Ocean and Coastal Management 168 (2019) 307–321

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Measuring congruence between electronic monitoring and logbook data in Australian Commonwealth longline and gillnet fisheries

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ARTICLE INFO

Keywords:
Fisheries management
Electronic monitoring
Cameras
At-sea observers
Gillnet
Longline
Bycatch
Discards
Protected species

ABSTRACT

Electronic monitoring (EM) has the capacity to collect fisheries-dependent data to support fisheries management decision-making. Following successful pilot studies, EM was introduced into several Australian Commonwealth fisheries in 2015, including the Eastern Tuna and Billfish Fishery (ETBF) and the Gillnet, Hook and Trap (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF). We compared two years of EM analyst and fisher-reported logbook data from the ETBF and GHAT sector to examine the level of congruence in reporting of both retained and discarded catch and protected species interactions. In general, congruence between EM analyst and fisher-reported logbook data in both the ETBF and GHAT sector was higher for retained than for discarded catch, and the ETBF had a higher level of data equivalency than the GHAT sector. Fishery-wide estimates of congruence, however, concealed a large amount of variation among individual and groups of species. EM analyst and fisher-reported logbook data were highly congruent for some species (e.g. tunas, swordfish and gummy shark), but for others there were clear taxonomic (e.g. escolar and rudderfish), identification (e.g. sharks, marlins) and reporting (e.g. draughtboard shark and elephantfish) issues, which reduced overall congruence. There was evidence of increased congruence through time, particularly for discarded bycatch species in the GHAT sector, due presumably to increased manager feedback and communication with fishers on their logbook reporting. While EM analyst and fisher-reported logbook interactions with protected species in the GHAT sector were equivalent, this was not the case for species other than seabirds in the ETBF. In the ETBF, a greater number of interactions were reported by fishers in their logbooks, suggesting a need to modify existing or install additional EM technology to improve on-board vision for the EM analyst. It is important to review the performance of any integrated EM system through time to ensure it is fulfilling the data requirements for the fishery and meeting the overall objectives of the program.

1. Introduction

Fisheries management relies on the collection of fishery-dependent and independent data to obtain estimates of fishing mortality and stock biomass, as well as monitor interactions with protected species and the use of mitigation measures and devices (FAO, 1997). Fishery-independent data is generally collected through research vessels (scientific fishing surveys), while fishery-dependent data is usually collected from commercial vessels, either in the port of landing (port sampling) or at-sea (vessel logbook and at-sea observer programs).

At-sea observers have traditionally been used to independently monitor commercial fisheries and collect data for science, management and compliance purposes (McElderry, 2008). Depending on the objectives of the observer program, this may include data on catch composition, fishing effort, vessel characteristics, protected species interactions, species biology (i.e. length and age frequency) and the use of mitigation measures and devices. Despite their versatility, scheduling and logistical difficulties associated with placing observers on board vessels, as well as financial costs (Ames, 2005; Evans and Molony, 2011; WCPFC, 2016), have often been implied as leading to lower than anticipated coverage levels (Clarke et al., 2013; Williams et al., 2016), coverage that is 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).

Over the last two decades, technological advancements in fisheries monitoring have led to the implementation of electronic monitoring (EM) in a variety of fisheries as both a replacement and supplement to

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https://doi.org/10.1016/j.ocecoaman.2018.11.003
Received 25 July 2018; Received in revised form 23 October 2018; Accepted 9 November 2018

at-sea observers (Larcombe et al., 2016; NMFS, 2017; Ruiz et al., 2015). EM is a combination of hardware and software that collects records in an automated manner, which is closed to external or manual input (Dunn and Knuckey, 2013). 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 later onshore by an EM analyst for both management and compliance purposes. Typically, the footage is either used to census all, or review a proportion (which can then be extrapolated or raised), of fishing effort to estimate catch composition and/or to audit a proportion of fishing effort to verify fishing logbooks (Mangi et al., 2015). To improve readability, we use the term *integrated EM system* in this paper to jointly describe the technological (i.e. onboard camera and sensors) and logistical (i.e. on-shore analysis of records) aspects of EM.

Historical fishery-dependent data collection tools in Australian Commonwealth fisheries have included fishing logbooks, at-sea observers, catch disposal records (landing records) and in-port sampling (Larcombe et al., 2016). More recently, an integrated EM system was introduced in several fisheries by the Australian Fisheries Management Authority (AFMA) as a replacement for at-sea observers from 1 July 2015. Two of these fisheries included the Eastern Tuna and Billfish Fishery (ETBF) and the Gillnet Hook and Trap (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF). While the integrated EM system in the GHAT sector was initially used as a replacement for at-sea observers when fishing within the Australian Exclusive Economic Zone (EEZ), in September 2017, at-sea observers were re-introduced primarily to collect biological data for ageing purposes (AFMA, 2017c). Under the current program, AFMA uses the integrated EM system to validate fisher-reported logbook information with an audit target of 10% of sets (defined here as the haul of catch from a single set) from each vessel. This audit includes an analysis of catch composition, discards and interactions with protected species[1] (AFMA, 2015a). Through the auditing process and accompanying feedback to fishers, AFMA aims to independently validate fisheries logbook information so that it can be trusted (or not) as a source of data for assessing and managing fisheries. This aspiration to validate logbook reporting is due to the acknowledgement by AFMA that fisher-reported logbook data can be inaccurate, particularly for discarded and protected species (Larcombe et al., 2016). For example, Macbeth et al. (2018) identified systemic issues with respect to the accuracy of fisher reporting of sharks when comparing at-sea observer and fisher-reported logbook data in an Australian demersal shark longline fishery, while Hamer et al. (2008) highlighted significant underreporting in fisher-reported logbooks of short-beaked dolphin (*Delphinus delphis*) encirclements and mortalities in an Australian sardine fishery. Inaccuracies in the logbook can be caused by underreporting or non-reporting of catches and/or misrepresentation of the species composition of catches (Macbeth et al., 2018). These inaccuracies can be a result of *inter alia*, variation in species identification competency among skippers, high catch volumes and species richness making it logistically difficult to accurately record all catch, and fears of compliance action and/or increased regulation because of reporting interactions with protected species (Mangi et al., 2016; Sampson, 2011).

Various pilot studies and trials have indicated that integrated EM systems in both longline (e.g. ETBF) and gillnet (e.g. GHAT) fisheries are capable of *inter alia*, independently verifying catch composition and monitoring interactions with protected species (Ames et al., 2007; Lara-Lopez et al., 2012; McElderry, 2008; McElderry et al., 2003; Stanley et al., 2015). Furthermore, there is evidence that integrated EM systems, when used as an audit tool, can improve both the accuracy and timeliness of fisher-reported logbook data (Larcombe et al., 2016; Stanley et al., 2011).

One of the key objectives of the AFMA EM program is "increased confidence in data quality achieved through cross validation with data captured in logbooks and observer records" (AFMA, 2015a). In order for this objective to be achievable, the integrated EM system would need to be able to accurately record all retained and discarded catch and all interactions with protected species. Furthermore, fishers would need to be responsive to the feedback mechanism instituted by AFMA (i.e. audit report sent to fishers) by improving their logbook reporting. In this paper we aim to assess both EM capability and fisher logbook reporting, by comparing two years of EM analyst and fisher-reported logbook data from the ETBF and GHAT sector to examine the level of congruence in reporting of all retained, discarded catch and protected species interactions. Congruence is defined as the level of equivalency between fisher-reported logbook and EM analyst numbers of individuals retained, discarded or interacted with during a set. To our knowledge, this is one of only a few studies to examine congruence between fisher-reported logbook and EM analyst data at a fishery, species group (target, byproduct and bycatch) and individual species level using a multi-year dataset from fisheries where an integrated EM system has been fully implemented (i.e. not a trial or pilot study). The established AFMA EM program provides our analysis with a longer time-series of data, including all full-time vessels in the fleet, compared to similar pilot studies that have been limited to a short time period for a small number of volunteer vessels.

The greatest risk for the AFMA EM Program not meeting its key objectives would be if the EM analyst has difficulty recording all retained and discarded catch and protected species interactions, which would be observed by fishers in their audit report (through reduced numbers of individuals reported by EM relative to logbook) and potentially create a disincentive for fishers to accurately report in the future. Therefore, it is important to identify where discrepancies in data reporting occur, and to determine how the integrated EM system could be modified or fisher-logbook reporting improved to increase congruence in the future and ensure that the data requirements for the fisheries, and overall objectives of the AFMA EM program, are being met.

2. Methods

2.1. Description of fisheries

The ETBF is (for the most part) a pelagic longline fishery that operates within the Australian EEZ and high seas waters targeting yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alulunga*), broadbill swordfish (*Xiphias gladius*) and striped marlin (*Tetrapturus audux*). The ETBF operates from Cape York east and south to the Victorian – South Australian border, including waters around Tasmania and the high seas of the Pacific Ocean (AFMA, 2017a) (Fig. 1). In 2016, there were a total of 37 longline and two minor line vessels active in the ETBF (Patterson et al., 2017). In the ETBF, vessels that have fished more than 30 days in the previous or current fishing season must have operational EM technology installed.

The GHAT sector is a demersal trap, gillnet, demersal longline, dropline and auto-longline fishery that operates in waters south of the New South Wales – Victorian border, around Tasmania and west to the South-Australian-Western Australian border targeting gummy shark (*Mustelus antarcticus*) (AFMA, 2017d) (Figs. 2 and 3). The gillnet and hook sectors of the GHAT had 36 and 26 active vessels, respectively, in the 2015/2016 fishing season (Patterson et al., 2017). In the GHAT sector, gillnet and auto line boats that have fished more than 50 days in the previous or current fishing season must have operational EM

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[1] According to AFMA (2017a), "Interaction" means "any physical contact that you (personally, your boat or your fishing gear) have with a protected species that causes death, injury or stress to an individual member of a protected species. This includes any collisions, catching, hooking, netting, entangling, or trapping of a protected species".

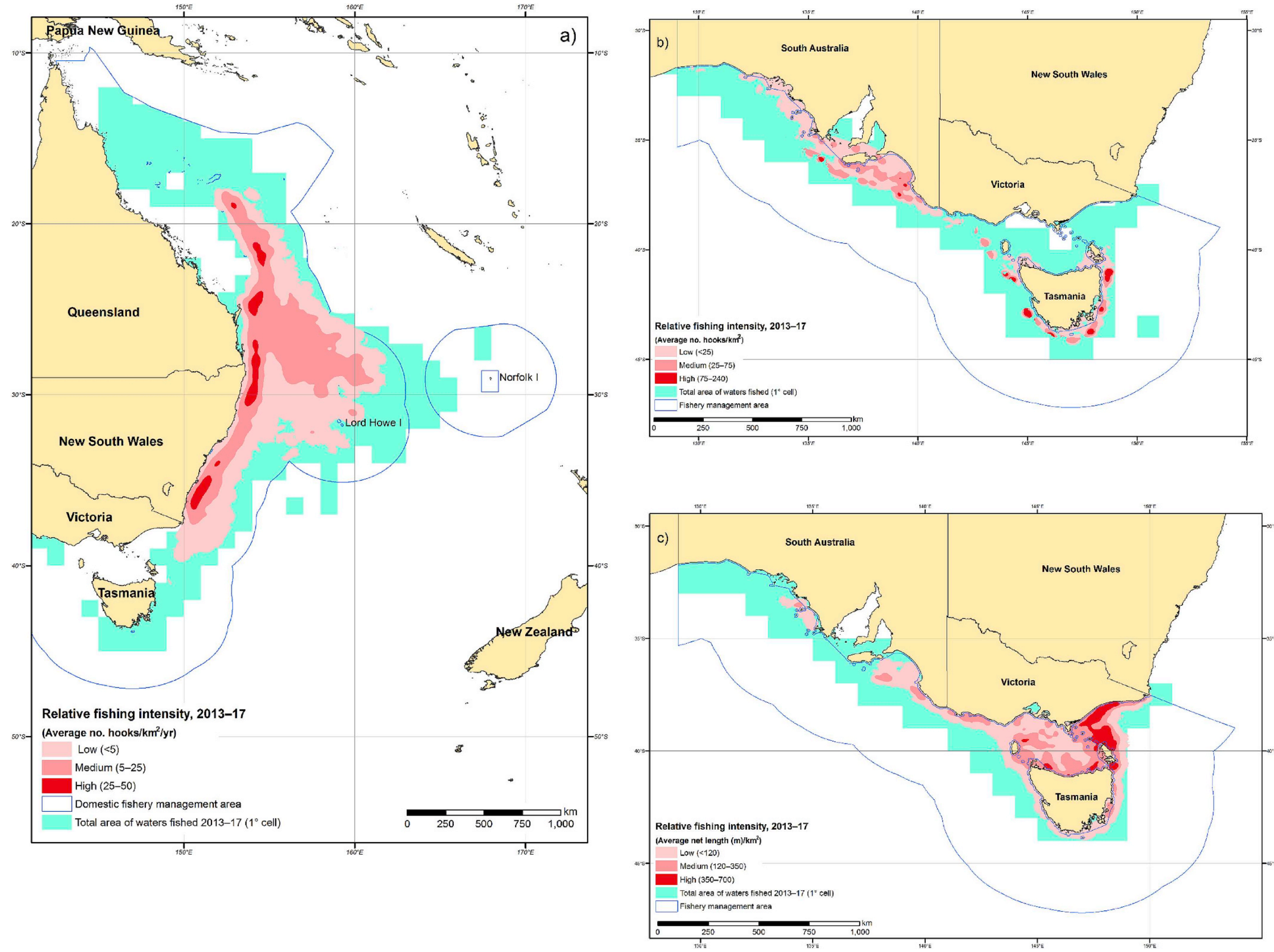

Fig. 1. Area and relative fishing intensity in the: (a) eastern tuna and billfish fishery (b) line sector of the gillnet hook and trap and; (c) gillnet sector of the gillnet hook and trap between 2013 and 2017 calendar years.

technology installed, while manual longline vessels must have fished for more than 100 days.

In both fisheries, AFMA instructed fishers to accurately record all catch composition (retained and discarded) in their daily fishing logbook, along with any interactions with protected species. These requirements have not changed in the years prior to and during the operation of the integrated EM system.

2.2. Electronic monitoring service provider

AFMA uses Archipelago Asia Pacific Ltd (AAP) as their preferred EM service provider. Under instruction from AFMA, AAP aims to review 10% of all sets from each vessel in both the ETBF and GHAT sector. Once an individual set has been reviewed, a series of data quality control checks are undertaken by AAP analysts. For example, specific footage may be re-analysed to check species identification if the piece counts of individual species are underestimated relative to those reported in the logbook (AFMA, 2016). Furthermore, for around 10% of the sets initially reviewed, another AAP EM analyst reviews the same footage, which allows data precision and EM analyst performance to be measured. Analysis of data precision among multiple reviewed sets by AAP suggests a very low level of bias. EM analysts are instructed by AFMA to record all catch composition/piece counts during a review, whether catch items are retained or discarded as well as any interactions with protected species (AFMA, 2015a). All catch items are identified to the lowest taxonomic level possible. If an individual species cannot be identified to species level, they are identified to the next lowest taxonomic level/group (e.g. Houndsharks – Triakidae Family for gummy (*Mustelus antarcticus*) and school shark (*Galeorhinus galeus*)).

2.3. Data collection

EM analyst and fisher-reported logbook data were compared for the first two years of operation (1 July 2015 to 30 June 2017) in both fisheries (ETBF and GHAT sector) to examine the level of congruence in data for retained and discarded catch and interactions with protected species. This was undertaken using two separate methods: (i) generalised linear model analysis and; (ii) percentage difference analysis.

All data were collated and aggregated by set and the total number of species (individual or species group) caught as reported by both the EM analyst and fisher in their logbook. Species were classified based on their role in the fishery – target, byproduct and bycatch (see Table 1). Target species were those species identified by AFMA (AFMA, 2017a), while byproduct species were those that were retained for sale more often than discarded (total numbers) in the 2015/16 fishing season. All other species were classified as bycatch, as they were discarded more often than retained in 2015/16. As fishers in the GHAT sector were only required to record in their logbook the estimated weight (not count) of individual species up until April 2016, there were several records with missing count data. Records that contained both weight and count data

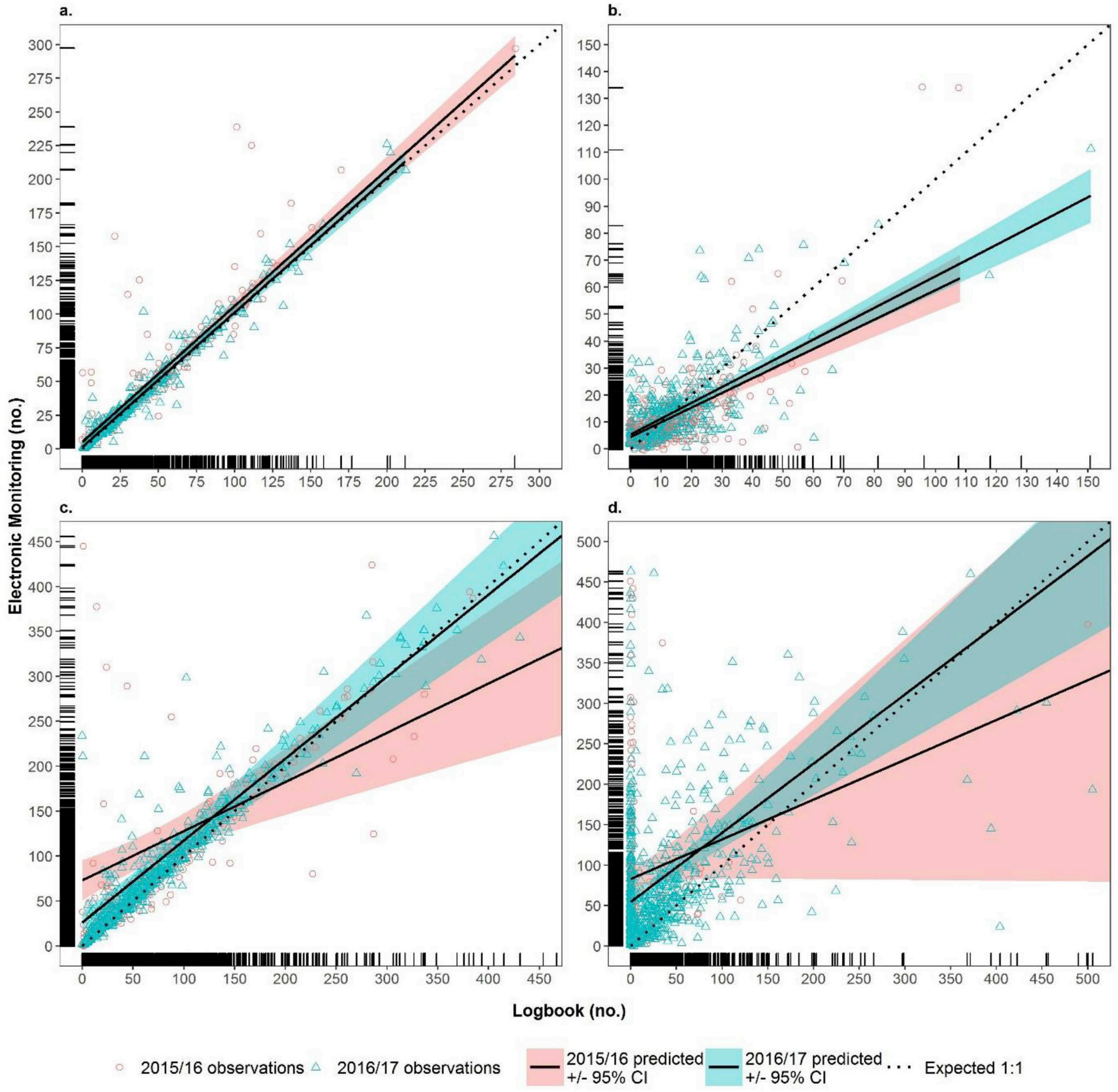

Fig. 2. Estimated regression for 2015/2016 (solid black line with red shading) and 2016/2017 (solid black line with blue shading) and equal 1:1 relationship (dotted black line) between EM analyst and logbook reporting of individuals retained (a) and discarded (b) in the ETBF and retained (c) and discarded (d) in the GHAT (gillnet, auto-longline and set-longline) sector. Note Fig. 2c and d have been truncated to eliminate extreme values and to reveal patterns in the majority of data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

were used to calculate the average weight of an individual species and then used to estimate the number of individual species caught for those records with only estimated weight data. All subsequent data analysis was undertaken using R (version 3.2.0).

2.4. Data analysis

We fitted generalised linear models (GLM) to catch data (counts of individuals) reported for each set in each year to evaluate the variability between EM and logbooks in reporting retained and discarded catch for each fishery, species group (target, byproduct and bycatch) (Table 1) and year. The GLM approach was based on that of Briand et al. (2017) and was used to estimate overall congruence between the two methods rather than as a predictive model. The form of the GLM was as follows:

$$EM \sim L * Y + \varepsilon \tag{1}$$

Where *EM* in [1] is the count of individuals in each set from electronic monitoring, L is the count of individuals in each set from fisher logbooks, Y is the year and ε is the model error assumed to be normally distributed. Only sets where catches were observed (number > 0) from either EM analyst or logbook data were included in the analysis.

Overdispersion was detected in the models because variance among catches tended to be higher than the mean and there were multiple zero-catch records. Therefore, standard errors were corrected using a quasi-GLM where the variance is given by $\varnothing \times \mu$ where μ is the mean and $\varnothing$ is the dispersion parameter (Zuur et al., 2009).

Model fit was determined using the pseudo R^2 measure for estimating the deviance explained by the model (D^2) following Guisan and Zimmermann (2000) as:

$$D^2 = \frac{(Null\ deviance - Residual\ deviance)}{Null\ deviance} \tag{2}$$

Where the null deviance in [2] is the deviance of the model that includes only the intercept, while the residual deviance is the deviance that is unexplained by the model when the EM variable is included.

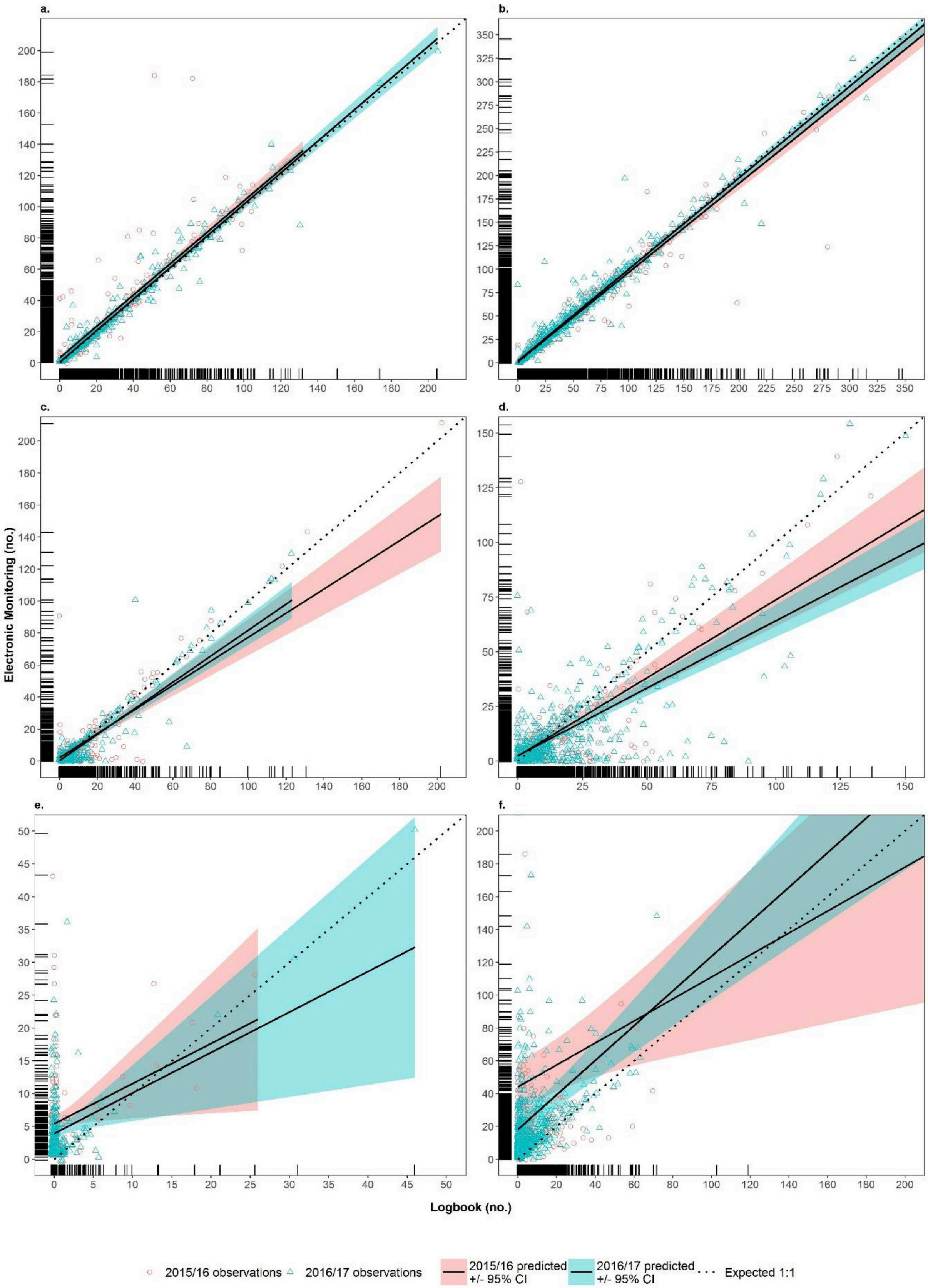

Fig. 3. Estimated regression for 2015/2016 (solid black line with red shading) and 2016/2017 (solid black line with blue shading) and equal 1:1 relationship (dotted black line) between EM analyst and logbook reporting of retained target (a, b), byproduct (c, d) and bycatch (e, f) in the ETBF (left side) and GHAT (gillnet, auto-longline and set-longline) sector (right side). Note Fig. 3b, d and 3f have been truncated to eliminate extreme values and to reveal patterns in the majority of data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
List of species that were classified as either target or byproduct (i.e. retained more than discarded) for each fishery. All other species classified as bycatch (i.e. discarded more than retained).

Fishery	Target	Byproduct
ETBF	Albacore tuna (*Thunnus alalunga*) Broadbill swordfish (*Xiphias gladius*) Yellowfin tuna (*Thunnus albacares*) Striped marlin (*Kajikia audax*) Bigeye tuna (*Thunnus obesus*)	Mahi mahi (*Coryphaena hippurus*) Moonfish (mixed) (Lampridae) Ray's bream (*Brama australis*) Shortbill spearfish (*Tetrapturus angustirostris*) Shortfin mako (*Isurus oxyrinchus*) Wahoo (*Acanthocybium solandri*) Rudderfish (*Centrolophus niger*) Southern bluefin tuna (*Thunnus maccoyii*)
GHAT	Gummy shark (*Mustelus antarcticus*)	Common sawshark (*Pristiophorus cirratus*) Elephantfish (*Callorhinchis milii*) School shark (*Galeorhinus galeus*) Snapper (*Pagrus auratus*) Southern sawshark (*Pristiophorus nudipinnis*)

The regression slope, y-intercept and standard deviation of the residuals were estimated and the fitted model was compared to the expected 1:1 relationship (slope of 1, y-intercept of 0). Where the confidence intervals encompassed or approached 0 for the intercept and 1 for the slope, the data reported from EM and logbooks were considered to be congruent (Pineiro et al., 2008). The main effect of Y and the interaction between L and Y were used to evaluate whether the intercept and/or the slope of the relationship between EM and logbook data varied between years respectively.

To explore the difference in reporting for individual species and interactions with protected species, we calculated the percentage difference in reported catches from fishers in their logbook and EM analysts rather than use GLMs, because the number of observations were too low and variance too high. The percentage difference was calculated as the difference between the number of individuals reported by the EM analyst and by fishers in logbooks divided by the number of individuals reported by the method with the greatest number. For example, if fishers reported 38 individuals in their logbook and the EM analyst reported 53 individuals across one set, the percentage difference would be $(38–53)/53 = -0.28$ or -28%, meaning that the EM analyst reported 28% more individuals than fishers in their logbook for that set. While a multitude of studies use at-sea observers as a standard of comparison for measuring congruence (Ames et al., 2007; Briand et al., 2017; Chavance et al., 2013; Ruiz et al., 2015), we felt that using the higher-reported number of individuals from either method was more appropriate given there should be no incentive for either to over-report total numbers and both the fisher-reported logbook and EM analyst (and at-sea observer) data have their own unique suite of errors (Kindt-Larsen et al., 2012) and there is no true standard of reference or precise benchmark from which to measure accuracy (Ames et al., 2007; Ruiz et al., 2015).

3. Results

3.1. Fishery

Congruence between EM analyst and fisher-reported logbook data was high for total retained catch in the ETBF (Table 2 and Fig. 2a). For total discarded catch in the ETBF, the congruence was not as high, meaning that the EM analyst and fishers in their logbook did not equally report total discarded catch (Table 2 and Fig. 2b). On average, fewer discarded individuals were reported in logbooks than by the EM analyst when the EM analyst reported catches less than approximately 10 catch items in 2015/16 and 15 catch items in 2016/17; and fewer discarded individuals were reported by the EM analyst than in logbooks, on average, when fishers in their logbook reported more than approximately 10 catch items in 2015/16 and 15 catch items in 2016/17 (see Fig. S1a and S1b to view detail for small catches).

In contrast, congruence between EM analyst and fisher-reported logbook data in the GHAT (gillnet, auto-longline and set-longline) sector was not high for both retained and discarded catch (Table 2 and Fig. 2c and d). On average, the EM analyst reported greater numbers of retained and discarded individuals per set than were reported in logbooks. This was particularly evident for discarded individuals, with zero or very small catches reported in logbooks when larger catches were reported by the EM analyst (Fig. 2d and Supplementary Material – Fig. S1c and S1d). However, for both retained and discarded catch, there was evidence of significant improvement in congruence in 2016/17 relative to 2015/16. Model fits, particularly for discarded catch ($D^2 = 0.20$) were poor, however, indicating that there was a large amount of deviance that was not accounted for by the model.

3.2. Species group (target, byproduct and bycatch)

For retained target species in both the ETBF and GHAT (gillnet, auto-longline and set-longline) sector, congruence between EM and fisher-reported logbook data was high (Table 3 and Fig. 3a and b). On average, it was not possible to detect a difference in reported retained target species between fisher-reported logbooks and the EM analyst in both fisheries. For retained byproduct species, the congruence was not as high as for target species in both the ETBF and GHAT sector (Table 3 and Fig. 3c and d). Fishers in both the ETBF and GHAT sector reported more individuals in their logbook, on average, than the EM analyst, when reporting more than approximately 10 and 9 catch items in the ETBF and GHAT sector respectively in 2015/16 (Supplementary Material – Fig. S2c and S2d). While there was no significant difference in congruence between years in the GHAT sector, there was a slight improvement in the ETBF in 2016/17. For retained bycatch species, the model fit in the ETBF was poor ($D^2 = 0.14$) (Table 3), and there was a large number of sets for which fishers reported 0 or 1 catch items in their logbook, but the EM analyst reported catches up to 43 catch items (Fig. 4e and Supplementary Material – Fig. S2e). In the GHAT sector, the EM analyst reported greater numbers of retained bycatch species than was reported by fishers in their logbooks but there was a significant improvement in congruence in 2016/17 relative to 2015/16 (Fig. 3f).

For discarded target species in the ETBF and the GHAT (gillnet, auto-longline and set-longline) sector, it was clear that the EM analyst reported fewer catch items than were reported in logbooks when the total discards for a set were greater than one (Table 4 and Fig. 4a and b). The model fit for the GHAT was poor ($D^2 = 0.04$) indicating there was large amount of deviance that was not accounted for by the model. For discarded byproduct species in the ETBF and GHAT sector, congruence was poor with the EM analyst reporting fewer individuals than were reported in logbooks when fishers in their logbooks reported more than approximately 1 and 10 catch items in the ETBF and GHAT sector

Table 2
Summary statistics and estimated parameter outputs from the GLM regression between EM analyst and logbook reporting for fishery-level comparison of sets (N = number of sets observed, D^2 = deviance explained by the model).

Fate	Fishery	N	D^2	Parameters	Estimates	Confidence Intervals		P-value
						2.5%	97.5%	
Retained	ETBF	741	0.91	Intercept	5.19	3.68	6.89	< 0.001
				Logbook	1.01	0.96	1.06	< 0.001
				Year	−3.79	−5.72	−1.97	< 0.001
				Logbook*Year	−0.01	−0.08	0.06	0.77
	GHAT	1110	0.57	Intercept	73.14	44.95	78.80	< 0.001
				Logbook	0.55	0.70	0.94	< 0.001
				Year	−46.92	−50.15	−12.64	< 0.001
				Logbook*Year	0.36	−0.08	0.06	0.01
Discarded	ETBF	745	0.51	Intercept	4.51	3.51	5.62	< 0.001
				Logbook	0.54	0.46	0.63	< 0.001
				Year	0.93	−0.46	2.28	0.22
				Logbook*Year	0.04	−0.06	0.15	0.46
	GHAT	1104	0.20	Intercept	82.92	68.99	98.53	< 0.001
				Logbook	0.49	0.15	1.01	0.06
				Year	−28.50	−46.57	−11.32	0.002
				Logbook*Year	0.36	−0.19	0.78	0.19

respectively in 2015/16 (Supplementary Material – Fig. S3c and S3d). Congruence declined significantly for the ETBF in 2016/17, with the EM analyst reporting fewer individuals than reported in logbooks (Table 4 and Fig. 4c and d). For discarded bycatch species in the ETBF, there was no significant difference between years (Table 4), with fishers in their logbooks reporting fewer discarded bycatch species than the EM analyst, when the EM analyst reported less than approximately 10 catch items, while fewer discarded bycatch species were reported by the EM analyst than in logbooks when fishers in their logbooks reported more than approximately 10 catch items in 2015/16 (Fig. 4e and Supplementary Material – Fig. S3e). In the GHAT (gillnet, auto-longline and set-longline) sector, congruence was again poor with a significantly greater number of individuals reported by the EM analyst than in logbooks. However, in 2016/17 there was a significant improvement in congruence relative to 2015/16 (Fig. 4f).

3.3. *Individual species*

The examination of congruence at a fishery and species group level (Figs. 2–4) using GLMs, concealed a large amount of variation among individual species when examined using the percentage difference analysis.

For species commonly retained in the ETBF, congruence was high (within 16%), with the only exceptions escolar (*Lepidocybium flavobrunneum*) and rudderfish (*Centrolophus niger*), with substantially more of the former reported by the EM analyst and the latter by fishers in their logbook (Fig. 5a, Table 5).

There was a large amount of variation for commonly discarded species in the ETBF, with some species having high mean discard numbers per set in the logbook, while others had higher numbers when reported by the EM analyst (Fig. 5b, Table 6). For example, there were 174 sets in 2016/17 where the EM analyst reported a total of 538 snake

Table 3
Summary statistics and estimated parameter outputs from the GLM regression between EM analyst and logbook reporting for groups of retained species by set (N = number of sets observed, D^2 = deviance explained by the model).

Fishery	Role	N	D^2	Parameters	Estimates	Confidence Intervals		P-value
						2.5%	97.5%	
ETBF	Target	730	0.92	Intercept	3.39	2.46	4.45	< 0.001
				Logbook	1.00	0.96	1.05	< 0.001
				Year	−2.85	−4.01	−1.75	< 0.001
				Logbook*Year	0.01	−0.05	0.06	0.85
	Byproduct	634	0.79	Intercept	2.21	1.43	3.17	< 0.001
				Logbook	0.75	0.65	0.86	< 0.001
				Year	−1.75	−2.35	−0.83	0.004
				Logbook*Year	0.06	−0.08	0.16	0.42
	Bycatch	419	0.14	Intercept	5.41	4.29	6.72	< 0.001
				Logbook	0.61	0.18	1.21	0.03
				Year	−1.49	−2.98	−0.10	0.04
				Logbook*Year	0.005	−0.68	0.64	0.99
GHAT	Target	1053	0.96	Intercept	1.49	0.68	2.53	0.006
				Logbook	0.95	0.92	0.98	< 0.001
				Year	0.73	−0.48	1.83	0.28
				Logbook*Year	0.02	−0.02	0.07	0.25
	Byproduct	927	0.63	Intercept	2.33	1.34	3.58	< 0.001
				Logbook	0.71	0.60	0.84	< 0.001
				Year	0.17	−1.28	1.49	0.83
				Logbook*Year	−0.10	−0.24	0.04	0.20
	Bycatch	1090	0.56	Intercept	44.12	30.26	61.20	< 0.001
				Logbook	0.67	0.31	1.18	0.002
				Year	−25.92	−44.18	−10.05	0.003
				Logbook*Year	0.38	−0.19	0.85	0.14

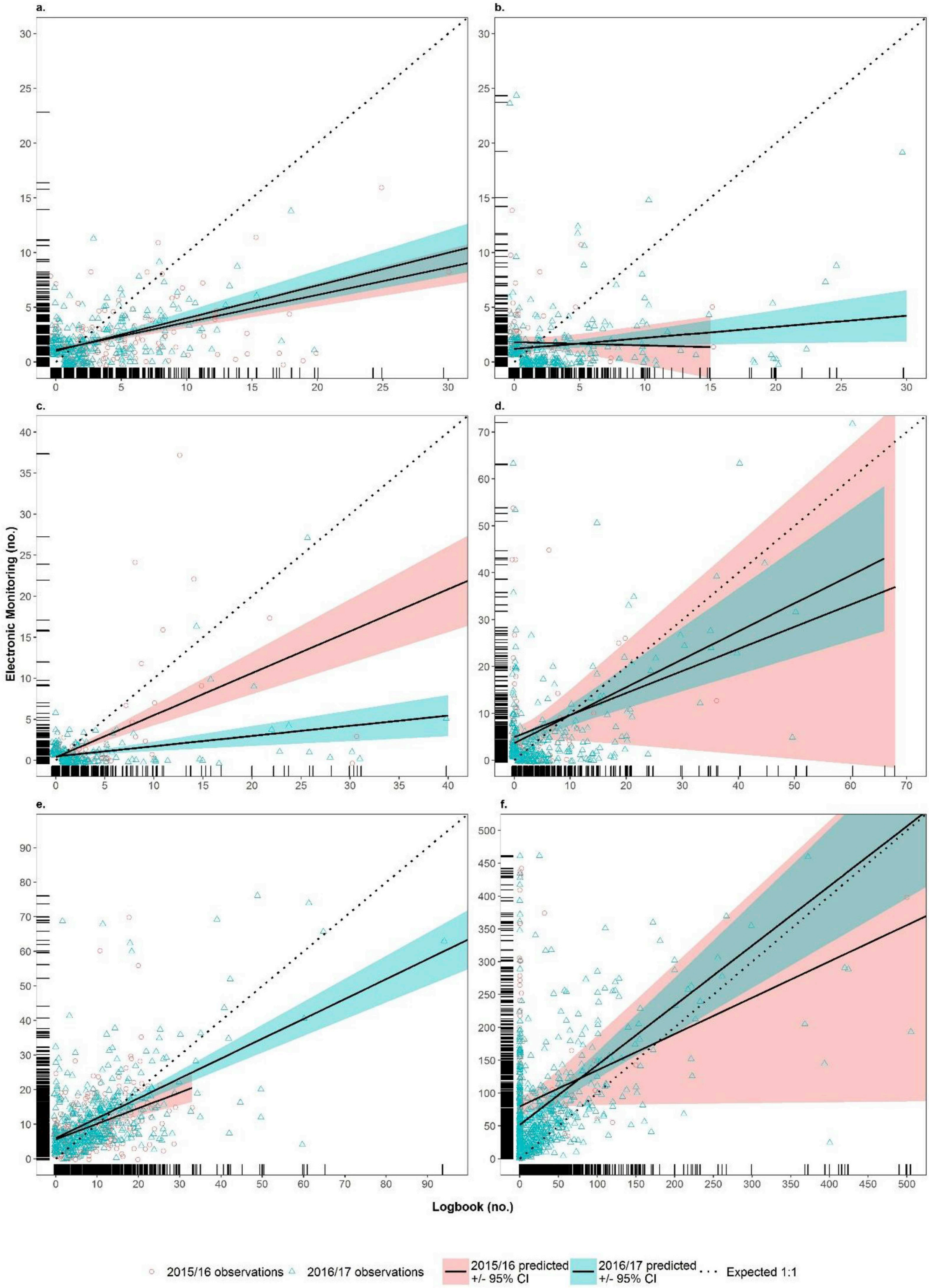

Fig. 4. Estimated regression for 2015/2016 (solid black line with red shading) and 2016/2017 (solid black line with blue shading) and equal 1:1 relationship (dotted black line) between EM analyst and logbook reporting of discarded target (a, b), byproduct (c, d) and bycatch (e, f) in the ETBF (left side) and GHAT (gillnet, auto-longline and set-longline) sector (right side). Note Fig. 4a, c, 4e and 4f have been truncated to eliminate extreme values and to reveal patterns in the majority of data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Summary statistics and estimated parameter outputs from the GLM regression between EM analyst and logbook reporting for groups of discarded species by set (N = number of sets observed, D^2 = deviance explained by the model).

Fishery	Role	N	D^2	Parameters	Estimates	Confidence Intervals		P-value
						2.5%	97.5%	
ETBF	Target	491	0.39	Intercept	1.11	0.84	1.42	< 0.001
				Logbook	0.35	0.20	0.31	< 0.001
				Year	−0.10	−0.46	0.26	0.63
				Logbook*Year	0.05	−0.04	0.14	0.33
	Byproduct	343	0.48	Intercept	0.38	0.21	0.71	0.03
				Logbook	0.51	0.39	0.63	< 0.001
				Year	0.10	−0.27	0.38	0.62
				Logbook*Year	−0.39	−0.52	−0.25	< 0.001
	Bycatch	743	0.36	Intercept	5.61	4.34	7.02	< 0.001
				Logbook	0.45	0.30	0.60	< 0.001
				Year	0.36	−1.31	1.94	0.67
				Logbook*Year	0.12	−0.05	0.29	0.16
GHAT	Target	418	0.04	Intercept	1.82	1.18	2.45	< 0.001
				Logbook	−0.03	−0.23	0.17	0.77
				Year	−0.62	−1.35	0.10	0.09
				Logbook*Year	0.13	−0.09	0.35	0.24
	Byproduct	573	0.24	Intercept	4.96	2.80	7.12	< 0.001
				Logbook	0.47	−0.10	1.05	0.11
				Year	−1.29	−3.81	1.22	0.32
				Logbook*Year	0.12	−0.50	0.75	0.69
	Bycatch	1103	0.21	Intercept	79.65	65.89	95.14	< 0.001
				Logbook	0.55	0.17	1.13	0.05
				Year	−27.97	−45.80	−11.10	0.002
				Logbook*Year	0.35	−0.26	0.81	0.23

mackerel (*Gempylus serpens*) discarded, compared to fisher-reported logbooks where only 314 were reported as discarded (Table 6). In most cases, snake mackerel were reported either in large numbers by the EM analyst and not in logbooks or vice versa. Many discarded species were reported in higher numbers by fishers in their logbook than by the EM analyst, which suggests that either the EM technology is not always capable of recording the capture of these species, or the EM analyst is having difficulties in identifying them to a species level. This was particularly the case for sharks (e.g. blue shark (*Prionace glauca*) and bronze whaler (*Carcharhinus brachyurus*)) and non-retainable marlin species (e.g. blue marlin (*Makaira nigricans*)) that are likely to be cut off the line and not brought on board (Fig. 5b, Table 6).

In the GHAT, retained target and byproduct species, including gummy shark (*Mustelus antarcticus*), school shark (*Galeorhinus galeus*) and snapper (*Chrysophrys auratus*), were reported in comparable numbers by both fisher-reported logbooks and the EM analyst (Fig. 6a, Table 5). However, there was variability in the numbers for both fisher-reported logbooks and EM analyst for all other retained species. For example, common (*Pristiophoridae cirratus*) and southern (*Pristophorus nudipinnis*) sawsharks and boarfishes (*Caproidae* spp.) were reported in higher mean numbers per set in logbooks than by the EM analyst, while elephantfish (*Callorhinchus milii*) were reported in higher mean numbers per set by the EM analyst than reported in logbooks. Sawsharks and sixgill and sevengill sharks unspecified, which were two grouped categories, were also reported more by the EM analyst, suggesting that the EM analyst was having difficulty identifying these sharks to a species level.

This same level of variability was also evident for discarded species in the GHAT (Fig. 6b, Table 6). Some species, such as Port Jackson sharks (*Heterodontus portusjacksoni*) and elephantfish, were reported in higher mean numbers per set by the EM analyst than reported in logbooks, while others such as piked spurdog (*Squalus megalops*) and southern sawshark were reported in higher mean numbers per set by fishers in their logbooks. Identification issues were also apparent in the recording of draughtboard shark (*Cephaloscyllium laticeps*) and draughtboard sharks (mixed) with EM analysts recording them as the former and fishers in logbooks as the latter (Fig. 6b, Table 6).

3.4. *Protected species interactions*

The results comparing the mean number of protected species interactions reported across all sets by both the EM analyst and fishers in the logbook are displayed in Fig. 7. Apart from seabirds in the ETBF, it is evident that some protected species interactions are being missed by the EM analyst with fishers in their logbooks consistently reporting higher numbers. There was however, a slight improvement in overall congruence in 2016/17 relative to 2015/16 (Fig. 7). In the GHAT (gillnet) sector, the mean level of congruence ranged from 0 to 33% more interactions reported by the EM analyst than reported in the logbook (Fig. 7). The small sample size of interactions with protected species resulted in relatively large standard errors, which all overlapped with zero, except for sharks in 2015/16. This indicates that it was not possible to detect a difference between the EM analyst and fisher-reported logbooks in the number of reported interactions with protected species.

4. Discussion

Technological advancement has led to the consideration of integrated EM systems as a data collection tool to supplement and support (Dunn and Knuckey, 2013; WCPFC, 2015) or replace (Piasente et al., 2012) at-sea observer programs. This is because integrated EM systems have the capacity to collect a range of fishery-dependent data including: retained and discarded catch, spatial and temporal setting and hauling operations, gear specifications, the use of mitigation measures and/or devices and interactions with protected species (Ames, 2005; McElderry, 2008; McElderry et al., 2010; Piasente et al., 2012). Depending on the objectives of the specific EM program, the data is typically used to either census all fishing effort for catch monitoring purposes, or to audit a proportion of fishing effort to verify fishing logbooks (Mangi et al., 2015). If an integrated EM system is used as a validation tool coupled with an effective monitoring, control and surveillance (MCS) program, then it allows managers to assess the veracity of logbook data as a source of information for assessing and managing fisheries.

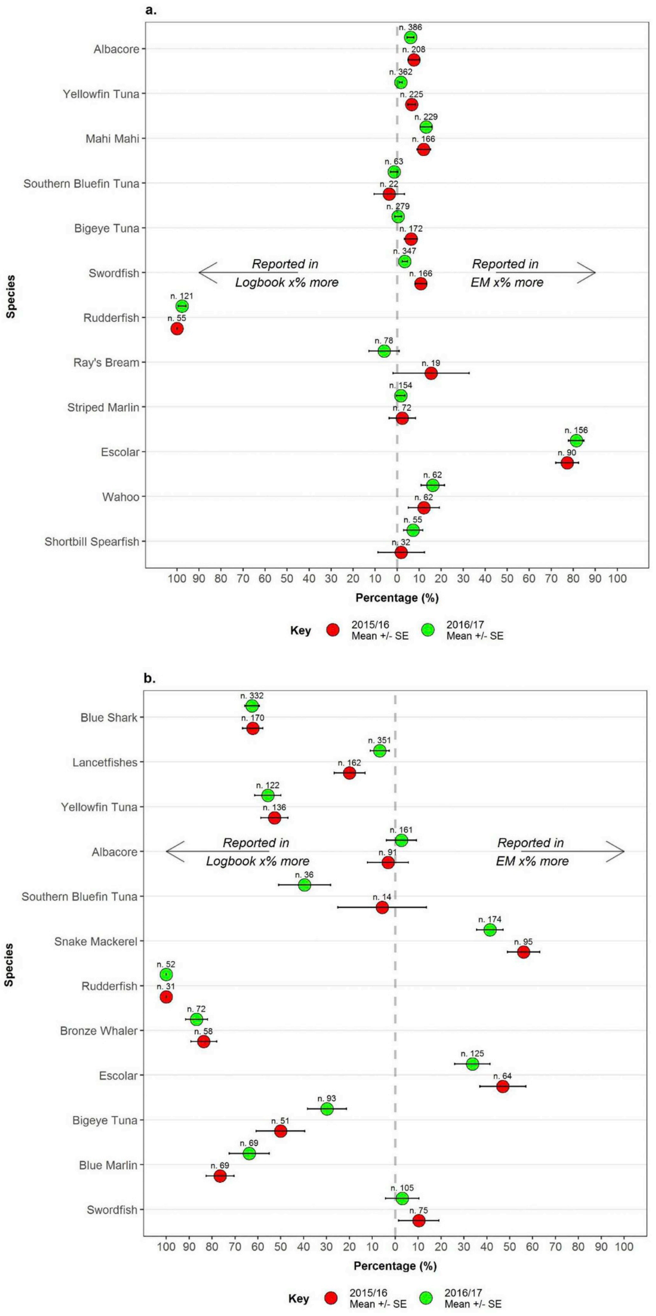

Fig. 5. Proportional difference in individual species reported as (a) retained and (b) discarded in the ETBF by fishers in logbook and EM analyst across all sets in 2015/16 and 2016/17 financial years. Species are ordered by top twelve reported (a) retained and (b) discarded species from 2015/16 and 2016/17 logbook data. The number above the mean is the total shots audited where that species was (a) retained or (b) discarded.

In Australia, an integrated EM system was introduced (as an audit tool) in several Commonwealth commercial fisheries in 2015, including the ETBF and GHAT sector with the main aim to validate logbook information through reviewing 10% of all sets (100% of all gillnet sets for protected species interactions in the Australian Sea Lion Management Zones) for both retained and discarded catch, as well as monitor interactions with protected species (AFMA, 2015a, 2017b). In the ETBF and the auto-longline sector of the GHAT there are also additional requirements for monitoring the deployment of seabird mitigation devices (e.g. tori lines) (AFMA, 2015a). We reviewed the overall level of data congruence between the EM analyst and logbook reported retained and discarded catch and interactions with protected species from the first two years of operation to determine whether the AFMA EM program was meeting its key objective of "increased confidence in data quality achieved through cross validation with data captured in logbooks and observer records" (AFMA, 2015a).

While overall congruence between the ETBF and GHAT sector was higher for retained than discarded catch, fishery-wide estimates of congruence concealed a large amount of variation among individual and groups of species. In our analysis, EM analyst and fisher-reported logbook data were more consistent in deriving estimates of target retained species than discarded species in both the ETBF and GHAT sector. The accurate reporting of target species in the logbook in both fisheries may have been due to quota management, which requires weights of quota species to be independently verified upon landing (Larcombe et al., 2016). Similarly, given target species would be regularly processed in the hauling station area, they were more likely to be observed by and familiar to the EM analyst reviewing the footage.

On average, catches reported by the EM analyst and by fishers in their logbook were more similar for longline than gillnet fishing gear. The higher congruence for longline than gillnet fisheries may have been due to method in which fish are landed (van Helmond et al., 2015). In the GHAT sector, catch is brought on deck or to the sorting station via the net roller, and in some instances multiple individuals of more than one species can be brought onto a vessel simultaneously. Conversely, in the ETBF, catch is brought on deck one individual at a time during hauling. Increases in the number of species landed simultaneously can reduce the performance of integrated EM systems (McElderry, 2008). For example, Bartholomew et al. (2018) reported that EM analysts had difficulty in distinguishing between individuals when the catch exceeded 15 individuals on deck in Peruvian small-scale gillnet fisheries. Similarly, the ability of fishers to record all species in their logbooks is highly dependent on the fishing method used and the number and diversity of species. For example, in the gillnet component of the GHAT sector, an integrated EM system trial found that the length of time available for at-sea observers to identify and count catch as it was landed in the net was restricted by the need for fishing operations to continue (Lara-Lopez et al., 2012). Furthermore, the gear selectivity and overall species richness in the ETBF is considerably less than in the GHAT sector. In the past, the GHAT sector has reported catching approximately 210 species, compared with approximately 90 species in the ETBF. Prior to the integrated EM system implementation, it was common for the GHAT logbooks to have insufficient space for fishers to report all bycatch species (AFMA, 2015b). Reporting the full species composition of catches may therefore be more difficult for fishers in the GHAT sector relative to the ETBF, which may be a reason why congruence was lower for both retained and discarded species. Therefore, it is critical that either a mechanism is developed to increase the ability for fishers to expediently record high volumes of mixed catch in their logbook without reducing operational efficiency, or AFMA increases the tolerance levels for logbook reported discards if the costs of comprehensive reporting (in terms of time and changes to operational practices) are considered prohibitive.

There was no difference in logbook and EM analyst reporting of protected species interactions in the GHAT sector, but there was clear issues with EM analyst reporting of individuals in the ETBF. The reduced congruence in the ETBF may have been due to the interactions not being observed by the EM analyst because the camera was not positioned appropriately, or fishers (in the case of no-take marlins and protected sharks) releasing these individuals before bringing them on board in view of the camera. The improvements in congruence in 2016/17 however are promising and could be due to the modification and addition of wide-angle cameras on board vessels by AFMA and AAP.

The comparison of total retained and discarded catches between the EM analyst and fisher-reported logbooks by fishery concealed a large amount of variation among individual and groups of species. While the reporting of retained target species in the ETBF and GHAT sector by

Table 5

Total numbers of top twelve retained species (as listed in Figs. 5a and 6a) reported by fishers in logbooks and by the EM analyst in the ETBF and GHAT (gillnet) sector in 2015/16 and 2016/17.

Fishery	Species	2015/2016		2016/2017	
		Logbook	EM	Logbook	EM
ETBF	Albacore tuna (*Thunnus alalunga*)	3507	4038	6204	6504
	Yellowfin tuna (*Thunnus albacares*)	2570	2701	2907	2947
	Mahi Mahi (*Coryphaena hippurus*)	1919	1636	880	977
	Southern Bluefin tuna (*Thunnus maccoyii*)	809	813	1943	1946
	Bigeye tuna (*Thunnus obesus*)	992	1083	1476	1464
	Broadbill swordfish (*Xiphias gladius*)	731	852	1709	1763
	Rudderfish (*Centrolophus niger*)	407	0	517	4
	Ray's bream (*Brama australis*)	69	148	683	602
	Striped marlin (*Kajikia audax*)	120	117	260	268
	Escolar (*Lepidocybium flavobrunneum*)	138	667	151	750
	Wahoo (*Acanthocybium solandri*)	68	83	71	84
	Shortbill spearfish (*Tetrapturus angustirostris*)	42	41	60	68
GHAT	Gummy shark (*Mustelus antarcticus*)	17763	17342	36442	36994
	Common sawshark (*Pristiophorus cirratus*)	992	374	3687	1826
	Elephantfish (*Callorhinchis milii*)	1567	2125	2985	3833
	School shark (*Galeorhinus galeus*)	894	884	1396	1388
	Southern sawshark (*Pristiophorus nudipinnis*)	467	20	1711	304
	Boarfishes (grouped category)	501	188	1399	218
	Broadnose shark (*Notorynchus cepedianus*)	429	154	783	652
	Draughtboard sharks (mixed) (grouped category)	271	4	574	1
	Sawsharks (grouped category)	1	853	493	3261
	Snapper (*Pagrus auratus*)	102	80	326	422
	Blue morwong (*Nemadactylus valenciennesi*)	139	33	240	8
	Sixgill and sevengill sharks (grouped category)	36	326	233	655

fishers in their logbook and the EM analyst were equivalent, there were large discrepancies for other byproduct and bycatch species, particularly those discarded. The observed divergence between the EM analyst estimates and logbook reporting by fishers may have been due to one, or a combination of: (i) misidentification of species and taxonomic issues, (ii) missed observations from both the EM analyst and fisher and/or, (iii) incomplete logbook reporting.

It was evident that some species, particularly those discarded could not be identified by the EM analyst in both fisheries, leading to them being grouped into more general species categories, including, *inter alia*, unknown or other, tuna (mixed), sharks (mixed), sawsharks (mixed), and marlin, spearfish and sailfish (Emery et al., unpub. data). In the ETBF for example, 46% of discarded tuna species were grouped into the tuna (mixed) category by the EM analyst, while this proportion

Table 6

Total numbers of top twelve discarded species (as listed in Figs. 5b and 6b) reported by fishers in logbooks and by the EM analyst in the ETBF and GHAT (gillnet) sector in 2015/16 and 2016/17.

Fishery	Species	2015/2016		2016/2017	
		Logbook	EM	Logbook	EM
ETBF	Blue shark (*Prionace glauca*)	662	170	1716	655
	Lancetfishes (Alepisauridae)	575	304	1745	1207
	Yellowfin tuna (*Thunnus albacares*)	516	211	272	87
	Albacore tuna (*Thunnus alalunga*)	299	143	412	320
	Southern bluefin tuna (*Thunnus maccoyii*)	189	198	269	107
	Snake mackerel (*Gempylus serpens*)	112	169	314	538
	Rudderfish (*Centrolophus niger*)	111	0	251	0
	Bronze whaler (*Carcharhinus brachyurus*)	129	16	218	11
	Escolar (*Lepidocybium flavobrunneum*)	63	145	238	261
	Bigeye tuna (*Thunnus obesus*)	121	30	131	66
	Blue marlin (*Makaira nigricans*)	123	18	93	17
	Broadbill swordfish (*Xiphias gladius*)	87	83	119	112
GHAT	Draughtboard sharks (mixed) (grouped category)	973	8	11041	6
	Port Jackson shark (*Heterodontus portusjacksoni*)	621	4157	4334	8111
	Draughtboard shark (*Cephaloscyllium laticeps*)	243	9897	2814	34980
	Elephantfish (*Callorhinchis milii*)	221	726	1352	2307
	Crabs (grouped category)	0	29	1225	2437
	Piked spurdog (*Squalus megalops*)	394	4	825	327
	Gummy shark (*Mustelus antarcticus*)	136	154	937	395
	Whitefin swellshark (*Cephaloscyllium albipinnum*)	151	1	728	0
	Common sawshark (*Pristiophorus cirratus*)	35	32	266	132
	School shark (*Galeorhinus galeus*)	52	108	187	154
	Angel sharks (grouped category)	19	34	178	106
	Southern sawshark (*Pristiophorus nudipinnis*)	16	8	133	63

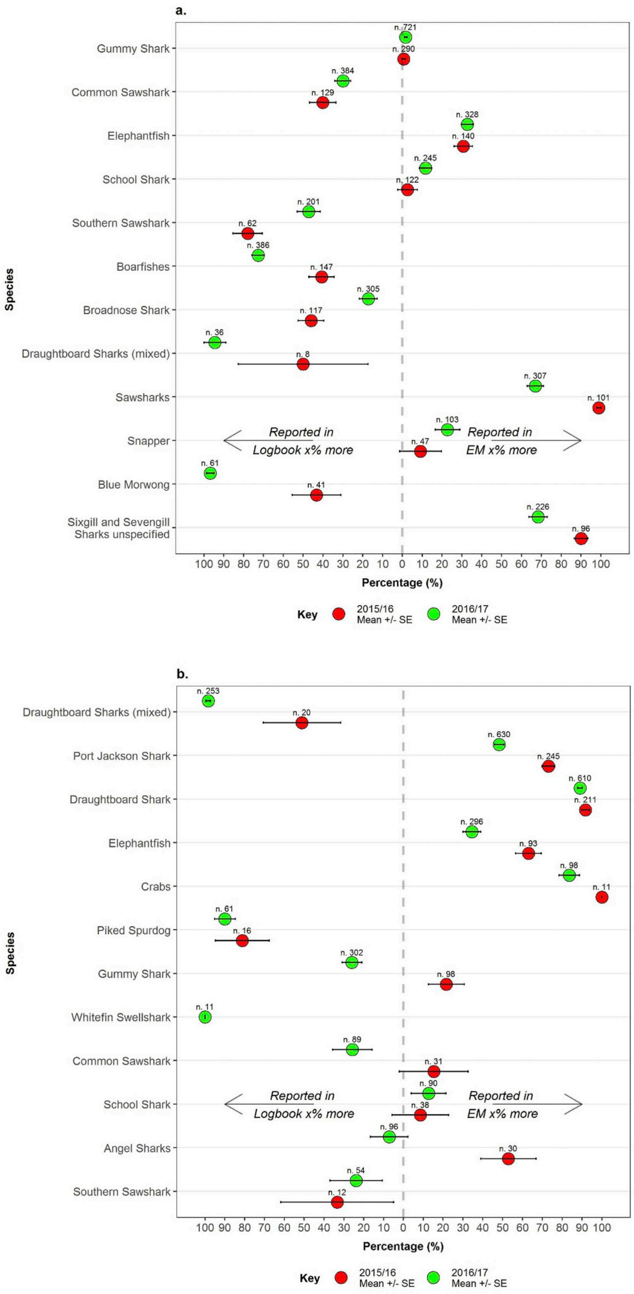

Fig. 6. Comparison of logbook to EM analyst reporting in 2015/16 and 2016/17 financial years by set for individual species caught in more than 50 sets audited in the GHAT (gillnet) for (a) retained catch and (b) discarded catch. Species ordered by highest EM to logbook mean percentage difference in 2015/16.

was even higher (76%) for marlins, spearfish and sailfish species (Emery et al., unpub. data). Likewise, in the GHAT sector, 46% of discarded gummy and school sharks were grouped into the hound sharks category, while 56% of angel shark species were grouped into the angel sharks category (Emery et al., unpub. data). The grouping of species into more general categories by the EM analyst was similarly observed by Ames (2005) in a comparison of at-sea observer and EM data in the Alaskan Pacific halibut longline fishery.

In the ETBF, there were some clear taxonomic issues in regard to the reporting of escolar and rudderfish, which led to the EM analyst reporting them as escolar and fishers reporting them as rudderfish in their logbook. Anecdotal evidence also points to similar issues in the logbook reporting of snake mackerel and escolar in the ETBF, with some fishers incorrectly reporting them as escolar (Trent Timmiss [AFMA], pers. comm. 2018). Differentiating the species of smaller sized tuna (e.g. juvenile bigeye and yellowfin) from video footage was also challenging in the ETBF integrated EM system trial and among pilot studies on tropical tuna purse seiners in the Indian and Atlantic Oceans (e.g. Briand et al., 2017), which may explain why higher numbers of discarded bigeye and yellowfin tunas were reported in logbooks than by the EM analyst (Larcombe et al., 2016). In other integrated EM system trials and pilot studies, EM analysts have also had trouble distinguishing similar looking species, such as rockfish (McElderry et al., 2003). The inability to correctly identify individuals to a species level is a challenge for integrated EM systems to resolve, as precise taxonomic identification is critical for assessing fish stocks (Ruiz et al., 2015; Vecchione et al., 2000).

Species identification issues for the EM analyst can also arise due to poor image quality caused by external factors, such as weather, waves and lighting, or the quality of the cameras themselves (Evans and Molony, 2011; Mangi et al., 2015; van Helmond et al., 2015; Wallace et al., 2013). The influence of these external factors for Australian fisheries may be lessened as alternative random hauls can be reviewed if poor image quality prevents a review being conducted to an appropriate standard (AFMA, 2016). Nevertheless, the lack of lighting on some vessels in the ETBF has limited the ability of the EM analysts to record whether tori lines have been deployed in accordance with AFMA's regulations during night setting operations (Larcombe et al., 2016). In a study of the congruence between EM and at-sea observer reporting in French tropical tuna purse-seine fisheries, Briand et al. (2017) noted that recording individuals to a species level was difficult when cameras were not in close proximity to discard operations, or discard operations occurred outside the camera's field of vision. A similar issue has been noted for some vessels in the GHAT sector, where fishers have leaned over the side of the vessel to discard individuals from the net outside the view of the camera, requiring later on-board adjustment of the cameras.

There are several factors to consider in order to improve species identification. Firstly, it is important that EM analysts are familiar with target, by-product and bycatch species of the specific fishery and ideally have on-board (i.e. at-sea observer) experience in the fishery prior to reviewing any footage (Chavance et al., 2013). Alternatively, with time, difficulties with species identification could be resolved through automated computer recognition software (Storbeck and Daan, 2001). Secondly, additional cameras can be placed on-board vessels to cover a larger proportion of fishing operations. In the GHAT sector, there is a particular need to affix an additional camera to cover both sides of specific vessels to capture the discarding of individuals. Thirdly, image quality and therefore species identification could be improved by having stringent protocols in place to manage and maintain equipment on board the vessel as advocated by van Helmond et al. (2015), as well as an automated warning system, which alerts the skipper when image quality is poor and there is a need to clean the camera lens.

Failure of the EM analyst and/or the fisher to detect the capture of some species likely contributed to some of the variation between EM and logbook data. In the ETBF, for instance, shark and marlin species, along with marine turtles, were reported in greater numbers in logbooks than by the EM analyst. This could be due to these species being cut off (i.e. in the case of sharks to avoid potential injury to the crew) or dropping off the line before entering the camera's field of view, thus preventing detection by the EM analyst. This was observed during the integrated EM system pilot study in the ETBF and the Alaskan Pacific halibut longline fishery (Ames et al., 2005, 2007; Larcombe et al., 2016). Ruiz et al. (2015) also noted that EM analyst estimates for shark species in a tropical purse seine fishery were significantly lower than at-sea observer estimates, while Bartholomew et al. (2018) found that EM analysts only captured turtle interactions 50% of the time in Peruvian small-scale gillnet fisheries. Conversely, in a Danish integrated EM system trial, porpoise bycatch was reported in higher numbers by the EM analyst than in logbooks, as they dropped out of the net before

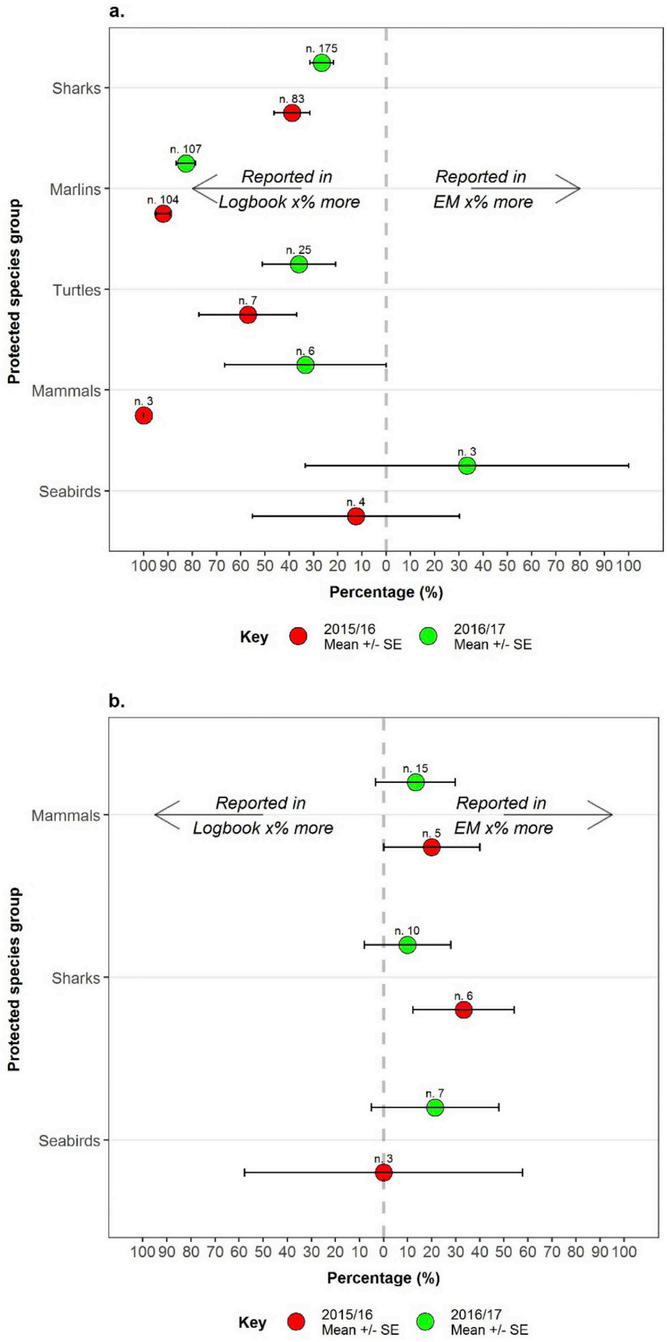

Fig. 7. Comparison of logbook to EM analyst reporting in 2015/16 and 2016/17 by set for interactions with protected and no-take species (i.e. wildlife) in the ETBF and GHAT (Gillnet only).

being observed by the fishers, but cameras were placed appropriately to capture these interactions (Kindt-Larsen et al., 2012).

To improve the possibility of shark species and marine turtles being detected and correctly identified by the EM analyst, there is a need to improve existing camera location, orientation and image quality (i.e. resolution, frame rate, cleaning). While there was modification to existing cameras and the addition of wide-angle cameras to some vessels in 2016/17 by AAP and AFMA, there is clearly still a need for ongoing refinements as each vessel's configuration and catch handling processes are unique. AFMA could also work with fishers to develop a standardised approach for handling species that would improve the view for the EM analyst and their ability to accurate identify catch items (Anon, 2016; Briand et al., 2017; McElderry, 2008; Piasente et al., 2012; Ruiz et al., 2015). For example, requesting fishers to bring all species in proximity of the hauling station camera prior to being cut off the line or released. However, safety concerns need to be considered, as changes to handling practices could have adverse health and safety consequences for the crew.

Fishers could also have failed to record all of the species retained or discarded in their logbook. In the GHAT sector, the EM analyst in both years reported over 30% more retained elephantfish (*Callorhinchis milli*) than was reported in the logbook by fishers. Furthermore, there were also many discarded species that were either not reported or reported in low numbers in the logbook relative to the EM analyst. Initially this is likely to have been influenced by the change in logbook, with fishers not required to report counts of discarded catch (only weights) for the first ten months of the AFMA EM program. This could also have been a result of fishers either not observing species capture or simply a decision to not record them as observed by Kindt-Larsen et al. (2012) in a

Danish EM trial. AFMA has recognised there is a need to continually educate fishers on the importance of accurate reporting of discarded catch in their logbook and these efforts may have led to an improvement in congruence in the GHAT sector between EM analyst and logbook data for discarded bycatch species in 2016/17 relative to 2015/16. A similar result was also evident during the second year of an EM trial in the New England groundfish fishery, where a timely feedback loop between EM analysts and fishers improved both the consistency of their logbook reporting and the relative accuracy of their weight estimates, which resulted in increased congruence between EM analyst and fisher-reported logbook data (Anon, 2016). Given various studies have confirmed that some fishers are poor at identifying species and underreport discards in their logbook (Faunce, 2011; Macbeth et al., 2018; Mangi et al., 2016; Nakano and Clarke, 2006), there is a clear need for AFMA to continually educate fishers on the importance of accurate reporting of catch composition and fishing activities in their logbook to reduce the likelihood that management decisions will be based on biased estimates of fishing mortality. A specific case in point is for elephantfish (*Callorhinchis milli*), where prior to 2018, AFMA used logbook estimates of retained catch (which according to this study were over 30% underreported) in the CPUE standardisations to inform total allowable catch (TAC) setting.

Notwithstanding some problems in the logbook reporting of specific species, there were some clear weaknesses in the ability of the integrated EM system to accurately record all retained and discarded catch to a species level as required by AFMA (AFMA, 2015a). It has been contended by Wallace et al. (2013) that integrated EM systems have not been effective in delivering data sets equivalent to those collected by at-sea observers that are necessary for accurately estimating discards. However, while this may be true for some fisheries, it is also apparent that the implementation of the AFMA EM program has improved the reporting of discarded species and protected species interactions in the logbooks (AFMA, 2017b; Larcombe et al., 2016). Improvements in logbook reporting through time have also become apparent, particularly in the GHAT sector for both retained and discarded bycatch species in 2016/17 relative to 2015/16. Given similar improvements in logbook reporting observed in other fisheries (Anon, 2016), the presence of cameras on-board, coupled with an effective feedback loop, may create incentives to improve the accuracy of logbook reporting to a standard similar to that of at-sea observers.

5. Conclusion

Integrated EM systems have the capability to collect a diversity of fishery-dependent data that can be analysed to reduce uncertainty and make informed management decisions. This study has shown that congruence was highest in both longline and gillnet fisheries for retained target species, but declined for discarded species, particularly those classified as byproduct and bycatch. The integrated EM system also had difficulty recording captures of species such as sharks, marlins and marine turtles in the ETBF, which are usually released or drop off the line outside the camera's field of vision, as well as identifying many commonly discarded species in both fisheries to a species level, resulting in their grouping. Consequently, in order to fulfil the current objectives of the AFMA EM program, the existing camera configurations may need to be reviewed or additional cameras affixed to the vessel with the aim to improve the field of vision for the EM analyst. This is already an ongoing practice for AAP and AFMA, with wide-angle cameras introduced on a number of vessels in 2016/17 in order to resolve blind-spots (Trent Timmiss [AFMA], pers. comm.). Furthermore, while the integrated EM system has previously been shown to be effective at improving logbook reporting of both retained and discarded catch, as well as protected species in the ETBF (Larcombe et al., 2016), this may not have occurred to the same extent in the GHAT sector, with an increase in logbook reporting only initially observed for protected species (AFMA, 2017b). This indicates a continual need to remind fishers of the importance of comprehensive logbook reporting and to investigate whether this could be further improved through, for example, modification of existing management incentives (e.g. evaluation standards for logbook auditing) or increased timeliness of the feedback loop between EM analysts and fishers, which has shown to improve logbook reporting (Anon, 2016). Furthermore, if EM technology is not perceived as a legitimate data collection tool among GHAT sector fishers (i.e. acceptance of the applied regulations as justified and reasonable (Jentoft, 2000; Nielsen, 2003)) then continual communication of the benefits (e.g. individual accountability and access to previously closed areas) could be critical in ensuring long-term cultural change. The need to improve logbook reporting of discards, particularly bycatch species, in the GHAT sector has already elicited a management response from AFMA in terms of heightened communication with fishers, which has improved overall reporting in 2016/17 relative to 2015/16. Given the abundance and diversity of species in the GHAT sector relative to the ETBF, it may be that increased tolerances for logbook reporting of discarded species or allowances for grouping of species are required in the formulation of any quantitative evaluation standards for auditing by AFMA. Similarly, the purchase of additional cameras to identify species such as sharks, marlins and marine turtles in the ETBF, which are usually released or drop off the line may be unwarranted if incentives for fishers to continue to accurately report their capture remain durable.

Our study has identified some deficiencies in the ability of the current AFMA EM program to meet its objectives of recording and identifying to a species level all catch composition and interactions with protected species in the ETBF and GHAT sector. This is important because if not addressed, these deficiencies could create a disincentive for fishers to accurately report in their logbook if they believe the EM analyst is failing to observe all retained, discarded catch and protected species interactions during their audit. This could potentially result in the AFMA objective for the EM program not being attained. However, the AFMA EM program is still in its infancy and is flexible enough to continue to evolve in response to ongoing scientific review and feedback from stakeholders. The issues identified in this study could be addressed through more effective camera placement, changes to vessel operational practices, increased education of fishers or modification of the existing management incentives for logbook reporting. Determining prescribed tolerances for logbook reporting of retained, discarded catch and protected species interactions in quantitative evaluation standards, as similarly undertaken in Canadian fisheries (Stanley et al., 2011), may also facilitate greater certainty among industry as to AFMA's expectations and improve overall logbook reporting performance.

Acknowledgments

The authors would like to thank Lee Georgeson from ABARES as well as Trent Timmiss, Don Bromhead, Brodie MacDonald and George Day from AFMA for their valuable comments on the manuscript. We would also like to acknowledge Andrew Fedoruk, Matthew Piasente and other EM analysts from Archipelago Asia Pacific Ltd for providing an insight into the capability of electronic monitoring and how camera footage is reviewed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2018.11.003.

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