Pacific Islands Forum Fisheries Agency, Pacific Community, Agreement on the Conservation of Albatrosses and Petrels, and EM supplier websites, and a web platform used by practitioners working with EM (EMInformation.com). Particularly relevant conference proceedings were also targeted and searched for relevant information, e.g. American Fisheries Society and the International Fisheries Observer and

Monitoring Conferences. Social media searches were conducted using three EM-specific hashtags (#EM4Fish, #EM4Fisheries and #FisheriesEM).

To access work that is unavailable publicly as yet, information was also sought from practitioners active on Twitter, using a post with the hashtags above. To reach the broader fisheries science community with a request for information, a posting was created on the online Scientific Forum for Fish and Fisheries (FISH-SCI@SEGATE.SUNET.SE).

Expert consultation

To build on searches and broadcast requests for information, EM practitioners were contacted directly to seek information. Responses were guided by focusing the request for information in the following areas:

- Objectives of the focal EM programme
- Fishing methods encompassed
- Taxa of threatened, endangered, and protected species relevant to the programme
- Type of programme (e.g. EM pilot, business-as-usual fisheries monitoring, technological development or research programme)
- Types of interactions that were the focus of the programme, and/or that were identified and described during imagery review
- Review and analytical approaches relevant to protected species
- Whether machine learning approaches were considered or applied to the review
- Information on training of imagery analysts
- Outcomes, recommendations and learnings; and,
- Any documentation of the information provided.

Information to follow up on publicly available material (e.g. from published papers, reports or conference proceedings) was also sought directly from experts.

Information management

Information found during searches and received from experts was summarised and tabulated in a searchable form.

Results

Interactions with fishing gear

EM has been widely tested and proven to effectively record captures of endangered, threatened, and protected species in fishing gear. Most programmes reported in published, grey and conference literature are trials or pilots. However, the amount of reporting from operational (i.e. EM as business-as-usual fisheries monitoring) programmes is increasing (e.g. AFMA 2015; NOAA 2016). Effectively monitoring rare events such as captures of threatened, endangered and protected species is challenging particularly on a trial basis when test systems typically provide limited coverage of fishing effort. Therefore, in some studies, proxies have been used to confirm the detection capabilities of EM (Pria et al. 2014; Middleton et al. 2016a).

EM applications are considered by species group below. Groups include marine species legally classified as protected in New Zealand[2].

Seabirds:

The use of EM has been explored for monitoring seabird captures in pelagic and demersal longline, trawl, set net/gillnet and purse seine fishing gear (Table 1; Ruiz et al. 2017). This includes captures on hooks, and entanglements in longline gear and nets. The locations of trial EM deployments that have detected seabird captures include Australia, Hawaii, New Zealand, Peru, Solomon Islands, northeastern USA, northwestern USA (Alaska), and South Georgia. Operational EM programmes in which seabird captures are monitored include pelagic longline fisheries in Australia (AFMA 2015), and in the Pacific and Indian Oceans (G. L. Marcos, pers. comm.). EM has been used effectively to identify seabirds caught on fishing gear to species level, including penguin, albatross, petrel, shearwater, fulmar, gull and gannet species. Identifications to higher taxonomic levels are also reported (McElderry et al. 2008, 2010, 2011; Northeast Fisheries Science Center 2014; Pria et al. 2014; Denit et al. 2016; Hosken et al. 2016b; Bartholomew et al. 2018; Thompson and McKenzie 2018; S. Fitzgerald, pers. comm.).

As well as documenting captures in fishing gear, EM has been deployed in pilot studies with the objective of monitoring seabird strikes on trawl warp cables and third wires in Alaskan and New Zealand trawl fisheries respectively (McElderry et al. 2004a, b, 2011). Achieving effective camera placements for documentation of cable strikes has proved challenging in these pilot trials, for example, due to cable movement and sea conditions. Further, imagery can be difficult to interpret. McElderry et al. (2004a, b, 2011) concluded that using EM to assess the abundance of seabirds immediately around trawl warp cables and third wires was more likely to be effective than attempting direct assessments of strikes themselves. Correlations between warp strikes and seabird abundance are well documented (e.g. Abraham 2009).

Marine mammals:

Cetacean captures have been reported from EM in set net/gillnet and trawl fisheries operating in Australia, New Zealand, northeastern USA, the North Sea and Peru (Table 1). Identifications reported from EM imagery at the species level have included harbour porpoises, bottlenose, common, dusky, and Hector's dolphins. Identifications reported at higher taxonomic levels include *Delphinus* spp. and *Tursiops* spp. (McElderry et al. 2007, 2011; Evans and Molony 2011; Lara-Lopez et al. 2012; Kindt-Larsen et al. 2012; Pria et al. 2014; Northeast Fisheries Science Center 2014; Bartholomew et al. 2018).

Pinniped captures have also been documented by EM deployments in gillnet fisheries, in Australia, the northeastern USA, and Peru (Table 1). Identification of pinnipeds to species level is reported for Australian and South American sea lions, and gray and harbour seals (Lara-Lopez et al. 2012; Northeast Fisheries Science Center 2014; Bartholomew et al. 2018).

In Australia, monitoring pinniped and cetacean captures in gillnets is now part of an operational EM programme (AFMA 2015).

Marine reptiles:

The efficacy of EM in detecting captures of marine turtles has been confirmed from trials conducted in pelagic longline and gillnet fisheries operating from Australia, New Zealand, Hawaii, the Solomon

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[2] Legal protection is established under the Wildlife Act 1953 and Marine Mammals Protection Act 1978.

Islands, and Peru. Sea snake captures have also been documented by EM, during monitoring conducted on a trawl vessel in Australia (Piasente et al. 2012a; Table 1).

EM has enabled species-level identification of green, hawksbill, leatherback, loggerhead and olive ridley turtles caught in fishing gear (McElderry et al 2008, 2010; Hosken et al. 2016b; Bartholomew et al. 2018).

Fish:

The capability of EM to record imagery of protected fish is well reflected by numerous EM programmes documenting fish catch. Many programmes at trial or pilot stage, and operational EM programmes, have sought to document fish catch to meet a variety of objectives (e.g. to assess compliance with retention and discarding regimes, to enable catch accounting, and to verify fisher catch reporting. Given the significant number of reports documenting these programmes and the breadth of species they cover, examples are provided in Table 1.

In relation to sharks and rays more specifically, captures of numerous species have been documented in longline, pot/trap, set net/gillnet, trawl and purse seine fisheries (Table 1). Amongst captured sharks and rays detected by EM, genera and species protected in New Zealand are reported, e.g. *Mobula* spp., basking shark, white pointer shark, oceanic whitetip shark, spinetail devil ray and manta (Evans and Molony 2011; Piasente et al. 2012b; Northeast Fisheries Science Center 2014; Ruiz et al. 2014; Hosken et al. 2016b; Larcombe et al. 2016; Bartholomew et al. 2018).

Corals:

No studies were found in which EM was specifically deployed to detect coral bycatch. However, instances of coral and other benthos being detected and identified from EM imagery are reported.

An EM trial on a longliner working in the Patagonian toothfish fishery around South Georgia recorded imagery of black coral (Antipatharia), gorgonians (Gorgonacea), hydrocorals (Stylasteridae), sponges (Porifera), anemones (Actiniaria) and other benthic invertebrates being landed (Benedet 2016). (However, EM analysts detected some benthic species significantly less frequently than the onboard observer).

Piasente et al. (2012a) reported that benthos was visible in their trawl fishery EM trial, where catch was emptied onto a conveyor in camera view. Experienced observers considered that from this imagery, most catch on the conveyor could be identified to the level of genus. Benthos was also detected in trawl catch monitored using EM in the northeastern USA. In that case, sponges and snails were reported (Northeast Fisheries Science Center 2014).

Life status of captured animals

Extraction of information on life status of captured protected species is possible from EM imagery. Having crew handle animals within camera fields of view facilitates assessment of life status (e.g. Piasente et al. 2012b). Assessing the level of activity, deportment on landing, and behaviour on release of captured animals all have importance in this regard. For example, Pria et al. (2014) report instructions to EM analysts to document whether particular species of interest were moving or not moving, as a proxy for life status. McElderry et al. (2011) report the distinct white shape and vigorous movement captured in imagery of an Australasian gannet live-caught in a trawl net in their study. In contrast, Middleton et al. (2016a) report a “lifeless seabird shape” alongside live captures in the imagery they collected from a demersal longline vessel. McElderry et al. (2010) note that three captured leatherback turtles in their pelagic longline study appeared vigorous and were observed in EM imagery swimming away on release, but a bottlenose dolphin caught in a trawl net was motionless and considered lifeless when it came aboard (McElderry et al. 2011).

When fish are released in the water, life status was reported to be more difficult to assess (Piasente et al. 2012b).

Protected species handling

When protected species are captured and still alive on retrieval of fishing gear, handling can influence survival prognosis (e.g. Swimmer et al. 2006, 2014; Anonymous 2017). Further, handling of live catch items has ethical and legal implications, in terms of animal welfare. EM provides a tool to monitor the methods used to handle catch (e.g. Pria et al. 2014; Smith et al. 2017). Piasente et al. (2012b) monitored protected species handling during their pilot study conducted in the longline fishery for tuna and billfish in eastern Australia, e.g. the live release of a hooked albatross. In Australian fisheries, EM imagery enabled the Australian Fisheries Management Authority to identify issues with inappropriate handling and mistreatment of bycatch, especially sharks and rays (Wallis and Barrington 2017). In response, a fisher education programme was initiated (AFMA 2016a, b, 2018a, b).

EM is also used to monitor bycatch handling practices on some purse seiners operating in the Atlantic and Indian Oceans. Imagery from these vessels is monitored for compliance with a code of good practice for handling turtles, sharks, manta rays and whale sharks (Uria and Zulueta 2017; G. L. Marcos, pers. comm.).

Unusual or unexplained behaviour

In some cases, human behaviour onboard vessels may preclude EM systems detecting protected species capture events. Cases of deliberate camera obstruction may occur when vessel skippers and crew are aware that a species of interest has been captured and they do not wish that to be recorded in imagery[3]. Another way for fishers to avoid the detection of species captures is to remove sensitive catch items from gear before they come within camera range, e.g. dropping longline clips with catch attached (Piasente et al. 2012b), or dislodging or cutting loose catch from the gear out of camera view (Kindt-Larsen et al. 2012). While the catch may not be visible to the extent that identification is possible, the human behaviour patterns seen in at least some of these cases are so unusual that EM analysts can identify them as distinct, unexplained, and potentially indicative of a capture event (Pria et al. 2014). Such events can be flagged during review for appropriate follow-up.

Factors affecting capture risks

In addition to documenting direct interactions between protected species and fishing gear, EM has been explored as a tool for monitoring risk factors that affect these interactions, and compliance with measures intended to reduce them.

Deployment of bycatch mitigation measures:

The use of EM in detecting the deployment of seabird bycatch mitigation devices is reported from trawl and longline fisheries, both in pilot or trial programmes and operational monitoring (Ames et al. 2005; McElderry et al. 2008, 2011; Piasente et al. 2012b; AFMA 2015; Denit et al. 2016; Archipelago Marine Research 2018; D. Colpo, pers. comm.). Imagery recorded showed that detecting

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[3] https://www.coastalleader.com.au/story/4756691/fishermen-convicted-in-naracoorte/ [Accessed 1 April 2018]

the presence of devices was the key data element. McElderry et al. (2008) found that while streamer lines were readily observed in imagery, their performance was difficult to assess. Similarly, Piasente et al. (2012b) noted that the presence of streamer lines was evident, but assessing their specifications for compliance monitoring was not possible. Longline programmes assessing the presence of streamer lines are reported from small and large vessel fisheries (Ames et al. 2005; McElderry et al. 2008; Smith et al. 2017; Archipelago Marine Research 2018; D. Colpo, pers. comm.). In trawl fisheries, detecting the presence of both streamer lines and warp scarers is possible using EM (McElderry et al. 2011).

EM was also effective in monitoring the deployment of turtle excluder devices (TEDs) in trawl nets used in the Australian prawn fishery (Piasente et al. 2012a). However, the use of bycatch reduction devices (BRDs) was more difficult to monitor. BRDs are significantly smaller than TEDs, which made their presence and configuration relatively more difficult to detect (Piasente et al. 2012a).

Pingers in place on set nets were detected by McElderry et al. (2007), although monitoring pinger deployment was not a specific objective of that study. In addition to detecting the presence of pingers visually in imagery, McElderry et al. (2007) considered that their operation could be assessed by integrating a hydrophone into the EM system.

Protected species abundance around vessels:

Information on protected species abundance may be collected in a structured way (e.g. at specific stages of the fishing cycle, and in specific areas around the vessel or gear), or opportunistically as protected species are detected around vessels (Pierre et al. 2015). Structured approaches to the collection of seabird abundance data using EM have been tested in longline and trawl fisheries in Alaska and New Zealand. In the Pacific halibut longline fishery in Alaska, the collection of abundance information during longline setting was attempted as one of four monitoring objectives (but without specific camera placement for that purpose). The imagery collected was not considered adequate to meet the objective, and Ames et al. (2005) concluded that focusing cameras on a specific data collection task would have delivered better results. In the eastern Australian tuna and billfish fishery, Piasente et al. (2012b) categorised abundance and activity (floating, diving, not interacting) around fishing gear at setting.

In trawl fisheries, documenting seabird abundance using EM was explored as part of an investigation of seabird interactions with third wires in Alaska (McElderry et al. 2004b) and the broader use of EM for protected species monitoring in New Zealand (McElderry et al. 2004a, 2011). McElderry et al. (2004b) found that broad enumeration of seabirds at group level was feasible astern the vessel (i.e. within camera view) but species-level identification was not routinely possible with the system and technology in place at that time. They categorised abundance in terms of the number of seabirds seen within a camera view per minute (less than one, 1 – 4, and more than 4 birds). In 2011, McElderry et al. reported that abundance ranges could be estimated from imagery showing the area astern the focal trawl vessel, to a maximum distance of < 100 m astern. More typical distances within which abundance estimation was possible were within 25 m of the vessel. Birds were better resolved when recorded against the sky or very close to the vessel. Large seabirds were more effectively resolved than smaller ones. However, sea conditions also affected the robustness of abundance estimates from imagery.

Dolphins were also detected in EM imagery by McElderry et al. (2011). These could not be identified to species beyond distances of approximately 5 m from the vessel stern. Further, McElderry et al.

(2011) noted that in anything other than calm sea conditions, detection would be difficult to the extent that count data could not be considered robust.

Opportunistic detection of dolphins has been reported by Carlson and Scott-Denton (2016), in their trial of EM to monitor smalltooth sawfish interactions with shrimp trawl fisheries in the USA.

Fish waste discharge

McElderry et al. (2011) conducted opportunistic analyses of the efficacy of EM in detecting fish waste discharge, and concluded that dedicated recording would be more effective in documenting discharge. Piasente et al. (2012b) reported the effective detection of fish waste discharge during hauling in the eastern Australian tuna and billfish longline fishery. Discarding is a focus of a number of other EM programmes globally. The ease and efficacy of monitoring varies with fishing method but with appropriate onboard systems in place, discarding can be effectively monitored using EM (e.g. Northeast Fisheries Science Center 2014; Ulrich et al. 2015; NOAA 2016; Middleton 2016b; Pria et al. 2016).

Table 1. Summary of electronic monitoring (EM) projects documenting protected species captures in commercial fishing gear. Taxa considered include those legally protected in New Zealand. The significant number of EM programmes that have monitored fish catch are broadly considered using examples, with more specific attention on sharks and rays given the legal protection of some of these species in New Zealand.

Protected species group	**Fishing method**	**Country/Region**	**Sources**
Seabirds	Pelagic longline	Australia, Solomon Islands, USA (Hawaii)	McElderry et al. 2010; Piasente et al. 2012b; Hosken et al. 2016b
	Demersal longline	New Zealand, South Georgia, USA (Alaska)	Ames et al. 2005; McElderry et al. 2008; Benedet 2016; Middleton 2016a; Thompson and McKenzie 2018
	Trawl	New Zealand, USA (Alaska)	McElderry et al. 2004b, 2011
	Set net / Gillnet	New Zealand, USA (northeast), Peru	McElderry et al. 2007; Tilander and Lynneryd 2010, cited in ICES Advisory Committee 2010; Northeast Fisheries Science Center 2014; Pria et al. 2014; Bartholomew et al. 2018
Cetaceans	Trawl	New Zealand	McElderry et al. 2011
	Set net / Gillnet	Australia, New Zealand, North Sea, Peru, USA (northeast)	McElderry et al. 2007; Evans and Molony 2011; Kindt-Larsen et al. 2012; Lara-Lopez et al. 2012; Pria et al. 2014; Northeast Fisheries Science Center 2014; Bartholomew et al. 2018
Pinnipeds	Gillnet	Australia, USA (northeast), Peru	Lara-Lopez et al. 2012; Northeast Fisheries Science Center 2014; Bartholomew et al. 2018
Marine reptiles	Pelagic longline	Australia, New Zealand, Solomon Islands, USA (Hawaii)	McElderry et al. 2008, 2010; Piasente 2012b; Hosken et al. 2016b
	Gillnet	Peru	Bartholomew et al. 2018
	Trawl	Australia	Piasente 2012a

Protected species group	Fishing method	Country/Region	Sources
Fish	Pelagic longline	e.g. Australia, New Zealand, Solomon Islands, USA (Hawaii, Atlantic)	e.g. McElderry et al. 2008, 2010; Piasente 2012b; Hosken et al. 2016b; Larcombe et al. 2016; NOAA 2016
	Demersal longline	e.g. Canada (British Columbia), New Zealand, USA (Alaska)	e.g. Ames et al. 2007; McElderry et al. 2008; Al-Humaidhi et al. 2014; Stanley et al. 2014; Northeast Fisheries Science Center 2014; AFMA 2015; NOAA 2016
	Pot/trap	e.g. USA (Alaska)	e.g. Al-Humaidhi et al. 2014; Buckelew et al. 2015; NOAA 2016
	Set net/gillnet	e.g. Australia, USA (northeast), New Zealand, Peru	e.g. McElderry et al. 2007; Lara-Lopez et al. 2012; Northeast Fisheries Science Center 2014; Pria et al. 2014; Bartholomew et al. 2018
	Purse seine	e.g. Indian, Atlantic, Pacific Oceans	e.g. Ruiz et al. 2013, 2014; Briand et al. 2018
	Trawl	e.g. New Zealand, Netherlands, USA (Alaska)	e.g. Al-Humaidhi et al. 2014; Northeast Fisheries Science Center 2014; van Helmond et al. 2014; Middleton et al. 2016b; Pria et al. 2016; NOAA 2016
• Sharks and rays	Pelagic longline	Australia, New Zealand, Solomon Islands, USA (Hawaii)	McElderry et al. 2008, 2010; Piasente et al. 2012b; Hosken et al. 2016b; Larcombe et al. 2016
	Demersal longline	New Zealand, USA (northeast)	McElderry et al. 2008; Northeast Fisheries Science Center 2014
	Pot/trap	USA (Alaska)	Buckelew et al. 2015
	Set net/gillnet	New Zealand, Australia, USA (northeast), Peru	McElderry et al. 2007; Evans and Molony 2011; Lara-Lopez et al. 2012; Northeast Fisheries Science Center 2014; Pria et al. 2014; Bartholomew et al. 2018
	Trawl	New Zealand, USA (northeast)	McElderry et al. 2011; Northeast Fisheries Science Center 2014
	Purse seine	Indian, Atlantic, Pacific Oceans	Ruiz et al. 2014; Briand et al. 2018

Protected species group	Fishing method	Country/Region	Sources
Corals	Demersal longline	South Georgia	Benedet 2016

The EM process

Detection of protected species interactions using EM results from a multi-stage process that starts with the specification of monitoring objectives (Figure 1). While the focus of this report is detection and description of protected species interactions and species identification by EM analysts, what is possible at review is significantly affected by components of EM that apply prior to imagery being recorded, and that imagery coming ashore. Consequently, pilot studies often report actions for implementation at sea that can be used to facilitate data extraction from imagery, and ultimately improve data quality (see references below). To provide context for what is achievable at review, relevant steps leading up to imagery coming ashore are briefly discussed below.

System design and imagery capture at sea:

Once monitoring objectives are specified, appropriate camera placement on vessels at sea is essential to enable EM to be effective. While required placements may appear straightforward when objectives are clear, numerous pilot studies report that the efficacy of monitoring would be improved by modifying camera locations after initial trips. For example, camera position may need to be refined to ensure every haul event is captured, to see catch handling on deck better, or angles of view altered to ensure animals are detectable if they fall from gear before being brought close to the vessel (McElderry et al. 2004b, 2007, 2011; Kindt-Larsen et al. 2012; Lara-Lopez 2012; Pria et al. 2014; AFMA 2015).

Optimising the performance of EM in recording protected species interactions also requires considering system capability, such as imagery frame rate. Where the imagery is recorded at an insufficient frame rate, detection and identification of catch is hampered (Ames et al. 2005; Lara-Lopez et al. 2012; Ruiz et al. 2014; Bartholomew et al. 2018).

Capturing interactions in imagery effectively can also be facilitated by training crew to follow onboard protocols that facilitate EM performance. For example, crew activities must be conducted such that camera views are not obstructed. Further, crew can facilitate detection of protected species by following handling protocols for the display of captured animals to cameras that ensure cameras can “see” characteristics critical for species identification (e.g. Piasente et al. 2012a; Fitzgerald et al. 2017). Handling captured protected species in view of cameras also facilitates assessments of life status (Piasente et al. 2012b).

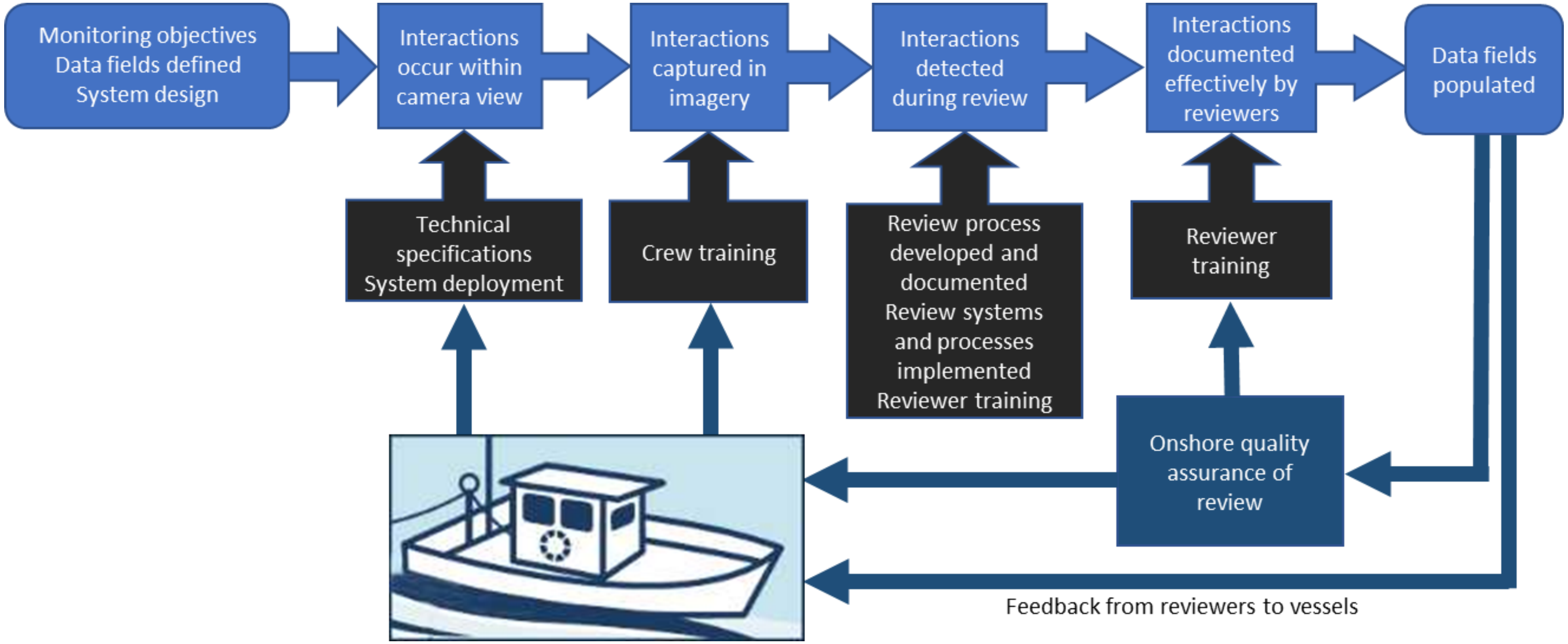

Figure 1. Overview of selected process steps, and inputs to those steps, that enable effective collection of information on protected species interactions with commercial fisheries using electronic monitoring.

Imagery review onshore:

Once imagery arrives onshore, two main factors affect the detection of protected species interactions by EM analysts. First, the review process must provide for detection to occur. Second, effective training must be in place to enable EM analysts to do their job well. The approach taken to review will be determined by the monitoring objectives of the EM programme.

A core consideration for EM programme design is whether a census or sample approach to review is required (Table 2). Rare events such as protected species captures are, by definition, difficult to detect as they occur infrequently. Sampling considerations in this regard have been applied to human observer monitoring (e.g. Babcock et al. 2003) and are also relevant to EM. For example, human observer monitoring that covers 20% of fishing effort provides for species comprising 35% of the catch to be estimated within 10% of their actual catch level 90% of the time (Babcock et al. 2003). For species comprising <0.1% of the catch, more than 50% observer coverage is required to estimate captures within 10% of true levels 90% of the time (Babcock et al. 2003). Where species and interactions are especially rare, the need for observer coverage levels of close to 100% has been recognised (Lawson 2006). Similarly for EM, the objective of detecting rare events such as protected species captures has led practitioners to review 100% of imagery (McElderry et al. 2011; Lara-Lopez et al. 2012; Wallis and Barrington 2017).

While they may be rare events requiring higher levels of review, if detecting protected species captures is the sole purpose of the EM programme, it should be possible to review most of the imagery collected at speeds significantly faster than real time, e.g. up to 16 times real time (Table 2. (McElderry et al. 2007; Pria et al. 2014)). Around capture events, review speed is then reduced, to enable identification and collection of other information required. However, when comprehensive documentation of target catch and bycatch is required, review must be conducted at slower speeds across a larger amount of imagery, which will be significantly more time consuming (e.g. McElderry et al. 2007). For other types of protected species interactions or monitoring risk factors related to interactions, review speed and time taken will be influenced by the operational stage and duration of fishing activity in which the event of interest may occur (e.g. longline setting, for the detection of tori lines).

Onshore review processes also link back to imagery collection at sea (Figure 1). EM analysts can detect issues such as when camera lenses require more frequent cleaning on a vessel, or crew need to follow handling protocols more closely. Providing feedback to vessel skippers and crews as soon as issues are detected by EM analysts improves the efficacy with which EM operates (Ecotrust Canada 2016).

Table 1. Overview of review approaches used to extract data on protected species interactions from EM imagery.

% imagery reviewed	< 100% of imagery	100% of imagery
Review characteristics	- Sample approach - Less effective for detecting rare events (sampling design considerations apply) - Less time-consuming to review	- Census approach - Most effective for detecting rare events - More time-consuming to review
Protected species quantified, identified	- Higher-speed review possible - Partial protected species dataset acquired	- Higher-speed review possible - Complete protected species dataset acquired
All catch quantified, identified	- More time-consuming than just reviewing for protected species - Partial catch dataset acquired	- Most time consuming review approach - Complete catch dataset acquired

Analysis of EM imagery

At review, data are harvested from EM imagery and associated information (e.g. vessel location details). For the collection of robust data from EM, monitoring objectives must link through business requirements to the specification of data elements. EM analysts must be instructed on what to extract from imagery (i.e. data fields are identified), what to document (i.e. data fields are well defined) and how to document extracted information in a robust way (i.e. ensure data extraction is repeatable and auditable). With process and data standards clear, training needs for EM analysts can be identified and training programmes and materials developed (Figure 2).

Figure 2. Steps towards the identification of training needs for analysts of EM imagery.

Currently, there are no universal standards or protocols for how EM analysts approach the detection, identification or documentation of protected species interactions in imagery. Many of the available reports and papers on EM discuss at-sea procedures relating to imagery capture. However, EM process and data standards, and the design and content of training programmes for EM analysts are less frequently described. In recent years, the need for EM process and data standards has been increasingly recognised (Al-Humaidhi et al. 2014; Hosken et al. 2016b; Smith et al. 2017). Some regional fisheries management bodies have initiated work programmes to progress such standards (e.g. Hosken et al 2016a; Ruiz et al. 2017; SPC and FFA 2017).

While standards are not yet commonplace, approaches implemented to date by practitioners using EM imagery to document protected species interactions with fisheries are discussed below.

Species identification:

Six approaches to facilitating species identification (including all species, not only protected species) by EM analysts were found in the course of this review.

- Recruiting previously trained at-sea observers to conduct EM review and/or providing EM analysts with the same species identification training as at-sea observers receive

Former or current fisheries observers are widely employed as EM analysts (Lara-Lopez et al. 2012; van Helmond et al. 2014; Buckelew et al. 2015; Monteagudo et al. 2015; Hosken et al. 2016b; Middleton et al. 2016a; Saltwater Inc. 2017; Briand et al. 2018; A. Barney, pers. comm.; G.L. Marcos pers. comm.). In these cases, observers have conducted the entire review, or a less experienced analyst has been tasked with taking screenshots and clipping segments of imagery for review by an observer (e.g. Lara-Lopez 2012).

- Providing EM analysts with the same resources on species identification as observers receive

EM analysts have a similar task to at-sea observers, so it is intuitive that resources supporting species identification will work in both contexts. Observer resources may usefully highlight key identifying characteristics, which can also be used when identifying species in imagery (e.g. Chase and Galbraith 2004, cited in Northeast Fisheries Science Center 2014; Northeast Fisheries Science Center, undated, a).

- Providing EM analysts with a list of species from which to assign an identification to what they detected during review

A species list was provided to EM analysts in two pilot studies. EM analysts were instructed to select identifications from the list for protected and other species of particular interest, or fish species, observed in imagery (respectively, Pria et al. 2014; Hosken et al. 2016b). In another study, authors noted the probable utility of such a list, to guide identifications (Lara-Lopez et al. 2012). In that study, there was divergence between species identifications conducted by a trained observer undertaking EM review and a less experienced analyst.

- Providing EM analysts with field guides

Field guides are standard identification tools for all species. Three studies reported using these as a species identification resource during review (McElderry et al. 2010, 2011; Northeast Fisheries Science Center 2014).

- Providing EM analysts with an image library of species

McElderry et al. (2008) report the use of an image library to facilitate identification of catch species detected in EM imagery from longline fisheries.

- Developing bespoke identification tools populated with reference images taken from EM imagery, and with taxon-specific field marks shown.

When seen in EM imagery, animals may be wet, incomplete, decomposing, covered in slime or scales, and not showing their natural (live) posture. Field guides and other materials used for live animals can facilitate identification. However, the creation of bespoke resources using screenshots from EM imagery, or other images of animals that have been captured by, or otherwise interacted with, fishing gear is likely to be particularly useful (Piasente et al. 2012b; Northeast Fisheries Science

Center 2014; Needle et al. 2015). Highlighting field marks in such images is valuable, and will contribute to documentation of the identifications made (e.g. Needle et al. 2015).

The rationale for identification to species or higher taxonomic levels may be based on one or more characteristics:

- Body size (e.g. a large dolphin and a small dark seabird (McElderry et al. 2011))
- Morphology (e.g. dolphin beak shape (Lara-Lopez et al. 2012), a square caudal fin (Needle et al. 2015))
- Distinctive markings (e.g. a dolphin's strongly contrasting black and white lateral markings (McElderry et al. 2007), a black lateral line (Needle et al. 2015))
- Colouration (e.g. a large white seabird (McElderry et al. 2011), a green mottled fish (Needle et al. 2015))

Species distributions also provide useful guidance on which to base identifications. However, these should not be used in isolation from other characteristics as the distribution of marine species is dynamic. For example, amongst protected species, vagrant seabirds challenge the *status quo* of species distributions on an ongoing basis, and increasing sea temperatures are expected to affect marine turtle distributions over time (Hawkes et al. 2009; Miskelly et al. 2017).

When EM analysts identify species in imagery, documenting this in a way that is repeatable by another analyst and can be audited is critical for programme rigour. Again, while its importance is well recognised, there are no existing industry standards for this. For example, one study reports that EM analysts were free to document their identifications in their own words. Identification based on a minimum of two identifying characteristics was required. This freeform documentation was useful in recording rationale for identifications, but it did not enable ready comparison amongst analysts (Northeast Fisheries Science Center 2014). Using (and documenting) two identifying characteristics for regulated groundfish species has become part of the NOAA review requirements for northeast groundfish electronic monitoring (A. Barney, pers. comm.). Saltwater Inc., a major global supplier of EM services, responded to the need to identify fish caught in a repeatable and documented way by developing "fishionaries" – fish image dictionaries. In development at the end of 2017, these are intended for use in EM analyst training, and machine learning work (Saltwater Inc. 2017). The need for fishionaries was recognised following a process of agreeing on the features that would be used to distinguish catch species in a project Saltwater Inc. conducted with the National Marine Fisheries Service.

Quality assurance:

Quality assurance is an integral part of the design of EM imagery review processes. As with other elements of EM, there is no existing standard for quality assurance including validation and verification. This is despite wide acknowledgement of the value of quality assurance processes, both when EM analysts are less experienced and refining their skills, as well as for experienced analysts to ensure review quality is maintained (Lara-Lopez et al. 2012; Course 2015; Hosken et al. 2016b; SPC and FFA 2017).

Focusing on the role of EM analysts, a defined standard of competence is a critical foundation for confidence in the data extracted from EM imagery. Formal assessment of skills at the end of initial training is a core component of quality assurance (e.g. Piasente et al. 2012b) which is currently in place in some observer programmes (e.g. Northeast Fisheries Science Center, undated, b). To ensure the ongoing quality of review, refresher training and associated competence assessments are also valuable and should be considered as part of a quality assurance framework.

Once initial training is completed and EM analysts are active in their work, quality assurance processes reported in the literature generally comprise a comparison of the datasets extracted by multiple analysts reviewing the same imagery. Differences between analysts' findings (e.g. with respect to species identification and the number of catch items seen) are then discussed as a quality control and training exercise. Archipelago Marine Research, one of the core global suppliers of EM imagery review services, reports conducting this kind of comparative check amongst its analysts monthly (Northeast Fisheries Science Center 2014). As part of their cost-benefit analysis conducted around a trial of EM in an Australian gillnet fishery, Lara-Lopez et al. (2012) provided for 5% of imagery to be re-reviewed as part of quality assurance processes. In the first phase of a pilot project conducted over five years, 4% of hauls monitored by EM were selected for independent review by two analysts. In the final phase of this trial, 1.5% of the hauls were reviewed by all EM analysts involved in the project (Northeast Fisheries Science Center 2014). Ten percent was the most common audit level found amongst information available for this review (Calahan et al. 2010; Ulrich et al. 2015; Thompson and McKenzie 2018). The method for determining how much imagery was reviewed more than once was not described in these studies.

Training EM analysts:

Numerous studies recognise the importance of local species knowledge and of training overall, for the effective extraction of information from EM imagery, including species identifications (e.g., McElderry et al. 2007, 2010, 2011; Lara-Lopez et al. 2012; Piasente et al. 2012a, b; Hosken 2016b; Ruiz et al. 2017). Effective training not only improves data quality, but has also been reported to reduce the cost of EM programmes by 50% (Lowman et al. 2014). There is currently no standard approach reflected in the literature or in use across EM programmes, though standardised regional training programmes covering parts of EM review exist in some areas (e.g. the Pacific Islands Regional Fisheries Observer "Interpret Electronic Monitoring Operations" unit PIROBS3.08E and assessments that observers undertake, e.g. on species identification, who may then become analysts of EM imagery (Northeast Fisheries Science Center, undated, b)). Providers of review services may also have their own training programmes that include the use of proprietary software products (e.g. EM Interpret™, by Archipelago Marine Research).

When trained and experienced observers are employed to conduct imagery review, only a small amount of additional training may be required. For example, several hours or a short course of two days of training could be sufficient to upskill an experienced observer (Piasente et al. 2012b; Needle et al. 2015). In this case, the observer is being trained largely in how to perform their work using imagery and a software product, rather than onboard a vessel. In contrast, for new and inexperienced EM analysts, five days of training was considered required to provide the required knowledge and skills to undertake imagery review, including species identification (Piasente et al. 2012b; G.L. Marcos pers. comm.). With effective training including real-time feedback, inexperienced analysts can be trained to perform similarly to experienced observers in relatively short timeframes.

Piasente et al. (2012b) describe the growth in capability amongst four EM analysts who underwent training during their study. Amongst other duties, analysts were tasked with recording fishing gear and operational information, seabird abundance and behaviour, interactions between gear and threatened, endangered and protected species, and compliance issues in a pelagic longline fishery.

From the start of their training through the first 10 longline sets examined, all four analysts demonstrated continuous improvement in species identification capabilities. Skills of one analyst did not improve subsequently, whereas the other three trainee analysts continued to improve. At around 20 sets despite having no or little prior knowledge of fish identification, three of the four analysts performed nearly as well as an experienced observer (Piasente et al. 2012b). Other studies confirm that analysts' skill levels improved with time (Ames et al. 2005; Al-Humaidhi et al 2014; Hosken 2016b), and that there was more variability amongst analysts when identifying rarely encountered species compared to more common ones (Hosken et al. 2016b).

Ames et al. (2005) describe training given to support seabird identification in their study assessing the capabilities of electronic monitoring in a longline fishery. The training involved a seminar comprising an introduction to common seabirds of the focal region (the north Pacific) and identification techniques. In their audience, just over half of the 14 participants had some prior relevant fisheries knowledge, and overall, the group encompassed a range of seabird expertise. The seminar was followed by participants examining six sample EM imagery clips showing seabird specimens. Subsequent assessment of participants' capabilities comprised three stages: (i) a 5-10 second clip of a longline-captured seabird that participants were tasked with identifying to the lowest taxonomic level, (ii) two still images taken from the same clip, and participants tasked with identification, and (iii) identifying the same two still images, but with tutors pointing out some of the key characteristics that could be used to guide identification. Seminar participants' identification skills increased with each stage of the training. From 25% to 46% and finally 69% of participants correctly identified the seabirds they were shown in stages (i) through (iii) of the training.

Participants followed a stepwise approach to make identifications of the seabirds they were shown. Steps followed are shown in Table 3. With this repeatable approach, decisions made at each step could be discussed with tutors to confirm identifications were robust and identify where errors occurred.

Kindt-Larsen et al. (2012) conducted a trial of EM for the detection of harbour porpoise captures in Danish gillnet fisheries. Prior to undertaking imagery review, Kindt-Larsen et al. (2012) provided analysts with 15 sample videos to test their ability to detect harbour porpoises. Of the 15 video files, 10 included imagery of porpoise captures. Analyst scores were recorded during this test, and analysts proceeded to conduct the actual review work. (In this case, any response to analysts' scores was not described).

Needle et al. (2015) provide a detailed description of the programme they used to train EM analysts tasked with identifying and measuring fish species caught on Scottish trawl vessels. In this case, analysts were already experienced in fish identification, given they were at-sea or market observers. Therefore, the goal of training was to grow capability in using EM imagery for identification, rather than trainees learning to identify fish for the first time. The programme comprised 15 one-hour sessions. Six of these sessions were supervised by an experienced analyst. In a one-hour session, analysts were trained to identify the six key fish species important to the study. Visual aids used in the session included images of the fish of interest under different lighting conditions and on different angles, with trainers pointing out distinctive features that enable identification even if the fish is partially obscured. Images of fish were presented to analysts as a self-test, and the same images then presented again with identifications, and field marks highlighted to enable learning. Identification sheets were also prepared with photos of key species and field marks highlighted. Images were screenshots from EM or photos taken at a fish market.

Following the hour of identification training, trainees undertook four hours of practice runs using imagery in which identifications required were of escalating difficulty. One or two of these practice runs were supervised. Trainee performance in practice runs was assessed against that of experienced analysts. Identification tests were the next step, with trainees conducting image analysis unsupervised over a four-hour period, with specifically selected segments of imagery used to test capability. The remainder of the 15-hour training period focused on length determination.

The repeatability of EM imagery analysis means EM imagery is an excellent training tool at the start of an analyst's career, to ensure ongoing quality of review, and to identify the need for additional training or upskilling (e.g. Hosken et al. 2016b). Overall, common elements amongst the training approaches used in EM programmes identified in this review are summarised in Figure 3.

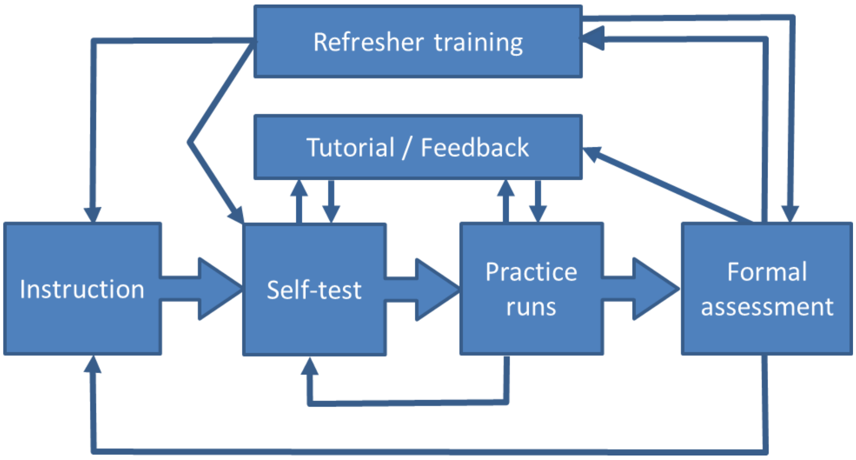

Figure 3. Elements of training approaches used to develop the capability of EM analysts, as described by programmes considered in this review.

Table 3. Steps followed in the seabird identification tests using video and still images recorded during electronic monitoring conducted by Ames et al. (2005).

Step	Description
1a	The animal on the hook is a seabird. (Proceed to 2a).
1b	The animal on the hook is not a seabird
2a	Estimate of the seabird's size by using known references that appear in the background, for example, gaffs, humans (or visible parts of their bodies), fishers' boots, and/or elements of fishing gear. (Proceed to 3a).
2b	If unable to determine the size, then the seabird is categorised simply as an unidentified seabird.
3a	Look at plumage colouration to place the seabird into a given species category. (Proceed to 4a).
3b	Unable to determine plumage colouration. Seabird is an unidentified seabird within a given size category.
4a	Look for individual features of the seabird's bill, feet and plumage. (Proceed to 5a).
4b	Unable to identify two or more distinct features associated with a species. Seabird is categorised as belonging to a particular (higher taxonomic level) group.
5a	Able to determine approximate size, along with two or more distinctive features that could be associated with a particular species. Conclude that the species could be identified with a reasonable degree of confidence.

Automated review

Currently, EM review is dependent on humans sifting through imagery streams to extract the data required to meet monitoring objectives. However, a growing body of work is exploring machine learning, and how artificial intelligence can expedite EM review. As yet, machine learning has not been operationalised at scale for routine analysis of EM imagery and most work has focused on fish rather than non-fish catch elements (e.g. NOAA 2016; Denit et al. 2016). However, this review found four independent projects (three in progress), in which practitioners focused on developing machine learning for the documentation of protected species captures (Kindt-Larsen et al. 2012; A. Cox, pers. comm.; M. Carnes pers. comm.; S. Fitzgerald, pers. comm.; F. Wallace, pers. comm.).

In time, machine learning may replace some or most of the functionalities of human imagery reviewers. However, many of the same considerations that enable human review to be effective apply to machine learning (Figure 4). Analogous to when human review is conducted, there is a continuum from vessel to shore, in terms of technological considerations and on-board practices that facilitate the use of video analytics (e.g. Fitzgerald et al. 2017). Machine learning also involves extensive training so that algorithms do their job well. Humans must have some role in labelling data elements to train algorithms to detect items or events of interest. This is a time-consuming but critical process.

Progression towards the integration of machine learning in EM review is logical where machine learning tools promote review efficiency. At a basic level, where the monitoring objectives of the EM programme include assessments of non-fish bycatch, a machine-based determination of whether or not a catch item is present on a longline snood, and if that is a fish or non-fish item would increase the efficiency of review significantly. EM analysts would not have to watch all imagery, instead focusing their time on catch items identified algorithmically. At a more complex level, breaking non-fish items into bird / turtle / cetacean / pinniped / and so on would promote further efficiencies in human analysts' time.

Species identification is a relatively complex function for EM review, but work on fish has progressed significantly such that high levels of accuracy in automated review are possible (e.g. Wang et al. 2017). In time, and with appropriate training datasets, it is reasonable to expect progression towards automated identification of a broader range of catch species.

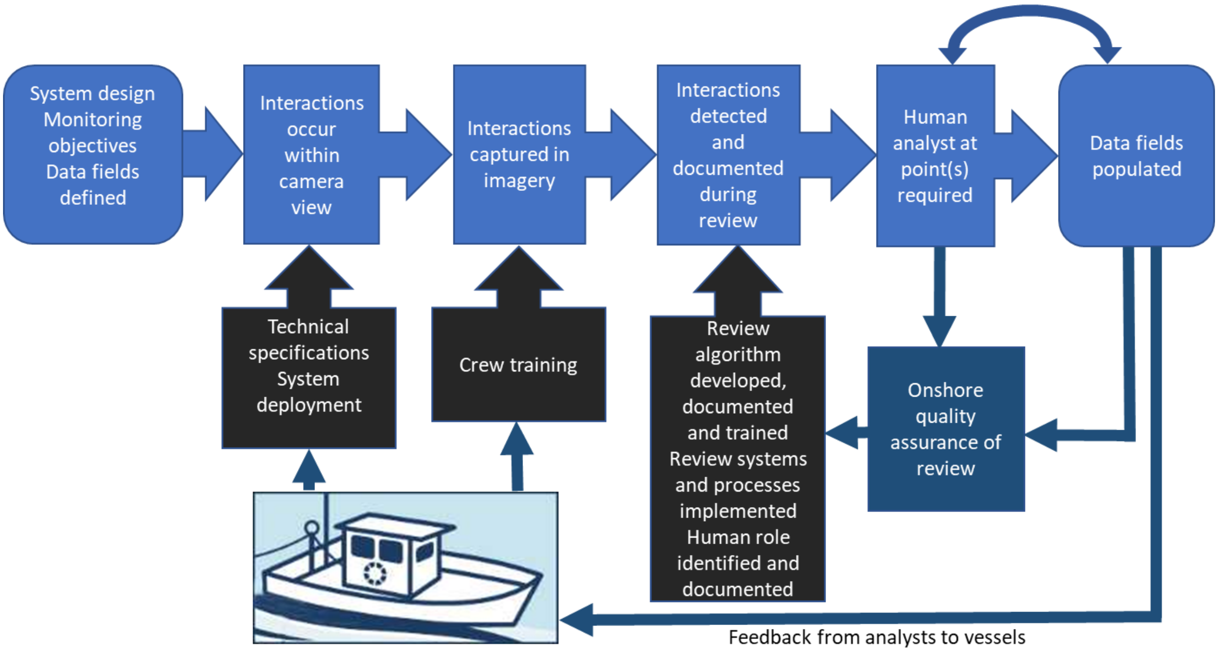

Figure 4. Overview of selected process steps, and inputs to those steps, that enable effective collection of information on protected species interactions with commercial fisheries using electronic monitoring and incorporating automated review.

Discussion

Monitoring protected species interactions

The suite of information collated for this review demonstrates that EM can be effectively used to monitor protected species captures in commercial fisheries. For seabirds, cetaceans, marine mammals, fish and reptiles, trial and pilot studies conducted in a range of fisheries and regions around the world demonstrate the capabilities of EM, including capturing imagery that is of sufficient quality to enable identifications of captured animals to species level. Beyond the pre-implementation phase (Lowman et al. 2013), operational programmes are also underway in some fisheries. For benthic species such as corals, preliminary information suggests that EM may have some potential as a monitoring tool, though outcomes to date are less promising than for other protected species. However, more investigation is necessary to explore and understand the application of EM as a tool for monitoring benthos caught.

Beyond captures, work to date has included the investigation of seabird strikes on wires associated with trawl fishing (trawl warp cables and third wires). Overall, results from these studies do not support further application of EM to monitoring cable/wire strikes.

EM can also be used to provide information about the fate of animals that interact with fishing gear. The best information describing life status can be extracted from imagery of animals brought aboard vessels and clearly seen moving, and animals seen to actively swim away from vessels on release. For animals released while still in the water, ascertaining life status is relatively more difficult. Information on life status that can be extracted from EM imagery is not perfect, but is of significantly better quality than no information. Handling of protected species and other catch items can also be monitored effectively, as long as this takes place within camera views.

Beyond the direct detection of protected species interactions with fishing gear, abnormal crew behaviour may also highlight where capture events have occurred. For example, crew may behave such that animals are removed from fishing gear before being landed on vessels, and before being in view of cameras. As such, unexplained behaviour is a useful trigger for further action, for example, interviewing skippers and crew to explore the cause of the behaviour observed.

Factors that affect capture risks

Predictably, the efficacy of EM in monitoring deployment of bycatch mitigation devices is influenced by the visibility of these devices. The deployment of tori lines, warp scarers, TEDs, and pingers can be effectively monitored by EM. Smaller devices such as BRDs are more difficult to detect.

Using EM to monitor the abundance of protected species around vessels has not been broadly successful. Abundance ranges and identification to species or species group level is possible using imagery in some cases. However, the extraction of information from imagery is affected by sea conditions, distance from the vessel, and sky conditions (in the case of seabirds in flight). These challenges limit the robustness and utility of information collected.

Discharge of fish waste has been widely documented using EM, both in the context of waste as a risk factor for seabird captures and as part of catch accounting and compliance with discarding regimes. Data on fish waste discharge can be successfully extracted from EM imagery.

Delivering quality data from EM imagery

To optimise the performance of EM in fisheries monitoring, technological capabilities need to be embedded in an end-to-end process that is focused on the provision of high quality data. Effective EM is implemented from shore (programme design and system installation) to sea (on vessels where imagery is collected) and back to shore again (where imagery is analysed and data are recorded). At sea, delivering effective EM necessitates considering camera placement, crew behaviour, and catch handling. Onshore, the extraction of high quality data requires process and data standards, reviewer capability and quality assurance.

The development of standards applicable to EM is in its early stages. The information collated for this review showed that there are no global standards in place as yet for EM programme design, review processes, data collection, quality assurance, or training. The development of standards appears most advanced in the Pacific, where regional fisheries management bodies are working together on draft longline, purse seine and transhipment process standards, and data standards (SPC and FFA 2017), and a documented training programme exists for EM analysts, that includes assessment of competence. Minimum data standards have also been provided to the International Commission for the Conservation of Atlantic Tunas, for data collection on purse seine vessels (Ruiz et al. 2017).

While the development of standards is in its early stages, common practices that emerged amongst EM programmes examined in this review include:

- Using trained current or former fisheries observers to carry out EM review,
- Ensuring training programmes have an assessment component that tests the skills of the future EM analysts,
- Structuring training programmes to include instruction, self-testing, practice runs using imagery samples, and tutorial-style feedback,
- Making species identifications using two distinctive characteristics, and documenting the characteristics used, and,
- Auditing 10% of imagery using a second independent review, and comparing the results of the two reviews to assess the accuracy.

Recommended next steps

Pilot deployments of EM systems have occurred in New Zealand fisheries since the early 2000s. While the future of regulated EM is to be confirmed, voluntary initiatives proceed in a number of New Zealand fisheries (e.g. bottom longline fisheries targeting snapper, bluenose and Antarctic toothfish, and inshore trawl targeting snapper). The growing technological capabilities underpinning EM, cost effectiveness compared to human observers, scale and scope of international deployments, and regional strategic priorities for electronic fisheries data collection (FFA and SPC 2017) suggest that adoption of EM will continue and increase in New Zealand. This includes the use of EM for monitoring protected species interactions with commercial fisheries. In the context of this review, recommendations to facilitate the use of EM for monitoring protected species interactions with New Zealand fisheries focus on developing and implementing standardised approaches around the review of EM imagery (Table 4).

Table 4. Recommendations for next steps to facilitate the use of electronic monitoring (EM) of protected species interactions with New Zealand commercial fisheries.

Action	Comment
Develop and document data standards to identify the information that EM analysts will extract from imagery	This involves five broad tasks: • Confirm protected species monitoring objectives that managers would like EM to address • Confirm business requirements that will meet these monitoring objectives • Identify data fields that deliver on business requirements • Define data field attributes that EM analysts will be required to complete • Document how analysts will assign a particular datum to an attribute
Develop quality assurance standards for EM review	A quality assurance standard ensures delivery of data of known quality from EM programmes. Quality assurance includes multiple components of validation and verification. In the review context, comparison of findings between analysts is currently how their accuracy is assessed. An evaluation of how much imagery must be audited to deliver confidence in review to a defined level would contribute to the development of a quality assurance standard for EM review. This work has not been conducted globally to date.
Develop training materials and programmes to enable EM analysts to populate data fields, and to document their findings	Training should include: • Instruction • Self-tests • Tutor feedback • Opportunities for practice Training must include formal assessment that provides evidence of competence, thereby providing assurance of a certain level of data quality in review datasets.
Remain abreast of the regional development of EM process and data standards	Fisheries management bodies in the Pacific are developing EM process and data standards. New Zealand can benefit from involvement in these processes, to both fast-track its own work where others are leading, and to ensure domestic and international approaches are harmonised to the extent possible and appropriate (e.g. in terms of process requirements which data are collected from imagery, and how data are documented).

Action	Comment
Initiate the development of training materials, where requirements are already understood	Fisheries monitoring is not a green-fields undertaking and assumptions can be made about some elements of the information that will be required from EM. In parallel to implementing the actions above, training materials for EM analysts can be prepared that cover: • Detection of protected species captures • Species identification • Life status of captured animals • Mitigation deployed • Unusual crew behaviour Training should include sample images and clips that are taken from EM, wherever possible.
Catalogue and store photos and videos taken by fisheries observers for use in EM training materials	Real-world images should be used in training materials wherever possible. While little imagery is available from New Zealand fisheries to date for use in training, observer photos and videos are an excellent resource from which to draw images of bycaught protected species and mitigation devices. For example, observer photos include soaked and imperfect specimens, that differ in appearance from the live images in field guides. Photos showing identifying characteristics are especially valuable as training tools. In time, catalogued images may also have value in training machine learning algorithms.
Encourage practitioners to make available process and data standards, review protocols and training materials	Sharing materials used to support EM programmes will promote efficiency and harmonisation of approaches, rather than a situation where each programme or service provider creates a unique approach. It is early days for the development of standards applicable to EM globally. Sharing materials that support programmes should allow for more rapid development of standards and facilitate timely adoption. A single repository attached to an EM information sharing platform may encourage this.

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Appendix 1: Scientific names of animals mentioned in the text

Antarctic toothfish	*Dissostichus mawsoni*
Bluenose	*Hyperoglyphe antarctica*
Pacific halibut	*Hippoglossus stenolepis*
Patagonian toothfish	*Dissostichus eleginoides*
Snapper	*Pagrus auratus*

Basking shark	*Cetorhinus maximus*
Oceanic whitetip shark	*Carcharhinus longimanus*
Smalltooth sawfish	*Pristis pectinata*
White pointer shark	*Carcharodon carcharias*
Whale shark	*Rhincodon typus*

Spinetail devil ray	*Mobula japanica*
Manta	*Mobula birostris*

Green turtle	*Chelonia mydas*
Hawksbill turtle	*Eretmochelys imbricata*
Leatherback turtle	*Dermochelys coriacea*
Loggerhead turtle	*Caretta caretta*
Olive ridley turtle	*Lepidochelys olivacea*

Australasian gannet	*Morus serrator*

Harbour porpoise	*Phocoena phocoena*
Bottlenose dolphin	*Tursiops truncatus* and *Tursiops* spp.
Common dolphin	*Delphinus delphis*
Dusky dolphin	*Lagenorhynchus obscurus*
Hector’s dolphin	*Cephalorhynchus hectori*

Australian sea lion	*Neophoca cinerea*
South American sea lion	*Otaria flavescens*
Gray seal	*Halichoerus grypus*
Harbour seal	*Phoca vitulina*