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RESEARCH PAPER

# The use of electronic monitoring within tuna longline fisheries: implications for international data collection, analysis and reporting

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**Abstract** Electronic monitoring (EM) consisting of on-board video imagery and on-shore analysis, offers an alternative or supplement to at-sea observer programs in commercial fisheries. In the western and central Pacific Ocean (WCPO), where observer coverage in most tuna longline fisheries has historically been $< 5\%$, the advent of EM has been perceived as a tool for meeting international data collection and exchange obligations. However, the capability of EM to collect and support interpretation of records into data for all fields currently collected by at-sea observers is still under assessment. We use the Western and Central Pacific Fisheries Commission (WCPFC) as a case-study to evaluate the longline WCPFC regional observer programme minimum standard data fields, their current scientific application, the proportion of member countries exchanging data and the capability of EM technology to collect these fields. We identify that 78% of the longline fields can be collected with current EM technology, with 84% of these used in scientific analyses. For the 16% of fields not routinely used in scientific analyses, the introduction of EM may facilitate a sufficient increase in data availability to support their future use. Alternative tools would be required to collect fields that EM could not record to ensure data continuity and scientific rigour are not compromised. In examining the capability of EM in the context of WCPFC member state requirements under international law, we advocate for a holistic and integrated approach to the use of EM in future research and monitoring programs in both the WCPO and global longline fisheries.

**Keywords** At-sea observers · Cameras · Data · Fisheries management · Tuna · WCPFC

## Introduction

Data are required to inform fisheries management and aid the decision-making process (FAO 1997). Data collection is usually achieved through the implementation of fisheries research and monitoring programs, which provide managers with either fishery-independent or fishery-dependent data. Fishery-independent data are generally collected through research vessels (scientific fishing surveys), while fishery-dependent data are usually collected from commercial vessels,

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either in the port of landing (port sampling and catch disposal records) or at-sea (vessel logbook and at-sea observer programs) (Cotter and Pilling 2007; Gilman et al. 2017; Nicol et al. 2013). While usually focused on specific objectives (Evans and Molony 2011), at-sea observer programs have the capacity to record information on catch (both retained and discarded) and effort (gear characteristics and their utilisation), while also collecting associated biological data (e.g. length and age composition) and recording interactions with SSI. The data provided by at-sea observers have been used to identify and understand trends in nominal and standardised catch rates and catch levels (e.g. Gilman et al. 2016; Hare et al. 2015; Walsh et al. 2009; Ward and Myers 2005), augment logbook and port sampling data in stock assessments (e.g. McKechnie et al. 2016; Takeuchi et al. 2016), identify new species of fish and requisite biological information (e.g. Roberts et al. 2015), and monitor the success of conservation and management measures (CMMs) at both a national and international level (e.g. Clarke et al. 2013).

Despite the associated benefits of at-sea observer data, the coverage (as a percentage of total fishing effort) may be lower than anticipated (Clarke et al. 2013; Williams et al. 2016), non-representative of fishing effort (Babcock and Pikitch 2003; Gilman et al. 2017; Nicol et al. 2013), or simply considered sub-optimal in meeting legislative or management objectives (Evans and Molony 2011; Gilman 2011; Larcombe et al. 2016). Low levels of observer coverage have often been inferred to be a result of the high financial costs of the program, as well as scheduling and logistical difficulties associated with placing observers on-board vessels (Ames 2005; Evans and Molony 2011; WCPFC 2016a). Health and safety is a particular risk on fishing vessels that are at sea for extended periods, or fishing in areas where piracy is prevalent, such as the western equatorial Indian Ocean (Ruiz et al. 2015). In addition, at-sea observer data may be biased due to the resulting non-random placement of observers on fishing vessels and changes in the crew's fishing practices and behaviour while the observer is on-board (i.e. observer effects) (Ames 2005; Benoît and Allard 2009; Faunce and Barbeaux 2011; Mangi et al. 2015). The individual identification skill and capability of observers may also vary and lead to inconsistency in data quality (Dunn and Knuckey 2013; Evans and Molony 2011).

Electronic monitoring (EM) is a reliable, innovative and potentially cost-effective system that does not have all the same limitations of at-sea observer programs (Banks et al. 2016). EM is a combination of hardware and software that collects records in an automated manner that is closed to manual or external input (Dunn and Knuckey 2013). These records are then transmitted and can be interpreted into data by an EM analyst reviewing the footage. On the vessel, EM technology consists of a central computer, combined with several gear sensors and video cameras that are capable of monitoring and recording fishing activities (McElderry 2008; Ruiz et al. 2015). The records are stored and can be independently reviewed and verified later onshore for both management and compliance purposes. Typically, the records are either used to census all fishing effort for catch monitoring purposes, and/or to audit a proportion of fishing effort to verify fishing logbooks (Mangi et al. 2015). To improve readability, we use the term *integrated EM system* in this paper when discussing in unison the technological (i.e. on-board camera and sensors) and logistical (i.e. on-shore analysis of records) aspects of EM.

The prevailing rhetoric in the literature is that integrated EM systems are a useful supplement to at-sea observer programs but not an adequate replacement if the objectives for research and monitoring are expansive (Banks et al. 2016). Integrated EM systems have been shown to work more effectively in longline fisheries where the catch is retrieved serially as opposed to high volume fisheries, such as trawl, where the catch is brought on board on mass (McElderry 2008). Furthermore, identifying individual retained and discarded species can be challenging in high volume fisheries where catch are composed of many similar species (Sylvia et al. 2016) or discarded close to the ocean surface and not brought on board. However, the latter could potentially be addressed through more effective camera placement. Species identification difficulties can also arise in any fishery due to poor image quality caused by external factors, such as weather and lighting or the quality of the cameras themselves (Mangi et al. 2015; Wallace et al. 2013). Collecting biological data on species length, age, sex, fate and condition upon release can also be difficult and in some cases impossible, in the absence of at-sea observers, and while some software tools are available (e.g. for length measurements), they may not be viable in all fisheries due to logistical or financial constraints (Ames et al. 2007; Dunn and Knuckey 2013; Evans and Molony 2011; Wallace et al. 2015).

In the Western Central Pacific Ocean (WCPO), various countries target highly migratory stocks in their EEZs and other high seas areas, including yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alalunga*) and swordfish (*Xiphias gladius*). These highly migratory stocks are managed cooperatively through the Western and Central Pacific Fisheries Commission (WCPFC), which is the relevant Regional Fisheries Management Organisation (RFMO) established under the Convention for the Conservation and Management of Highly Migratory Fish Stocks in the WCPO (The Convention). Its role is to assist countries in making decisions to sustainably manage these highly migratory stocks throughout their distribution (Gilman et al. 2014).

In 2007, the WCPFC established a Regional Observer Program (ROP), along with accompanying minimum standard data fields, as a way of monitoring associated fisheries. However, the coverage for longline fisheries as a proportion of total fishing effort has often been less than the 5% minimum requirement under WCPFC CMM 2007-01 (Gilman 2011; Molony 2005). For example, according to Peatman et al. (2018), annual at-sea observer coverage (proportion of number of hooks) of longline fleets in the Convention area (excluding west-tropical domestic fisheries) was around 1–1.5% between 2003 and 2010, before reaching a maximum of around 4.5% in 2013 and then varying between 2 and 4% up to 2017.

The difficulties associated with placing at-sea observers on longline vessels has led to the consideration of integrated EM systems as a way to increase coverage levels, with the commencement of a series of EM trials and pilot studies in various longline fisheries in the WCPO over the last decade (Hosken et al. 2016b, 2017; Mangi et al. 2015). The success of these trials and pilot studies, coupled with a lack of documented policies and standards for integrated EM systems in the WCPO, prompted the WCPFC to form an EM and Electronic Reporting (ER) Working Group in 2014 (WCPFC 2015b) tasked with drafting technical, logistical, data analysis and program standards for EM (WCPFC 2015c). The objective of establishing these standards is to ensure that integrated EM systems used across the WCPO meet minimum standards to ensure data collected remains timely, accurate and suitable for management decision-making.

However, the ability of integrated EM systems to collect and support interpretation of records into data for all fields currently collected by at-sea observers is still under assessment internationally. It is highly likely that EM records are unable to be converted into some data types that are currently collected by at-sea observers. Therefore, if an integrated EM system simply replaced at-sea observer programs, the absence of data fields previously collected by at-sea observers may cause a range of data continuity issues, with flow on effects in the delivery of scientific analyses and provision of scientific advice. For example, the data collected by these at-sea observer programs are used in various scientific analyses, such as estimating catch rates (e.g. Aires-da-Silva et al. 2014; Bromhead et al. 2012), SSI interaction rates (e.g. Morato et al. 2010; OFP 2010; Tremblay-Boyer and Brouwer 2016) and assessing the performance of mitigation devices and measures (e.g. Bromhead et al. 2012; Cox et al. 2007; Gilman 2011).

We use the WCPFC as a case-study to evaluate the use of integrated EM systems in longline tuna fisheries by examining the WCPFC ROP minimum standard data fields, their current (and potential future) scientific application, the proportion of member countries supplying these data, and the capability of integrated EM systems to collect these fields. We frame this analysis in the context of member state requirements under international law and recognition by the WCPFC that integrated EM systems are likely to form a major component of future research and monitoring programs in the WCPO longline fisheries.

## Methods

The WCPFC established the ROP through CMM 2007-01 and Article 28 of The Convention, with the objective of collecting "verified catch data, other scientific data, and additional information related to the fishery from the Convention Area and to monitor the implementation of the CMMs adopted by the Commission." Under CMM 2007-01 and CMM 2016-01, there are varying levels of observer coverage required depending on the fishing method employed with: (a) 5% observer coverage required on longline vessels, (b) 100% observer coverage required for purse seine vessels fishing within the area bounded by 20°N and 20°S exclusively on the high seas, on the high seas and in waters under the jurisdiction of one or more coastal states, or vessels fishing in waters under the jurisdiction of two or more coastal states, and (c) 100% observer coverage required for the receiving (carrier) vessel involved in transhipments on the high seas.

Accompanying the ROP is a set of minimum standard data fields, which were developed by the WCPFC Scientific Committee and ROP Intersessional Working Group to ensure that member states collect and provide fishery dependent data required by the Commission.[1] National at-sea observer programs operating within the WCPFC area of competence are required to collect the WCPFC ROP minimum standard data fields if their vessels:

- Fish exclusively on the high seas in the Convention area;
- Fish on the high seas and in the waters under the jurisdiction of one or more coastal states; or
- Fish in the waters under the national jurisdiction of two or more coastal states.

It is important to note that the WCPFC ROP minimum standard data fields were based on observer data standards that were originally developed by the Pacific Community (SPC) and the Pacific Islands Forum Fisheries Agency (FFA) through a Data Collection Committee (DCC), first established in 1995. The WCPFC ROP minimum standard data fields are therefore a subset of the fields developed and deemed useful for science by the DCC and that continue to be utilised and collected by SPC/FFA members (see Table 1) (SPC 2016b).

The decision by the WCPFC to task the EM and ER Working Group with the development of technical, logistical, data analysis and program standards for EM, led to SPC convening a technical workshop in 2016, where the capability of current integrated EM systems to collect at-sea observer data fields (which cover both the WCPFC ROP minimum standard data fields and additional fields required by the SPC/FFA DCC) was assessed by a group of experts (SPC 2016a). In 2017, the workshop reconvened and the capability of integrated EM systems to collect the same data fields was reassessed given anticipated changes in technology (SPC 2017). The agreed categories for assessing EM capability at the 2017 workshop and their accompanying definition were:

- *EM-R1*—Ready now
- *EM-R2*—Ready now but requires significant crew support
- *EM-R3*—Ready now but requires dedicated or additional camera/sensor
- *EM-R4*—Ready now but inefficient/costly for an EM analyst to interpret
- *EM-P1*—Possible with minor work
- *EM-P2*—Possible with major work
- *EM-NP*—Not possible

The EM-R2, R3 and R4 categories differ from EM-R1 in that additional time and/or financial costs (e.g. EM analyst review time, crew support or additional equipment) would be incurred with recording and analysing data fields. Additionally, technical and financial limitations in current camera and/or sensor technology (that may improve with time), were the main determinates behind data fields being classified as either EM-P1 or EM-P2.

While there are over 150 data fields in the WCPFC ROP minimum standard that at-sea observers are required to collect, which provide information on catch composition, vessel and gear specifications as well as SSI interactions, for the purposes of this study we chose to only review the 49 longline fishery data fields as of 2016 (noting that there have been some minor updates to instructions of fields since this time) (WCPFC 2017a). Our assessment of the capability of integrated EM systems to collect these 49 longline data fields was based on expert opinion from the SPC workshops in 2016 and 2017, along with a review of the relevant literature. Our assessment of their current (and potential future) scientific use and the proportion of member countries providing ROP longline data fields to the WCPFC Secretariat was made possible through WCPFC contracting SPC as its science services provider, whose responsibilities include managing its ROP data holdings, as well as undertaking agreed analyses for the WCPFC Commission and its subsidiary committees. It should be noted that our decision to provide information on data provision

[1] The WCPFC Minimum Standard Data Fields are available from: https://www.wcpfc.int/system/files/Table-ROP-minimum%20standard%20data%20fields%20-%202016%20update_1.pdf.

**Table 1** The WCPFC ROP minimum standard data fields (CMM 2007-01) for longline fisheries, WCPFC member country data provision specifics, an assessment of EM capability (after SPC 2017) and details of SPC scientific use

| WCPFC Regional Observer Programme (ROP) Fields | | | | | | Draft Longline Observer Electronic Monitoring Process Standards | SPC/FFA Regional Longline Port Sampling Form | SPC/FFA Regional Longline Logsheet | SPC-OFP Data Use |
|---|---|---|---|---|---|---|---|---|---|
| | ***Longline data fields*** | ***Description*** | ***Is field currently collected in SPC/FFA observer form?*** | ***Proportion of member countries providing some data for field (2012-2016)***[†] | ***Average proportion of observed trips from member countries where field was recorded (2012-2016)*** | ***Could this field be collected by EM?*** | ***Is field currently collected in SPC/FFA port sampling form?*** | ***Is field currently collected in SPC/FFA logsheet?*** | ***Main scientific use at current levels of observer coverage and current data provision*** *(**NB: Bold** = have been used in scientific analysis Non-Bold – theoretically could be used in scientific analyses)* |
| Vessel attributes | Refrigeration method | Indicate all different types of refrigeration methods on board (Y/N) | Yes | 82% | 72% | EM-NP | No | No | Evolution in fishing technology & fleet dynamics - effort creep/efficiency; Socio-economics; and Targeting. |
| General gear attributes | Mainline material | Mainline material | Yes | 88% | 79% | EM-NP | No | No | Evolution in fishing technology & fleet dynamics - effort creep/efficiency. |
| | Mainline length | Mainline length in miles or kilometres | Yes | 88% | 65% | EM-P2 | No | No | Evolution in fishing technology & fleet dynamics - effort creep/efficiency. |
| | Mainline diameter | Mainline diameter (mm) | Yes | 88% | 76% | EM-NP | No | No | Evolution in fishing technology & fleet dynamics - effort creep/efficiency. |
| | Branch line material(s) | Branchline material can be made up of many different materials | Yes | 88% | 76% | EM-NP | No | No | Evolution in fishing technology & fleet dynamics - effort creep/efficiency. |
| Special gear attributes | Wire trace | Is wire trace used (Y/N) | Yes | 82% | 70% | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardisation of shark species; Shark bycatch mitigation; and Inferring target species complex.** |
| | Mainline hauler | Existence of a mainline hauler (Y/N) | Yes | 82% | 75% | EM-R3 | No | No | CPUE standardisation - effort creep/efficiency. |
| | Branch line hauler | Existence of a branchline hauler (Y/N) | Yes | 82% | 73% | EM-R3 | No | No | CPUE standardisation - effort creep/efficiency. |
| | Line shooter | Existence of a line shooter (Y/N) | Yes | 88% | 81% | EM-R3 | No | No | Depth of gear. |
| | Automatic bait thrower | Existence of an automatic bait thrower (Y/N) | Yes | 82% | 73% | EM-R3 | No | No | CPUE standardisation - effectiveness of potential seabird bycatch mitigation. |
| | Automatic branch line attacher | Existence of an automatic branchline attacher (Y/N) | Yes | 82% | 73% | EM-R3 | No | No | CPUE standardisation - effort creep/efficiency. |
| | Hook type | Recorded at set level what type of hook is used | Yes | 88% | 73% | EM-NP | No | No | **Catch reconstruction and/or CPUE standardisation (catchability).** |
| | Hook size | Recorded at set level the size of the hook used | Yes | 88% | 73% | EM-NP | No | No | **Catch reconstruction and/or CPUE standardisation (catchability).** |
| | Tori line | Recorded at the set level whether the vessel uses a single or double tori lines when setting (Y/N) | Yes | 41% | 20% | EM-R3 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| | Side setting with bird curtain | Recorded at the set level whether the vessels used side-setting with bird curtain (Y/N) | Yes | 29% | 18% | EM-R3 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |

**Table 1** continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Weighted branch lines | At the trip level record whether or not the vessel uses weighted branch lines (Y/N) | Yes | 65% | 22% | EM-R3 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| | Shark lines | The total number of hooks that have been hung directly from the floatline for this set - assume this is "shark lines" | Yes | 82%[§] | 37%[§] | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardisation of shark species; Shark bycatch mitigation; and Inferring target species complex.** |
| | Blue dyed bait | Recorded at the set level, whether the vessel used bait that has been dyed especially to look blue (Y/N) | Yes | 82% | 51% | EM-R1 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| | Distance between weight and hook (in metres) | Measure the distance in metres from where the bottom of the weight is attached on the branch line to the eye of the hook | Yes | 29% | 5% | EM-NP | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| | Deep setting line shooter | Recorded at the set level whether the vessel used a deep setting line shooter (Y/N) | Yes | 94% | 86% | EM-R3 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| | Management of offal discharge | Recorded at the set level whether the vessel used the management of offal discharge (Y/N) | Yes | 65% | 25% | EM-R3 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| | Strategic offal disposal | Recorded at the trip level whether the vessel used strategic offal disposal (Y/N) | Yes | 59% | 23% | EM-R3 | No | No | **CPUE standardisation - effectiveness seabird bycatch mitigation.** |
| **Setting and Hauling information** | Date & time start of set | Date and time the first buoy enters the water to start the setting of line | Yes | 100% | 100% | EM-R1 | No | Yes | **Catch reconstruction and/or CPUE standardization (local abundance); and Mortality rates of bycatch and SSIs.** |
| | Latitude and longitude of start of set | GPS reading at time first buoy enters water | Yes | 100% | 100% | EM-R1 | No | Yes | **Catch reconstruction and/or CPUE standardization (habitat); and Mortality rates of bycatch and SSIs.** |
| | Date and time of end of set | Date and time the last buoy enters the water | Yes | 100% | 100% | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardization (local abundance); and Mortality rates of bycatch and SSIs.** |
| | Latitude and longitude of end of set | GPS reading at time last buoy enters water | Yes | 100% | 100% | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardization (habitat); and Mortality rates of bycatch and SSIs.** |
| | Total number of baskets or floats | Number of baskets set; usually it is the same as the number of floats set minus one | Yes | 100% | 100% | EM-R1 | No | No | **Quality assurance (total effort and hooks between floats).** |
| | Number of hooks per basket, or number of hooks between floats | Number of hooks between floats | Yes | 100% | 100% | EM-R4 | No | Yes | **Catch reconstruction and/or CPUE standardization (depth of gear) and/or models of gear configuration.** |
| | Total number of hooks used in a set | Total number of hooks set, usually calculated by multiplying the number of baskets by number of hooks between floats | Yes | 100% | 100% | EM-R1 | No | Yes | **Catch reconstruction and/or CPUE standardization and/or models of gear configuration.** |
| | Line shooter speed | if vessel has a line shooter it will normally have an indicator to show its line setting speed | Yes | 88% | 76% | EM-R3 | No | No | CPUE standardisation - effectiveness of potential seabird bycatch mitigation. |

**Table 1** continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Length of float line | Length of the line that is attached to the floats, usually remains same throughout trip | Yes | 100% | 100% | EM-P2 | No | No | **Catch reconstruction and/or CPUE standardization (depth of gear) and/or models of gear configuration.** |
| | Distance between branch lines | Mainline distance between branchlines | Yes | 88% | 81% | EM-R3 | No | No | Analyses of targeting. |
| | Length of branch lines | Length of branchline, measure the length of a sample of the majority of branch line used | Yes | 100% | 99% | EM-NP | No | No | CPUE standardisation - effectiveness of potential seabird bycatch mitigation; and Analyses of targeting. |
| | Time-depth recorders (TDRs) | Does the vessel use TDRs on its line | Yes | 88% | 81% | NULL | No | No | Rarely used by vessels, so ignored in analyses; and In theory could influence depth of gear. |
| | Number of light sticks | Recorded at the set level indicate whether the vessel uses light sticks on its line, record the number it used and where possible information on location | Yes | 82% | 39% | EM-R4 | No | No | **Catch reconstruction and/or CPUE standardization (catchability; target spp)** |
| | Target species | What species does the vessel target | Yes | 82% | 39% | EM-R1 | No | Yes | **Catch reconstruction and/or CPUE standardization (catchability; target spp).** |
| | Bait species | At the set level record the bait species used | Yes | 94% | 89% | EM-R3 | No | No | **Catch reconstruction and/or CPUE standardization (catchability; target spp).** |
| | Date and time of start of haul | Date and time the first buoy of the mainline is hauled from the water to start the haul | Yes | 100% | 100% | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardization (local abundance); and Mortality rates of bycatch and SSIs (e.g. turtles).** |
| | Date and time of end of haul | Date and time the last buoy of the mainline is hauled from the water to end the haul | Yes | 100% | 100% | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardization (local abundance); and Mortality rates of bycatch and SSIs (e.g. turtles).** |
| | Total amount of baskets, floats monitored by observer in a single set | How many floats or baskets monitored by the observer | Yes | 100% | 100% | EM-R1 | No | No | **Catch reconstruction and/or CPUE standardization (observed effort).** |
| **Information on catch for each set** | Hook number, between floats | Hook number that the fish is caught on | Yes | 94% | 85% | EM-R4 | No | No | **CPUE standardisation - effectiveness of potential bycatch mitigation.** |
| | Species code | FAO code of species caught | Yes | 100% | 99% | EM-R1 | Yes | Yes | **All scientific analyses.** |
| | Length of fish | Measure length of species using the recommended measurement | Yes | 100% | 99% | EM-R1 | Yes | No | **Stock assessment or indicator assessments; and Analyses of targeting.** |
| | Length measurement code | Code the type of measurement used | Yes | 100% | 99% | EM-R1 | Yes | No | **Required to interpret length records.** |
| | Gender | Sex the species if possible | Yes | 100% | 99% | EM-R2 | No | No | **Stock assessment or indicator assessments.** |
| | Condition when caught | Use condition codes to indicate status when caught. | Yes | 100% | 99% | EM-R1 (*if landed*) EM-R3 (*if not landed*) | No | No | **Indicator assessments, at-vessel mortality rates of bycatch and SSIs; and** Evaluation of handling practises. |
| | Fate | What happens to the fish after its caught use codes | Yes | 100% | 99% | EM-R1 (*if landed*) EM-R3 (*if not landed*) | No | Yes (recorded *retained* or *discarded* only) | **Indicator assessments; Catch reconstructions; and Catch utilisation** |
| | Condition when released | Use condition codes to indicates status when released to the sea | Yes | 88% | 80% | EM-R1 (*if landed*) EM-R3 (*if not landed*) | No | No | **Indicator assessments, at-release mortality rates of bycatch and SSIs; and** Evaluation of handling practises. |
| | Tag recovery information | Record as much information as possible on any tags recovered | Yes | 82% | 82% ‡ | EM-R1 | No | No | **Stock assessments; Habitat and movement mapping; and Mortality rates.** |

† The following fields were added to the WCPFC ROP Minimum Standard Data Fields during the time period assessed (2012–2016): *weighted branchlines, distance between weight and hook (in metres)* and *side setting with bird curtain.* These fields therefore may have lower levels of data provision relative to others

§ Shark lines is generally considered a "null" field as targeting of sharks has been banned in all member countries

‡ As the field *tag recovery information* is usually collected in the comments field and then stored in a separate tag recovery database by SPC, it is assumed for the purposes of this analysis that if this field is provided in the trip data of a member country, then it was collected on all (i.e. 100%) of trip

among member countries for each of the 49 fields between 2012 and 2016 allowed us to determine if the collection of some data fields by an integrated EM system was likely to have significant scientific implications. For example, if an at-sea observer data field was not reported often by member countries, but was used in scientific analysis and could be readily collected through an integrated EM system, then it would be of greater significance relative to a field that was reported often by member countries (not accounting for coverage).

## Results

Table 1 lists the 49 WCPFC ROP minimum standard longline data fields, along with a description and expert judgement from the 2017 technical workshop (SPC 2017) on the capability of current versions of integrated EM systems to collect those data fields. Table 1 also identifies the proportion of WCPFC member countries who provided some quantity of at-sea observer data to the WCPFC Secretariat for each data field between 2012 and 2016. It also outlines the average proportion of trips from all WCPFC member countries where the respective data field was recorded by at-sea observers between 2012 and 2016. An indication of the current (and potential future) scientific use of each data field by SPC is also provided in Table 1. In examining the results, it should be noted that while SPC is the scientific services provider for the WCPFC, there are many other potential users of the data, including scientists from universities, government agencies, non-governmental organisations and other RFMOs. Consequently, the main scientific use of the data fields captured in Table 1 does not represent an exhaustive list of all potential scientific uses.

### Capability of EM to collect the WCPFC ROP minimum standard data fields

In total, of the 49 WCPFC ROP minimum standard longline data fields (Table 1), 20 were classified by the SPC technical workshop experts as ready to collect now with integrated EM systems (EM-R1), one ready with crew assistance (EM-R2), 14 ready with additional dedicated camera and/or sensors (EM-R3) and three ready but costly for the EM analyst to interpret (EM-R4) (Fig. 1). This means that integrated EM systems can potentially collect 78% of the longline specific fields at present (not accounting for costs). Only eight fields (16%) were classified as not possible to be collected using integrated EM systems (EM-NP), with two additional fields (4%) possible to be collected in the future following technological advancement (EM-P2), and one (2%) classified as not applicable (Null) (Fig. 1).

### *Retained catch*

Various trials have indicated that the catch composition in terms of number of both target and non-target species can be accurately recorded by integrated EM systems and is often consistent with at-sea observer data due to the serial nature of catch retrieval in longline fisheries (McElderry 2008). For example, in the Alaskan longline fishery for Pacific halibut, catch composition data from integrated EM systems was not statistically different from at-sea observer data on the same trips for most species (Ames et al. 2007). Similarly, in the Solomon Islands trial in the WCPO, there was high correlation between at-sea observer and EM analyst data on the same trips in relation to the number and identification of common species (both target and non-target) caught during pelagic longline fishing operations (Hosken et al. 2016a). Other pilot studies in the Australian and Hawaiian pelagic longline fisheries highlighted that the total species piece counts between at-sea observers and the EM analyst for retained catch only differed by 0.4–1.6% when analysing the same hauls (McElderry et al. 2010; Piasente et al. 2012). While integrated EM systems (and frequently at-sea observers) cannot accurately record the weight of catch (Ames et al. 2007) this is often verified through processors or port sampling upon landing. Finally, expert opinion from the SPC technical workshop indicated that integrated EM systems have the capability to currently collect accurate data on catch composition data fields from the ROP minimum standard (SPC 2017). For example, it can accurately record the *species code* and allow an assessment of *fate* to be made by an EM analyst (Table 1).

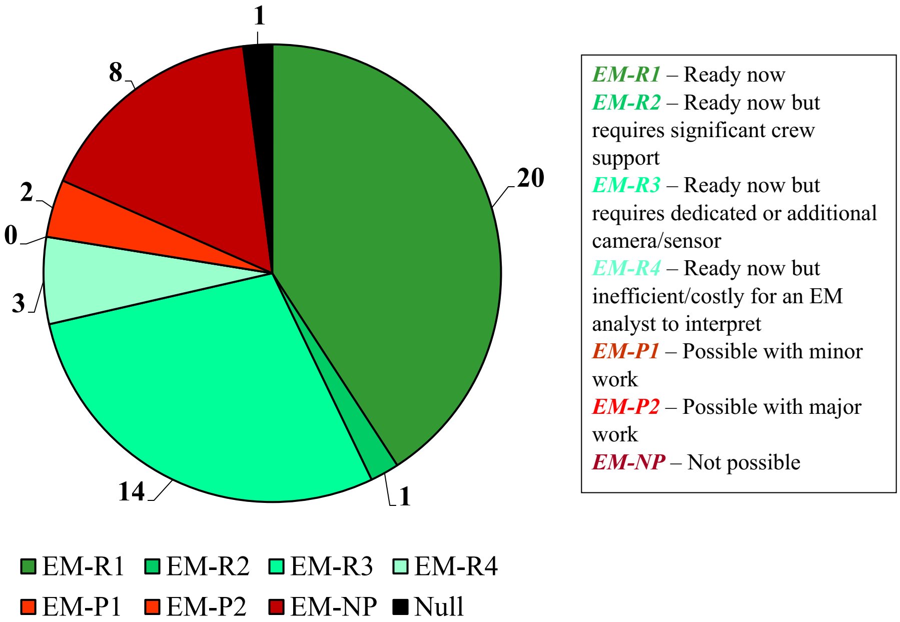


**Fig. 1** Assessment of EM capability to collect WCPFC ROP longline data fields. After SPC (2017)

*Discarded catch*

Trials of integrated EM systems in longline fisheries have had mixed results for recording discards. Accurate reporting appears to be dependent on suitable camera placement in the area of the hauling station to view the retracting line where it meets the water surface (Ames et al. 2007; Piasente et al. 2012). This is because most catch handling occurs in the area adjacent to the vessel and discarded species will not necessarily be brought on-board (McElderry 2008). For example, EM analysts in Hawaiian and Australian tuna longline trials reported only 60% and 35% respectively of the total discarded species reported by at-sea observers, due to species being cut off or jerked free outside the view of the camera (McElderry et al. 2010; Piasente et al. 2012). Conversely, in the Solomon Islands trial, there was less discrepancy in the piece counts of major discarded species between at-sea observers and EM analysts, but EM analysts encountered some difficulties in identifying rare species (Hosken et al. 2016a). In the absence of appropriate camera placement, at-sea observers (if they are directly viewing the hauling area) may be more capable than EM analysts in identifying discarded species that are rare or difficult to distinguish from other species (McElderry 2008). Revised handling protocols for discarded species may facilitate improved species identification for EM analysts, but this may have implications for their fate and/or condition on release, and may hinder fishing operations (van Helmond et al. 2015). However, the permanency of EM records, which allows the footage to be viewed multiple times (including using slow motion and stills), does allow other experts to assist EM analysts with species identification issues. While noting that accurate EM analyst reporting of discards may be fishery or even vessel-specific, if an integrated EM system is used as a compliance or audit tool and appropriately enforced, the presence of video cameras may have a concomitant impact on improving the logbook reporting of discards, as was evident in the Australian longline tuna fisheries (Larcombe et al. 2016; Emery et al. 2018b). Notwithstanding these potential issues, expert opinion from the SPC technical workshop (SPC 2017) (Table 1) indicated that integrated EM systems currently have the capability to record species caught, allowing an assessment of their *fate* if landed (and later discarded) to be made. However, additional dedicated cameras and/or sensors may be required for integrated EM systems to accurately record the *fate* of species when they are discarded away from the hauling station. This issue was evident in an analysis of data from Australian tuna longline fisheries, where shark and marlin species were cut off the line prior to landing and either not recorded by the EM analyst or not identified to a species level and instead grouped into mixed categories (Emery et al. 2018a).

*Vessel characteristics and fishing effort*

Integrated EM systems can accurately record the temporal and spatial elements of longline fishing effort in terms of time of set/haul and latitude/longitude, for example, when the cameras start and end their recording in response to drum rotation, and/or the integration of date/time and global positioning system (GPS) data (recorded at regular, high frequency rate) into the system. In terms of the capability of integrated EM systems to record certain gear attributes and effort statistics, it may rely on suitable space to effectively position cameras in the areas of the set and haul, along with assistance from the crew. In the trial in Australian tuna longline fisheries for instance, it was noted that accurate recording of the number of hooks deployed, use of wire trace and type of bait used was reliant on effective camera placement, particularly during hauling (Piasente et al. 2012). Furthermore, in the Solomon Islands trial, there were discrepancies identified between the hook number for individual catch recorded by at-sea observers and the EM analysts, with a tendency for the EM analyst to record a slightly higher hook number than the at-sea observer and default to a hook number equal to one when they lost count (Hosken et al. 2016a). It was for these reasons that the capability of integrated EM systems to collect specific longline gear data was perceived by experts at the SPC technical workshop to require further consideration (SPC 2017) (Table 1). For example, experts determined that it was not possible for integrated EM systems to accurately collect data on the *hook type* and *size* at an individual set level. Similarly, the *distance between weight and hook (in metres)*, *branch line material(s)*, *length of branch lines, refrigeration method, mainline material* and *mainline diameter* cannot be determined easily from EM images due to a lack of visibility (e.g. *refrigeration method*) or inability to easily calculate (e.g. *length of branch lines*). While it was agreed that *hook number and hooks between floats* could be determined using EM technology, it was noted that this would be time-consuming and thus costly for the EM analyst to calculate. All these fields, however, could be recorded through a pre-or-post trip in-port inspection to provide trip-level data or through reporting in the logbook or the use of at-sea observers to provide set-level data.

*SSI interactions and mitigation devices*

Integrated EM systems can accurately record interactions with SSI, such as seabirds and sea turtles if the interactions and subsequent remedial action occurs in clear view of the hauling station camera (McElderry 2008). For example, in the Australian tuna longline fisheries pilot study, most of the interactions recorded by at-sea observers were also seen by the EM analysts, as hook removal and disentangling from lines occurred in view of the camera near the hauling station. This allowed the EM analyst to not only accurately identify the SSI but also assess their condition (Piasente et al. 2012). Nevertheless, there is still the possibility that some interactions and consequent remedial action may occur outside the view of the camera and thus only be observable by at-sea observers or fishers, which was the case in the Hawaiian longline pilot study (McElderry et al. 2010) and in an analysis of the first 2 years of integrated EM system operation in Australian longline tuna fisheries (Emery et al. 2018a). Furthermore, if SSI are not brought on board, it may be more difficult for the EM analyst to assess condition relative to an at-sea observer who is close to the area and may view the release directly. In terms of integrated EM systems providing data on the use of SSI mitigation devices and/or measures, the Australian longline EM pilot trial indicated that tori line compliance could be ascertained, but poor lighting and night setting prevented this in some instances (Piasente et al. 2012). It was not possible, however, to determine whether tori lines and branch lines had been correctly deployed in accordance with the management authority's regulations and requirements in terms of length and weighting respectively (Larcombe et al. 2016). Consequently, the capability of integrated EM systems to collect data on mitigation devices and/or measures was noted by experts at the SPC technical workshop to be currently ready but, with the exception of *shark lines and blue-dyed bait*, required dedicated cameras and/or sensors, which will increase overall costs (SPC 2017) (Table 1). In terms of SSI interactions, expert opinion identified that integrated EM systems can collect data on *species code*, along with the *condition* (of the animal) *when caught* and whether it was *released* if landed. However, similar to discarded species, if SSI are not landed, these data fields would require dedicated cameras and/or sensors on board, which will increase overall costs (Table 1).

### *Biological data*

Integrated EM systems cannot collect biological samples (e.g. fish otoliths), which requires at-sea observer programs, or crew cooperation (McElderry 2008). In-port sampling programs may be used, however for extended, wide-ranging trips it can be difficult to determine the specific geographical location of the catch required for assessment purposes. The capability of integrated EM systems to collect biological data on length, fate, condition and sex of target and non-target species is heavily dependent on appropriate crew handling procedures and dedicated camera placement, which will vary based on the species landed. For example, EM technology has the capability with specialised software to measure the length of species. This can either be achieved through a grid set up at the hauling station and fishers adhering to specific catch handling procedures, as currently required in the British Columbia groundfish hook-and-line fishery (McElderry 2008) or through a dedicated camera that is systematically calibrated for each trip (Hosken et al. 2017). In the Solomon Islands trial, while there was consistency in the fate code used for target tuna species, there were discrepancies between at-sea observers and the EM analysts in the condition codes assigned. In particular the three "alive" categories (i.e. alive and healthy; alive injured or distressed, probably will survive; and alive, unlikely to live), where there was only 54%, 45% and 7% agreement respectively (Hosken et al. 2016a). Furthermore, while there was no attempt to determine the sex of teleost species in the trial, there were some discrepancies in the recording of the sex for sharks between at-sea observers and EM analysts with only 53% of females and 76% of males in agreement (Hosken et al. 2016a). Both SPC technical workshops noted these difficulties (SPC 2016a, 2017) and while they agreed that *condition at capture* and *release*, as well as *fate* could be accurately recorded if the species was landed, it was noted it would be more difficult to record when the species was discarded, in the absence of a dedicated camera/sensor. It was also noted that *gender* would be difficult to determine for all species in the absence of assistance from the crew and while *length* was agreed as *EM-R1*, it was noted that this would require dedicated software and appropriate camera placement and calibration (SPC 2017).

### Scientific use and exchange by member countries of the WCPFC ROP minimum standard data fields

Relevant ROP minimum standard data fields for catch, including *species code*, *condition when caught, fate*, *target species* and overall piece counts may be used by scientists to measure fishing mortality rates for target species, SSIs as well as examine targeting practices through time and the effectiveness of mitigation devices and/or measures. For example, ROP minimum standard data fields such as *condition when caught* have been used to evaluate the effectiveness of potential measures for reducing shark mortality in WCPO longline fisheries (Bromhead et al. 2012; Clarke et al. 2013; Lawson 2011). They may also be used in combination with fishing effort data to standardise catch per unit effort (CPUE) data, which provides an index of abundance for stock assessments to model biomass changes (Harley et al. 2001; Maunder and Punt 2004). For example, *bait species* and *target species* have also been used as an indicator of targeting, which have been integrated into catch standardisations for sharks (Bromhead et al. 2012). In turn, many of these fields are routinely used to examine indicators of WCPO shark stock condition (e.g. Rice et al. 2015). Equally important to the scientific use is the comprehensiveness of data collected across at-sea observer trips that is then provided by member countries. Of the nine data fields classified as "information on catch for each set" in the ROP minimum data standard, all were recorded greater than 75% of the time between 2012 and 2016 by the at-sea observer on individual trips when averaging across all member states. Fields such as *condition when caught, fate, species code* were recorded ~ 99% of the time by the at-sea observer on individual trips between 2012 and 2016.

The ROP minimum standard data fields for discards, including *species code*, *fate*, *target species* and overall piece counts have been used by scientists to measure fishing mortality rates for target and SSIs as well as model CPUE through fleet-wide extrapolations

(OFP 2010; Watson and Bigelow 2014). For example, the equivalent data fields for purse seine fisheries have been used to examine the incidence of non-target species catch and CPUE on associated (with fish aggregation devices (FAD)) and un-associated sets in the WCPO (Hare et al. 2015; Leroy et al. 2013; Nicol et al. 2009).

The ROP minimum standard data fields for longline gear have been used in CPUE standardisation and core stock assessment work. For example, the *hooks between floats* and *hooks per set* have been used to estimate catches and standardised catch rates for sharks in WCPO longline and purse seine fisheries (Bromhead et al. 2012; Lawson 2011). Similarly, *hook number between floats* and *length of branch lines* have been used to characterise the distribution in catch rates of albacore and non-target species in the American Samoa albacore fishery (Watson and Bigelow 2014). Specific gear attributes such as *wire trace* and *shark lines* have also been used as an indicator of targeting in assessments (Bromhead et al. 2012). The *date and time start of set* and *date and time start of haul*, coupled with soak time (time between the start of set and end of haul), has also been used in analyses to estimate longline catch and survival rates of species (Bromhead et al. 2012) and is an important factor in catch standardisation (Lawson 2011). Of the 18 data fields classified as "setting and hauling information" in the ROP minimum data standard, only two (*number of lightsticks* and *target species*) were recorded less than 75% of the time between 2012 and 2016 by the at-sea observer on individual trips when averaging across all member states. As both these fields were classified as EM Ready (*EM-R4* and *EM-R1* respectively), the implementation of an integrated EM system has the capacity to significantly improve their collection and provision for use in scientific analyses. Many of the gear attributes such as *hooks between floats, hooks per set*, *total number of baskets* which are used in CPUE standardisation and core stock assessment work were recorded ~ 99% of the time on individual trips between 2012 and 2016.

The ROP minimum standard data fields relating to longline mitigation devices and/or measures including *side setting with bird curtain, blue dyed bait and weighted branch lines* have been used to assess the effectiveness of different seabird mitigation measures by area, pre- and post-regulation in the Hawaiian longline fishery (Gilman et al. 2008). Equally, fields such as *hook type* and *bait used* have been used to assess sea turtle capture rates by area, pre- and post-regulations in the Hawaiian longline swordfish-targeting fishery (Gilman et al. 2006). Furthermore, the fields *wire trace* and *shark lines* have also been used in analyses measuring their relative effect, along with other environmental and fishing method factors, on catch of oceanic whitetip and silky shark in the WCPO (Bromhead et al. 2013). Similarly, *shark lines, wire trace* and *hook type* were used to characterise different fleet's gear configurations for an analysis examining how oceanic whitetip and silky sharks interact with longline gear and the effectiveness of various mitigation measures (e.g. circle hooks) (Harley et al. 2015). These data fields have also been used in risk assessments/analyses along with known biological information to provide information on the threat to species from fishing activities in the WCPO and whether interactions are within sustainable limits (Kirby 2006; OFP 2010; Watson and Bigelow 2014). ROP minimum standard data fields for SSI interactions including *species code*, *condition*, *fate* and *type of interaction* have often been used to estimate interaction rates and annual mortalities by area, for species such as sharks, marine mammals, sea turtles and seabirds in the WCPO (Molony 2005; OFP 2010; Waugh et al. 2012; Williams et al. 2009), as well as examine the effectiveness of mitigation measures (Clarke and Common Oceans (ABNJ) Tuna Project 2017) and the potential effectiveness of WCPFC CMMs (e.g. Harley and Pilling 2016). Of the 17 data fields classified as "special gear attributes" in the ROP minimum data standard, only three (*line shooter*, *mainline hauler* and *deep setting line shooter*) were recorded greater than 75% of the time between 2012 and 2016 by the at-sea observer on individual trips when averaging across all member states. Many of the SSI mitigation devices such as *tori line*, *side setting with bird curtain*, *shark lines*, *blue dyed bait*, *weighted branch lines* and *distance between weight and hook (in metres)* were not as well recorded on individual trips by at-sea observers when averaging across all member states. However, this could be due to the mitigation devices and/or measure simply not being used on the trip (i.e. null) and left blank instead of recorded as "no" by the at-sea observer, which would result in them being marked as zero and resulting in a lower than expected average. Furthermore, it is important to note that some of the fields such as *weighted branch* *lines*, *distance between weight and hook (in metres)* and *side setting with bird curtain* were newly added fields during the time period of analysis (2012–2016), which would explain their lower than expected result. Nevertheless, with the exception of *distance between weight and hook (in metres)* all these fields were classified as *EM Ready* in various forms, meaning that the implementation of an integrated EM system has the capacity to significantly improve their collection and provision for use in scientific analyses.

*Length of fish, gender, condition when caught and released* as well as *fate* are required ROP minimum standard data fields for longline biological information. Some of these data may be used by scientists in length-based, age structured models for both target and non-target species (Rice and Harley 2014). For example, *length* and *gender* were used to determine whether shark species in the WCPO were being caught at sizes below maturity and in the same study *fate* was used to determine whether regional regulations prohibiting shark finning were reducing the practice (Clarke et al. 2013). *Length* from regional at-sea observer programs have also been used in swordfish stock assessments (Davies et al. 2013; Takeuchi et al. 2017). Furthermore, *condition when caught, length* and *fate* have been used within ecological risk assessments to determine the susceptibility of 236 target and bycatch species to the effects of fishing (Kirby 2006). Weights of processed and unprocessed species recorded by Australian at-sea observers on board distant-water Japanese longline vessels have also been used to determine conversion factors for bigeye and yellowfin tuna, which are used in associated stock assessments for these species in the WCPO (Langley et al. 2006). Finally, these fields have been used to examine the potential implications of size-based catch limits and catch retention policies (Brouwer 2017).

## Discussion

The data requirements for fisheries targeting highly migratory or straddling fish stocks are not solely determined by national legislative and management objectives, but are also subject to international obligations for those states that are signatories to UNCLOS, the UNFSA, or who are members of relevant RFMOs. Some RFMOs, such as the WCPFC have instituted regional observer programs (e.g. WCPFC CMM 2007-01) and accompanying standards as a way of ensuring member states collect and provide verified catch and other data to inform their scientific research priorities and to monitor the implementation of CMMs. The premise is that at-sea observers can undertake a range of data collection and biological sampling tasks. However, logistical challenges, financial costs along with health and safety risks associated with placing at-sea observers on vessels have been inferred as reasons why longline observer coverage for some member states in the WCPO has remained low (less than the 5% minimum requirement) (Clarke et al. 2013; Molony 2005; WCPFC 2015a, 2016a). The advent of integrated EM systems has therefore been perceived as a way that member states can increase their monitoring of longline vessels and transhipment activities and thus meet their international data collection and exchange obligations.

The results from various pilot studies and trials have shown integrated EM systems to be capable of collecting accurate records of catch composition, particularly in longline fisheries, where the catch is brought on board serially (Ames et al. 2005; McElderry 2008; McElderry et al. 2010). It has also been shown to be effective in recording spatial and temporal data on setting and hauling operations (Piasente et al. 2012). Although the capacity of integrated EM systems to collect data on discards, biological information (e.g. gender) and explicit gear attributes (e.g. hook type and size) requires further development, it has been acknowledged that current issues may be resolved with technological improvements over time or in the interim through the use of supplementary data programs (e.g. vessel inspections) (SPC 2016a, 2017). Currently, the processing time for EM analysts to transfer records into data for certain gear attributes is a significant challenge and the costs may outweigh the benefits relative to the use of other data collection tools. In the meantime, the effectiveness of integrated EM systems is highly reliant on appropriate camera placement and the ability and cooperation of the crew to adopt changes to operational procedures, which will vary at an individual vessel and fishery level. The need for changes to crew operational procedures and catch handling methods is one of the major limitations of integrated EM systems (McElderry 2008; Ruiz et al. 2015), particularly if it requires specialist or additional training of crew (at an additional cost) in order to collect and exchange the required data. At-sea observers may still be required to collect data on the deployment and performance of mitigation devices and/or measures, in the absence of appropriate camera placement and/or vessel lighting. Similarly, the collection of biological samples (e.g. otoliths) or data on the sex of most teleost species would have to be collected through at-sea observers or in-port sampling programs. However, in-port sampling programs would be unable to record the lengths of fish discarded or processed (e.g. when the head/tail are removed) at-sea (Lawson 2008), nor collect set-level sampling information from those vessels embarking on extended, wide-ranging trips in the WCPO. In Australia, this led to the re-introduction of at-sea observers in the Commonwealth shark gillnet fishery following the implementation of an integrated EM system more than 2 years previous, primarily to collect biological data for ageing purposes (AFMA 2017).

Integrated EM systems have the potential to record additional gear attributes and other biological data, such as length, through managing industry incentives. This can take the form of compliance incentives (i.e. a legal requirement) or financial incentives (i.e. individual reductions in system costs). For example, lengths of fish could be accurately recorded more cost-effectively by the EM analyst if crew members were to place each fish on a measurement grid in the hauling area in view of the camera, as currently employed in the British Columbia groundfish hook-and-line fishery (McElderry 2008). This could be made a legal requirement, which would create an incentive to comply or face penalties. Similarly, hook type and other gear attributes could be accurately recorded by the EM analyst if the crew adopted practices that increased their visibility to the camera(s) (e.g. placing a hook in close view of the camera). Vessels with improved camera visibility and consequently expedited EM analyst review times could then receive a discount on their individual expenses, which would create a financial incentive to comply.

Currently 38 of the 49 WCPFC longline minimum standard data fields have been classified as *EM-R1-4*, which means 78% can be captured by integrated EM systems (Fig. 1). Notwithstanding that some may require managing fisher incentives and the use of dedicated cameras and sensors on board, which will increase the overall costs of any program, this represents 84% of the *EM-R1-4* fields that have been used in scientific analyses for WCPFC to date. Many of these analyses have included evaluating the effectiveness of seabird bycatch mitigation, analyses of targeting and catch reconstructions and/or catch rate standardisations (Table 1). For the remaining 16% of fields that are *EM Ready* in various forms, but not used in scientific analyses, the introduction of integrated EM systems may facilitate a sufficient increase in the quantity of data available for these fields to support their use in analyses undertaken by scientists for the WCPFC. These include analyses on catch rate standardisation for effort creep/efficiency change and evaluating the effectiveness of seabird bycatch mitigation (Table 1). Of the 20% of fields that either cannot be collected by integrated EM systems (*EM-NP*) or could possibly be collected in the future with major work (*EM-P2)*, 40% of these have been used in various scientific analyses for WCPFC. For example, two of these fields, *hook type* and *hook size* have been used in catch reconstruction analyses and catch rate standardisations (Table 1). Therefore, these fields would need to be collected using an alternative data collection tool at the set-level, such as at-sea observers, to ensure data continuity and scientific rigour was not compromised. The remaining 60% of fields, most of which could be utilised in analyses that review the evolution of fishing technology and fleet dynamics (Table 1), could be collected at a trip level through port sampling or vessel surveys in the absence of an at-sea observer program.

The importance of longline data fields for various WCPFC scientific analyses necessitates that member states consider issues of data continuity prior to implementing an integrated EM system in their national fisheries. The biases associated with collecting data vary among data collection methods, and knowledge of these biases is required when analysing temporal data sets derived from different data collection methods. For example, in the Australian tuna longline fisheries, the number of discarded target and non-target species reported in logbooks increased following the implementation of EM, as a consequence of improved logbook reporting (Emery et al. 2018b). Analyses of logbook data across this period would need to account for the effects of increased compliance with logbook reporting. To account for such effects, it is recommended that there is sufficient temporal overlap between at-sea observer programs and the implementation of integrated EM systems to allow for adequate data calibration and quality control. Equally, if an integrated EM system is used as a supplement to at-sea observer programs, an assessment of the efficiency of each data collection tool in collecting all ROP minimum standard data fields would be advantageous. This could improve the cost-effectiveness of the fishery's data collection program, while also increasing the total amount of data collected (e.g. through at-sea observers being able to collect more biological samples due to EM technology recording catch composition).

Data continuity assessments should be undertaken as part of a wider review of integrated EM systems and the development of accreditation processes to ensure appropriate systems are in place both nationally and regionally for data coordination, storage and security. It was to this end that the WCPFC formed the EM and ER Working Group in 2014 to develop appropriate technical, logistical, data analysis and program standards for EM. Developing standards for EM is in accordance with RFMO obligations under Article 10(e) of the UNFSA to "*agree on standards for collection…of data on fisheries for the stocks*" and are considered fundamental to the success or failure of any initiative (Stanley et al. 2015; Sylvia et al. 2016). EM data analysis standards for instance may specify mandatory and voluntary data fields, formatting and/or the required level of quality control (Dunn and Knuckey 2013), which will be informed by the information requirements and objectives of the WCPFC, as currently reflected in the ROP minimum standard data fields. They may also assist in improving the quality of data collected as member states will use standardised data fields and database formats, which will ultimately increase the efficiency of those conducting analyses of the data. Furthermore, EM program standards may specify agreed minimum standards that the WCPFC could use to audit national programs, which if found to meet the minimum standard, shall then be accredited by the WCPFC. Any accredited program would then be subject to periodic audits. This is not dissimilar to the agreed minimum standards in place for the ROP that WCPFC uses as part of its accreditation and audit process of national observer programs (WCPFC 2016b).

Once the capability of any integrated EM system has been assessed and standards developed, managers, scientists and industry will be able to more appropriately discuss how it should be integrated within their overall national research and monitoring plan(s). This could be done in a variety of ways. For example, inter alia where (a) all vessels are monitored and all fishing activities reviewed (to estimate the total catch of the fleet for example); or (b) where all vessels are monitored and a random sample of fishing activities reviewed (and extrapolated to estimate the total catch of the fleet); or (c) where all vessels are monitored and a random sample of fishing activities is reviewed to assess the accuracy of vessel logbook reporting (Stanley et al. 2015). The idea of the last approach, currently employed in the Australian Commonwealth tuna longline and shark gillnet fisheries, is that through an audit and feedback process with industry, the precision of logbook data will increase to the point where it can be used to accurately estimate the fishing activities of the fleet. This could have the concurrent effect of reducing future EM analyst review time (or even audit rates) and thus associated costs if the increased risks of misreporting are not deemed significant.

While 100% coverage of all vessels is ideal (even if only a percentage of the records are analysed) under any integrated EM system, in many cases this might not be possible due to associated financial costs, logistical issues with implementation, or a lack of technical capacity in the area. For example, in the Australian shark gillnet fisheries, only vessels that have fished more than 50 days in the previous or current fishing season are required to operate EM technology (AFMA 2015). This cap was implemented to reduce financial costs to operators who did not fish full-time and ensure that a minimum 90% of total fishing effort is covered by the integrated EM system (AFMA 2015). Similarly, in Alaskan groundfish and halibut fisheries (hook-and-line and pot), an integrated EM system has recently been implemented to assess catch composition and compliance with regulations, with priority given initially to small vessels under 60 feet which have difficulties accommodating at-sea observers. Currently vessels can opt-into the program as an alternative to at-sea observers, with an estimated coverage of 30% of all fishing trips expected in 2018 (NPFMC 2016; Viechnicki 2017). Ultimately, when coverage is less than 100%, consideration would need to be given on a fishery-basis as to which vessels should be prioritised for monitoring and whether the coverage is representative of the fleet to ensure scientific accuracy and precision are not compromised. For example, at-sea transhipments to fish carriers are routine for longline vessels fishing on the high seas in the WCPO and the difficulty of placing at-sea observers on these vessels can reduce monitoring of this activity (Hosken et al. 2016b). While WCPFC CMM 2009-06 requires at-sea observers on the carrier vessel (> 33 m) to monitor transhipment activities, without continuous monitoring of the carrier vessel while it is at-sea, there is no way to confirm it hasn't received catch from another longline vessel and failed to report (MRAG 2016). Therefore, initially prioritising those carrier and longline vessels likely to tranship on the high seas may be advantageous to enable monitoring of this activity in the WCPO.

The design of any integrated EM system would also need to consider the ability of the national fisheries authority to enforce compliance of EM legislation and regulations and if used an audit tool the required level of detail (i.e. accuracy) for reporting in the logbook. For example, these were both considered as part of the integrated EM system in the British Columbia hook and line groundfish fishery, where an audit score for the most recent trip and the mean audit score for the same vessel over the preceding 12 months are used to assign the current trip to a particular tier (good, fair and poor) (Stanley et al. 2011). If a trip fails an audit, then additional measures (such as an automatic full review of EM imagery, or carriage of an at-sea observer) may be imposed on the vessel for future trips by a review board (Stanley et al. 2011). Improvements in logbook reporting, as witnessed in the Australian and British Columbian fisheries however, may not manifest in those fisheries where there is an absence of appropriate enforcement of compliance with logbook legislation and regulations.

Determining the national and regional objectives of member state integrated EM systems (i.e. whether used as a replacement or supplement to at-sea observer programs, for either or both scientific and compliance purposes) will assist in shaping overall integrated EM system design and implementation. Ensuring there is capacity to enforce compliance of integrated EM system legislation and regulations, as well as an appropriate incentive structure in place, will assist industry in the transition and reduce overall financial and transaction costs of the integrated EM system in the long-term.

## Conclusion

Given at-sea observer coverage (as a percentage of total fishing effort) in longline fisheries in the WCPO is often below the level considered optimal (Gilman 2011; Molony 2005) alternative data collection tools are being considered by countries to meet their overarching fishery legislative and management requirements. Technological advancement has led to the contemplation of using integrated EM systems as a discrete record collecting tool, but in the WCPO, it is unlikely to be able to collect (with current technology) all of the ROP minimum standard data fields considered necessary by the WCPFC. Consequently, it is more likely that integrated EM systems will become a supplement to, rather than a replacement for, at-sea observer and in-port sampling programs (Banks et al. 2016; Dunn and Knuckey 2013; WCPFC 2015c). This supposition was reflected in the recommendation of the WCPFC Technical Compliance Committee (TCC) in October 2017 that "*observer coverage could be improved under the ROP and that EM can potentially supplement or complement observer monitoring.*" Integrated EM systems and at-sea observers working in parallel, with one supplementing or complementing the other, would allow for example, at-sea observers to focus on specific data collection tasks, such as biological sampling or tagging that would otherwise not be prioritised if the cameras were absent from the vessel (Dunn and Knuckey 2013). Furthermore, integrated EM systems may also be able to collect additional data fields in relation to compliance with bycatch handling or marine pollution regulations for instance, which may not have been routinely collected by at-sea observers prioritising collection of scientific data fields.

The advent of integrated EM systems has the potential to significantly increase the sampling coverage and assist states in the WCPO to meet their data collection and reporting obligations. This would concurrently reduce the amount of uncertainty in scientific analysis, particularly for the 78% of fields classified as *EM Ready* in various forms, of which 84% are routinely used in analyses evaluating the effectiveness of seabird bycatch mitigation, targeting and catch reconstructions and/or catch rate standardisations. For the remaining 16% of fields not currently used in scientific analysis, the increased level of coverage may facilitate a sufficient increase in the quantity of data available to support their future use. Integrated EM systems can also increase data precision through the EM analyst being able to review the footage repeatedly and/or seek expert opinion. EM analyst performance can also be measured through secondary review of the footage by a different EM analyst, as currently instituted in the integrated EM system for Australian Commonwealth fisheries. This can reduce the level of subjectivity in current at-sea observer fields such as *condition when caught* and *condition when released*, which was evident in the results of the Solomon Islands EM trial (Hosken et al. 2016b).

While integrated EM systems have the potential to increase both the coverage level and precision of data collected for longline fisheries in the WCPO, the actual amount of data collected will vary based on the type of data field. It is evident that integrated EM systems can collect records on target species counts; species length; setting and hauling date, time and location; and the number of interactions with SSI species. It may also have the capability to collect records on discards, gear specifications and use of SSI/bycatch mitigation devices and/or measures, dependent on suitable camera placement and crew handling practices. Biological data (e.g. otoliths, sex of target species) and other relevant data (e.g. mitigation devices and/or measures and gear-specifications) that cannot be accurately collected using integrated EM systems, can continue to be collected through either at-sea observer programs (for set level data) and/or in-port sampling programs (for trip level data, where that is considered sufficient). A holistic, integrated approach to satisfying the scientific data requirements is therefore needed. Furthermore, if the integrated EM system is also used for compliance purposes, it has the potential improve the veracity of logbook reporting through independent validation of logbook information and an accompanying feedback cycle to fishers. This may reduce the costs of the integrated EM system in the future, while also improving the precision and timeliness of analyses upon which decisions are based.

Internationally, the availability of low-cost EM technology has the potential to increase the quantity of fishery-dependent data available for many fisheries where monitoring with traditional methods (e.g. at-sea observers and logbooks) is challenging due to the large number of vessels, limited trained personnel and difficult working conditions on many vessels (Bartholomew et al. 2018; Salas et al. 2007). For example, many small-scale industrial, artisanal and subsistence fisheries simply cannot accommodate at-sea observers due to space limitations and operational health and safety concerns caused by the size of the vessel. In these fisheries, integrated EM systems are the only feasible (and safe) monitoring solution that also has the potential to enhance scientific understanding of associated levels of fishing mortality (Bartholomew et al. 2018). This would have a flow on effect of increasing the availability of data for stock assessments, particularly among straddling and highly migratory fish stocks managed by RFMOs, thereby mitigating or reducing the level of uncertainty in management decisions. For example, many RFMOs are required to extrapolate and estimate total catches of their managed stocks due to a lack of logbook data reporting from all member state vessels. In the Indian Ocean Tuna Commission (IOTC) for example, between 41 and 85% of the catches for neritic tuna species were either partially of fully estimated by the Secretariat due a lack of data provision by countries (IOTC. 2017). Similar issues with data quality have also been documented in other tuna RFMOs, where unreported catches from fisheries with limited monitoring have led to the underestimation of historical fishing mortality for some species and increased overall uncertainty (ICCAT. 2017).

The increased recognition of the benefits of EM technology internationally have made it an attractive option for fisheries managers to investigate how it can satisfy both their national and international data requirements, with various trials currently underway in the WCPO (Hosken et al. 2016a) and implementation in Australian Commonwealth longline tuna fisheries (AFMA 2015) with New Zealand and Papua New Guinea to possibly follow (Hosken et al. 2017). Other RFMOs (Convention for the Conservation of Southern Bluefin Tuna, South Pacific Regional Fisheries Management Organisation, and the Southern Indian Ocean Fisheries Agreement) are also commencing the process for considering integrated EM systems within their fisheries (CCSBT 2017; SIOFA 2018; SPRFMO 2016). Given the current state of technology, integrated EM systems are likely to be used as a supplement rather than a replacement at-sea observer programs at the regional level (WCPFC 2017b). Nevertheless, any integrated EM system must be able to meet both national and international requirements to ensure data collection, continuity, veracity and precision are not compromised and scientists have the required data to ensure they can continue to provide accurate advice to managers on the impacts of fishing on living marine resources.

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