The capability of electronic monitoring to measure logbook reporting performance and improve data for scientific analysis

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Scientists in the Fisheries Science Program at Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) have analysed EM and logbook data collected by the Australian Fisheries Management Authority (AFMA) since 2015, in the Australian Eastern Tuna and Billfish Fishery (ETBF), to assess a range of issues including:

- the impact of EM on logbook data reporting (Emery et al 2019a);
- the capability of EM to replace or supplement human observer data collection (Emery et al, 2018);
- improvements needed to both logbook and EM data collection systems (Emery et al. 2019b), and;
- how EM can assist both scientific assessments and fishery management decision making processes (Emery et al. 2025).

ABARES latest published paper (see attached) undertook an analysis of congruence between EM and logbook data reported in the ETBF at the individual vessel level. The analysis identified that there can be significant variation in congruence between logbook and EM reported data at the vessel-level. The paper highlights and discusses the value of vessel level analyses in identifying vessels with general (i.e. universal) or specific (e.g. particular species) logbook reporting deficiencies and/or issues with individual vessel EM systems (e.g. camera placement). This is information which:

- Managers can use to undertake education or compliance actions to improve vessel level, and therefore fleet level, improvements in both logbook and EM data reporting.
- Scientists can use to identify and filter out data reported by vessels for which there is perhaps less confidence in its reliability for use in a given scientific analysis (e.g. CPUE standardisation).

We will also describe how the implementation of EM can enable fishery managers to implement individual vessel-based accountability approaches to management, using the AFMA seabird management approach as an example.

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A B S T R A C T

Electronic monitoring (EM) systems are used to collect fisheries dependent data to support scientific analyses and management decision-making. In Australian Commonwealth fisheries, EM is also used to validate and improve logbook data reporting at the individual vessel level through the provision of consistent feedback to fishers on their logbook reporting. We compared five years of EM and logbook reported catch numbers for both retained and discarded key tuna and billfish species and, interactions with endangered, threatened and protected (ETP) species in the Australian Eastern Tuna and Billfish Fishery (ETBF). This was undertaken to examine congruence at an individual vessel level and determine how both EM and logbook reporting can potentially be improved in the future. At a fleet-wide level, overall congruence was higher for retained than discarded catch and higher for ETP groups (i.e., seabirds) than at an ETP species (i.e., wandering albatross) taxonomic level. Importantly, vessel-level estimates of congruence revealed significant inter-vessel variation in logbook reporting performance. For example, a small number of vessels were not reporting any bycatch and discards despite EM analysts observing these occurrences on these vessels, whilst other vessels had perfect congruence for some species across all audited sets. These results highlight the capability of EM to identify vessels with general (i.e. universal) or specific (e.g. particular species) logbook reporting deficiencies, that enable managers to undertake either incentive-based, education-based or (where required) compliance-based targeted actions to ensure that those vessels improve their future logbook reporting. Ultimately this approach will improve data inputs for scientific analyses and the fisheries management decisions that rely on them.

1. Introduction

Sustainable fisheries management relies on obtaining precise and unbiased estimates of the level of catch (and mortality) of species that interact with fisheries, that can then inform analyses of fishing mortality and stock biomass for target species, or risk assessments and risk management (including threat abatement) responses associated with general bycatch and endangered, threatened and protected (ETP) species. 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) (Emery et al., 2019b). Data collected from these programs supports various applications including, conducting stock assessments on target stocks, assessing the performance of harvest strategies and control rules, as well as calculating fleetwide, or individual vessel bycatch rates (Parsa et al., 2020; Roberson and Wilcox, 2022).

The value of fishery-dependent data for estimating the status of fishery impacts on target and non-target species has often been called into question because of:

- (i) biases in at-sea observer data caused by the non-random placement of observers on vessels (i.e. displacement effect) (Gilman, 2023),
- (ii) changes in fishing behaviour caused by at-sea observer presence (i.e. observer effect) (Gilman, 2023),
- (iii) susceptibility of at-sea observers to coercion or corruption (Suuronen and Gilman, 2020) and;
- (iv) misreporting of retained species catch composition, discards, and interactions with ETP species in logbooks (Sampson, 2011).

The latter (iv) can be due to variation in species identification competency among skippers, high catch volumes, or fears of compliance action and/or increased regulation (Brown et al., 2021; Mangi et al.,

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2016; Sampson, 2011). Inaccurate data makes it problematic for fisheries managers to develop effective regulatory regimes addressing target and non-target species. For example, biases along with gaps in logbook reporting at a vessel level make it problematic to model the behaviour of fishing fleets and accurately estimate fleetwide catch and discards (Brown et al., 2021; van Helmond, 2022). Furthermore, biased or incomplete data can impede sustainable management of stocks through reducing the precision of abundance predictions from stock assessment models, making it difficult to detect population trends through time (Brown et al., 2021; van Helmond, 2022)

Numerous studies comparing logbook and other data sources (e.g. at-sea observer data) have highlighted that fisheries logbook data is often incomplete and inaccurate (e.g. Brown et al., 2021; Faunce, 2011; Macbeth et al., 2018; Mangi et al., 2016; Suuronen and Gilman, 2020). Gilman et al. (2019) proposed that fishers may lack the motivation, either economically or due to regulatory disincentives, to accurately record data in their logbook.

Incentivising fishers to accurately report in logbooks can be achieved through a range of approaches, including through appropriate monitoring control and surveillance (MCS) frameworks. Electronic monitoring (EM) is a MCS tool that can be used by managers to collect data on catch composition, discards and interactions with ETP species, as well as monitor the use of bycatch mitigation measures (Moore et al., 2021; Suuronen and Gilman, 2020; van Helmond et al., 2020). The presence of EM on vessels can also encourage fishers to report more diligently in their logbooks (Emery et al., 2019a,b) and provide managers with a verification tool that can: (i) identify specific reporting issues and, (ii) provide a mechanism for targeted feedback to fishers to assist them in improving their logbook reporting. EM systems typically consist of a series of onboard cameras, global positioning systems, sensors and data loggers that collect information on fishing activities. The fishing activities that are recorded can either stored locally on a hard drive, or on a dedicated storage server. This data can then be reviewed and verified later onshore by an EM analyst for both management and compliance purposes. Typically, the footage is either used to census all fishing effort for catch monitoring purposes and/or to audit a proportion of fishing effort to verify fishing logbooks, such as is undertaken in both Australian and Canadian fisheries (Emery et al., 2019b; Mangi et al., 2015; Stanley et al., 2011).

Previous studies (Emery et al., 2019a; Larcombe et al., 2016; Stanley et al., 2015) have shown that the presence of EM as a MCS tool can lead to changes in logbook reporting behaviour. For example, Stanley et al. (2015) reported in the British Columbia groundfish hook and line fishery that logbook reporting of catch composition was adequate for almost all vessels by year two of the EM program, with most fishers meeting prescribed logbook reporting tolerance levels. Similarly, Emery et al. (2019a) showed significant increases in nominal discard per unit effort and interactions per unit effort between pre and post EM implementation in the Eastern Tuna and Billfish Fishery (ETBF) in Australia, indicating improved logbook reporting rates after the implementation of EM.

A previous comparative analysis of ETBF logbook and EM data (Emery et al., 2019b) looked at congruence in reporting of both retained and discarded species and interactions[1] with ETP at the fleet level in the two years following EM implementation. It identified a higher level of congruence for retained than discarded species, with a greater proportion of discarded species not able to be identified to a species level by the EM analyst. While reporting of seabird interactions was reasonably congruent, there were clear issues with the reporting of other ETP groups (sharks and turtles) by the EM analyst, with fishers reporting these in greater numbers in their logbook. However, this analysis was undertaken at a fleet-level and no attempt was made to analyse the data at an individual vessel level. This is important because fishing fleets are not homogenous and there is likely to be significant differences in skippers' skill and accuracy in logbook reporting (see, e.g. Macbeth et al., 2018), which if quantified might provide scientists and managers alike with valuable information to improve current and future scientific analyses and management decision-making.

Consequently, the aim of this study was to examine congruence between ETBF logbook and EM data using an updated dataset, at both fleet and individual vessel levels to determine how EM and logbook reporting can potentially be improved in the future. Congruence is defined here as the level of similarity between logbook and EM counts of individuals retained, discarded, or interacted with during a set. If there is a high level of congruence, there can be some confidence that logbook records provide a sufficiently precise and accurate account of retained and discarded catch, as well as interactions with ETP species. By comparing the congruence results across the fleet at the individual vessel level, specific vessels not reporting discards on logbooks when EM analysts did report discards (indicative of misreporting) or having very low EM recorded counts relative to logbook for ETP species (potentially indicative of EM system related issues), for instance, can be identified and investigated further by managers. Ultimately, this allows the management framework moving forward to improve fleet level reporting performance through implementation of an individual vessel-based approach to non-compliance with reporting requirements, which is likely to be more efficient (and therefore beneficial) when faced with limited resources and capacity.

2. Methods

2.1. Description of the eastern tuna and billfish fishery

The ETBF is a pelagic longline and minor line fishery that operates from Cape York east and south to the Victorian – South Australian border, including waters around Tasmania within the Australian Exclusive Economic Zone (EEZ) and the high seas waters of the Western and Central Pacific Fisheries Commission (WCPFC) (Fig. 1). The fishery primarily targets yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alulunga*), broadbill swordfish (*Xiphias gladius*) and striped marlin (*Tetrapturus audux*) with southern bluefin tuna (*Thunnus maccoyii*) also caught opportunistically during the winter months (although managed under an alternative regulatory plan). These six species are considered the key tuna and billfish species for the purposes of this study. In fishing for these species, the fishery also incidentally catches a range of other byproduct and bycatch species including, occasionally species that are protected under Australian environmental law (e.g. sea turtles, seabirds and marine mammals). In 2022, there were a total of 36 longline vessels active in the ETBF (Butler et al., 2023). Since 1 July 2015, all longline vessels must have operational EM technology installed (AFMA, 2020).

2.2. Australian Commonwealth electronic monitoring program

In the ETBF, the major EM program objectives include:

- verifying total catch and discards for all commercial and bycatch species as reported in logbooks,
- verifying total fishery interactions with ETP species, as well as bycatch handling practices and seabird mitigation (e.g. tori line deployment and night setting where necessary).

One of the key objectives of the EM program in the ETBF is to monitor interactions with seabirds, in order to determine spatially based capture rates and ensure they comply with reporting requirements under the Threat Abatement Plan (TAP) for the incidental catch (or bycatch) of

[1] An "interaction" is defined here as any physical contact a person, boat or gear has with a protected species including catching and colliding with any of these species. For further information, see: https://www.afma.gov.au/protected-species/endangered-and-threatened-species-reporting.

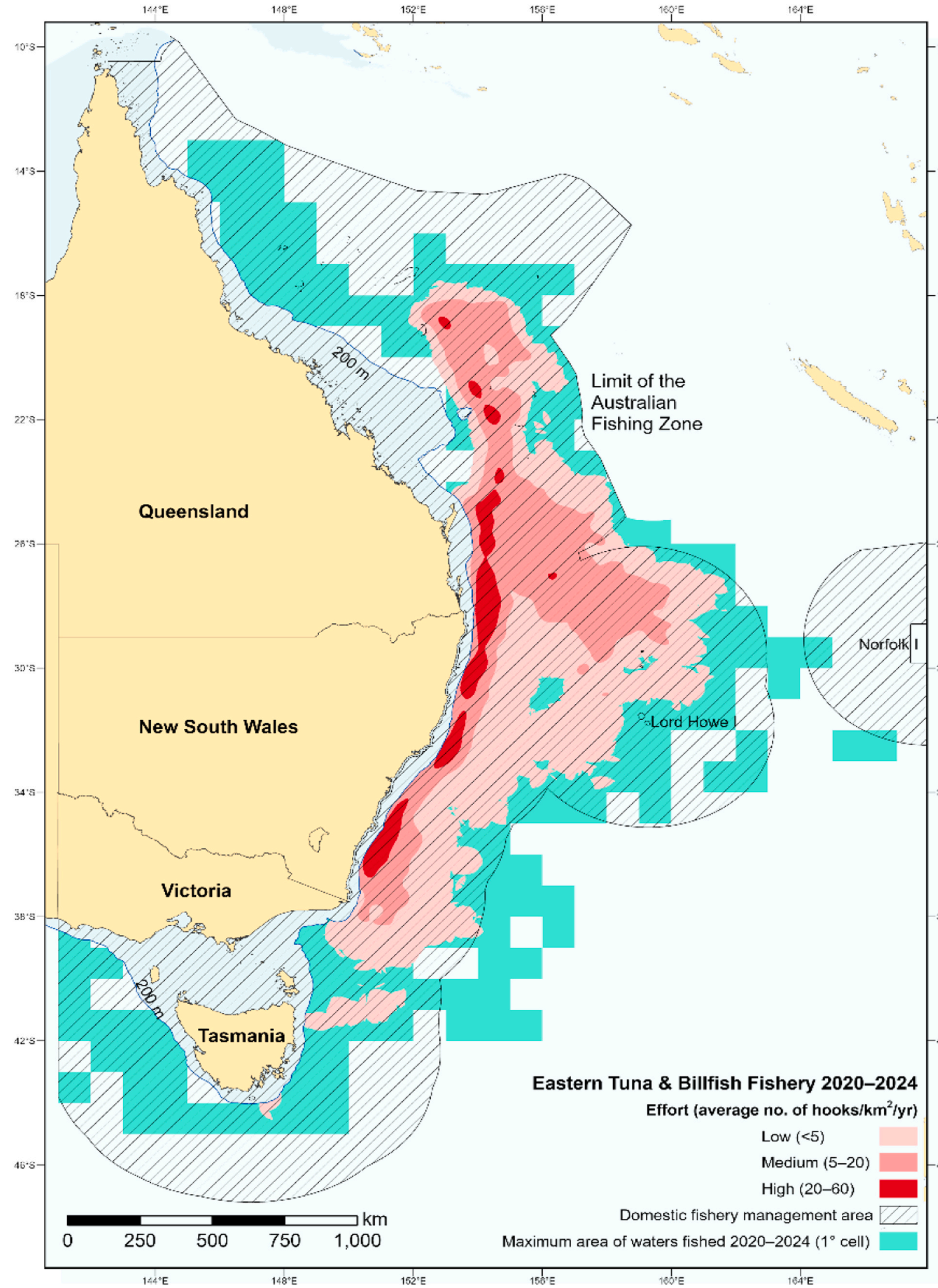

Fig. 1. Area and relative fishing intensity in the eastern tuna and billfish fishery between 2020 and 2024 calendar years.

seabirds during oceanic longline fishing operations (see: https://www.antarctica.gov.au/about-antarctica/environment/plants-and-animals/threat-abatement-plan-seabirds/). Individual vessels that fail to consistently avoid or minimise interaction rates with seabirds are subject to additional monitoring and mitigation requirements such as: daylight setting ban, amended line weighting, hook shielding devices, or a shift in area of operations (AFMA, 2019).

In the pursuit of the above objectives, The Australian Fisheries Management Authority (AFMA) instructs fishers to accurately record all catch composition (retained and discarded) in their daily fishing logbook or e-logbook, including any interactions with ETP species. Concurrently, AFMA requires EM systems to record all fishing activity and aims to review a minimum random 10 % of all the fishing haul events (hereafter termed "sets") on the hard drive (with a minimum of one set per vessel per month) (AFMA, 2020). The overall EM review coverage rates (percentage of hooks observed) in recent years (2021–2023) in the ETBF have been 9.9 %, 9.3 % and 9.3 % respectively (Butler et al., 2023). Electronic monitoring footage is reviewed by EM analysts from Archipelago Asia-Pacific (AAP) who are instructed to record the catch composition, discards, and all interactions with ETP species within each audited set along with their fate (retained/discarded) and life status (e.g., discarded alive and vigorous). All catch items are identified to the finest taxonomic level possible based on observing a specified number of distinguishing features. If an individual species cannot be identified to species level (e.g., yellowfin tuna), they are identified to the next lowest taxonomic level/group (e.g., tuna (mixed)).

Once an individual set has been reviewed by the EM analyst, the piece counts and fate of individuals are compared to logbook records and a series of data quality control checks are undertaken. 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, 2020). Furthermore, for around 10 % of sets initially reviewed, another EM analyst reviews the same set and compares the results, which allows data precision and EM analyst performance to be measured. The results of these quality control audits are for internal use only by AAP.

A "vessel feedback" report is generated for each hard drive that has been reviewed by AAP. This report consists of a comparison between EM-reported catch composition and logbook-reported catch composition (i.e. number of individuals). The report also records ETP species interactions that were identified during analyst review. These reports are provided to the vessels' nominated contact and relevant AFMA fisheries managers. There is also the possibility for an "untoward process" report to be generated following EM review, when there is found to be activity occurring that appears to be against the regulations imposed on the operators *inter alia*, for example, gross misreporting, or the system being turned off during fishing operations. This report is sent directly to the AFMA compliance team for further investigation.

Furthermore, since 1 January 2025, AFMA implemented a proactive approach to monitoring EM system use in near real time by integrating EM positional information and system health into the same software used to monitor vessel monitoring system (VMS) use. When an EM system does not poll to AFMA in this software, an AFMA officer will receive a notification and use VMS positional information to verify whether the vessel is in port or out fishing with a non-operational EM system. An AFMA officer will then contact the operator and has the option to direct the vessel to port if the issue cannot be resolved remotely. Over the short time this process has been implemented, AFMA has seen an increase in health statement data being received and system services being undertaken prior to fishing.

2.3. Data collation

EM analyst and fisher-reported logbook data from the ETBF were collated and aggregated by reviewed set for the period 1 July 2015–30 June 2020 to examine the level of congruence (i.e. similarity) in the data pertaining to the number of retained and discarded species, as well as number of interactions with ETP species. Sets with zero recorded EM and logbook observations (i.e., 0, 0) for either retained, discarded or ETP species were removed from the dataset for that specific species. This decision is aligned with other studies that have investigated the congruence between EM analyst and at-sea observer data (e.g. Briand et al., 2018; Forget et al., 2021; Ruiz et al., 2015), as retaining them in the dataset can inflate and consequently bias the congruence estimate. Following processing of the data there remained a total of 2226 linked EM audited, and logbook reported sets across the period assessed (Table 1).

2.4. Data analysis

To assess the level of congruence, analysis of set-level differences in counts (EM and logbook) were undertaken for various species of interest at both a fleet-wide and individual vessel level. This included key tuna and billfish species and ETP species. Noting that count data collected from either EM or logbook does not represent a "reference" or "true value" (Ames et al., 2007; Ruiz et al., 2015), two approaches were used to look at set-level differences.

The first approach evaluated congruence in two steps. Firstly, the difference between the EM and logbook counts of individuals was calculated (by subtracting the logbook count from the EM count) in each set, for each species and fate category (retained or discarded). Secondly, the mean difference in counts across all sets (for each species and fate category) was then calculated, including at each of the following grouping levels: whole fleet with all years combined; whole fleet by financial year (to evaluate changes over time); and individual vessels (all years combined).

The second approach then divided the mean difference in counts (above) by the mean catch per set, expressed as a percentage (see Table 2), where mean catch per set was calculated as the mean of the reported EM and logbook recorded individuals for each set. The second approach is important because, for a targeted species, such as tuna, a difference of five between EM and logbooks when 100 fish have been caught reflects good congruence, whereas a difference of five when only 10 fish are caught reflects poor congruence. Of course, for ETP species such as seabirds, the level of acceptance of differences in counts would be much lower.

Analysis of set-level differences in counts was undertaken using Bland-Altman plot analysis (Altman and Bland, 1983). The Bland-Altman analysis is frequently used in studies investigating the agreement and proportional bias between two quantitative measurement methods by studying the mean difference between the two methods (Forget et al., 2021). This graphical method was used to illustrate the difference between counts of an individual species from EM (K1) and logbook (K2). Scatterplots were made in which the X-axis represented the average number of retained/discarded individuals per set (i.e. average of EM and logbook recorded individuals), and the Y-axis represented the difference (K1 – K2) of the two measurements. Additionally, the mean bias (mean of K1 – K2) and its confidence limits (limits of agreement) were projected (2*standard deviation).

Finally, vessel level differences in logbook reporting were examined by looking at differences in counts as a proportion of average catch. This

Table 1
Number of audited linked sets by Australian financial year in the ETBF.

Fishery	Financial year (1 July-30 June)	Number of linked audited sets
ETBF	2015/2016	248
	2016/2017	495
	2017/2018	525
	2018/2019	486
	2019/2020	472

Table 2
Fleet-wide mean differences in counts between EM and logbook, average number (from both EM and logbook) reported caught per set, mean difference in counts as a proportion of average catch and proportion of zeroes reported by either EM or logbook across the time period examined for key tuna and billfish species in the ETBF. Note: a positive number indicates more were reported in EM and a negative number indicates more were reported in logbooks.

Species	Scientific name	Fate	Mean difference in piece counts	Average number reported caught in a set	Mean difference in counts as proportion of average catch	Proportion of 0 s reported by either logbook or EM
Albacore tuna	*Thunnus alalunga*	Retained	1.1 (±0.3)	18.5 (±1.4)	6 %	5 %
		Discarded	−1.2 (±0.3)	2.6 (±0.5)	−44 %	60 %
Bigeye tuna	*Thunnus obesus*	Retained	0.1 (±0.1)	4.2 (±0.3)	1 %	5 %
		Discarded	−0.8 (±0.2)	1.2 (±0.1)	−66 %	75 %
Southern bluefin tuna	*Thunnus maccoyii*	Retained	0.2 (±0.5)	37.3 (±6.0)	<1 %	2 %
		Discarded	−4.1 (±2.1)	10.9 (±3.3)	−37 %	36 %
Swordfish	*Xiphias gladius*	Retained	0.3 (±0.1)	5.0 (±0.2)	6 %	5 %
		Discarded	0.0 (±0.1)	1.5 (±0.1)	<1 %	50 %
Yellowfin tuna	*Thunnus albacares*	Retained	0.2 (±0.1)	11.0 (±0.6)	2 %	1 %
		Discarded	−1.9 (±0.2)	2.1 (±0.1)	−90 %	62 %
Striped marlin	*Kajikia audax*	Retained	< 0.1 (±<0.1)	1.7 (±0.1)	<1 %	6 %
		Discarded	−0.9 (±0.2)	0.8 (±0.1)	−119 %	79 %

ratio was graphically displayed to identify vessels whose reporting could be considered an “outlier” relative to the fleet. Note vessels were only included in the analysis where the selected species was recorded as either retained or discarded in ≥ 5 sets audited. All data analysis was undertaken using R (version 4.3.1).

3. Results

3.1. Key tuna and billfish

At a fleet-wide level, key retained tuna and billfish were reported in similar numbers by logbook and EM (Table 2, Fig. 2a). The mean difference as a proportion of the average number reported in a set was ≤ 6 % for all six species. There was also not a large proportion of sets (≤6 %) where zero individuals were being reported by a single data collection tool (i.e., EM) when ≥ 1 individual was reported by the other

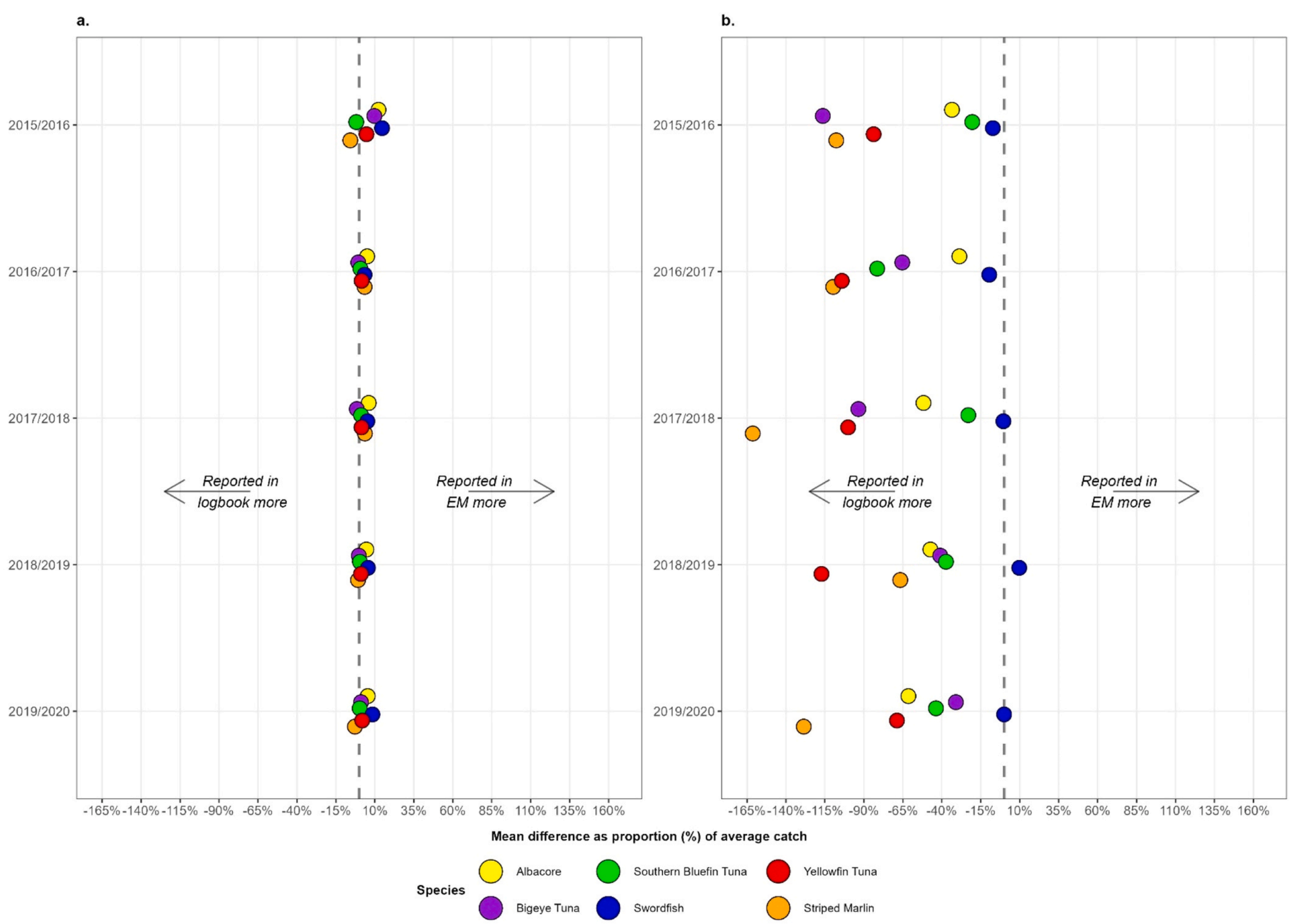

Fig. 2. The mean difference in retained (a) and discarded (b) fish counts as a proportion of the average catch (average of EM and logbook reported) per set for key tuna and billfish species in the ETBF, by financial year.

tool (i.e., logbook) (Table 2). Results from the Bland-Altman plot analysis indicate that most sets of key retained tuna and billfish had a mean difference (bias) close to zero, with many sets having no difference in logbook and EM counts (Fig. 3). For example, this included 74 %, 70 %, 69 % of all sets containing retained bigeye tuna, yellowfin tuna and swordfish respectively. The confidence intervals were also constrained with not a significant amount of variation among individual sets. Congruence was also stable temporally, with little difference observed in the mean difference in counts as a proportion of the average number reported in a set between 2016-17 and and 2019–20 financial years (Fig. 2a). When differences in counts between logbook and EM were observed in a single set these were typically around ~1–5 individuals depending on the species.

In contrast, at a fleet-wide level, congruence between EM and logbook reporting for key discarded tuna and billfish was lower (Fig. 2b). There were higher instances of zero reporting by one data collection tool where discarding was reported by the other and generally both the variation in the mean difference in counts and those expressed

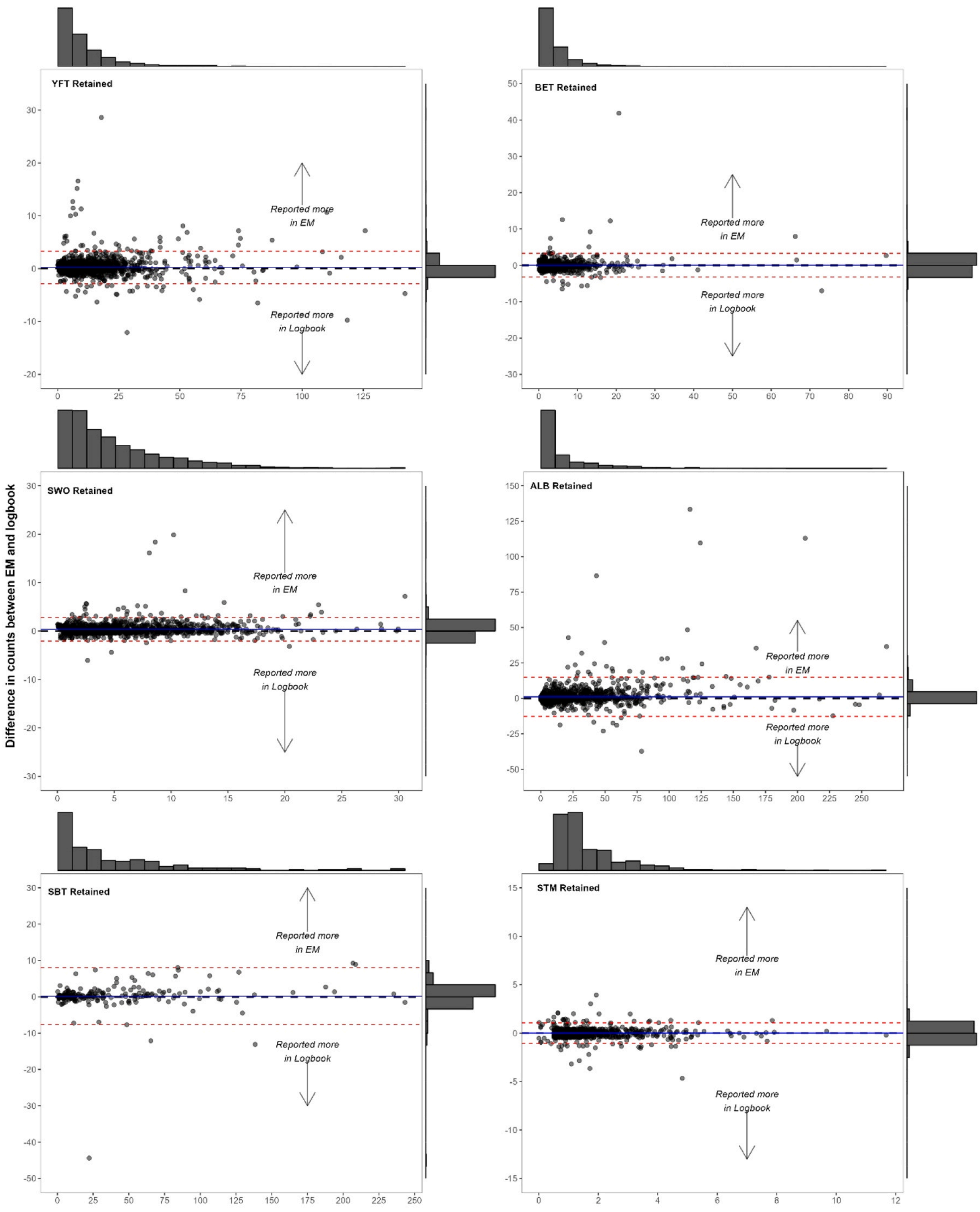

Fig. 3. Bland-Altman plots illustrating the mean difference in counts between EM and logbook recorded key retained tuna and billfish species in the ETBF and average no. of retained individuals per set. Solid blue lines represent the mean bias, red dotted lines represent the 95 % CI. The marginal histograms denote the frequency distribution of the X and Y variables.

as a proportion of the average catch were higher than for retained catch of the same species (Table 2, Fig. 2b). Apart from swordfish, there was also a large amount of temporal variation in the results for all key discarded tuna and billfish, but particularly for striped marlin between 2015-16 and and 2019–20 (Fig. 2b). In many instances discarded species were being reported by one data collection tool and not the other in the same set. This suggests discarded individuals are either being misreported or unreported by fishers, or the EM analyst. In most cases, logbooks were reporting much higher numbers of discarded individuals at the species level than EM (Table 2, Fig. 2b) (there were some exceptions to this, which are described further below).

Results from the Bland-Altman plot analysis indicate that apart from swordfish, most sets of key discarded tuna and billfish had a mean difference (bias) that was not close to zero, and had much greater variation among sets, with the confidence intervals much wider than for retained catch of the same species (Fig. 4). The Bland-Altman plot (Fig. 4) also indicates that for discarded southern bluefin tuna and striped marlin, the differences observed between EM and logbook reporting does not

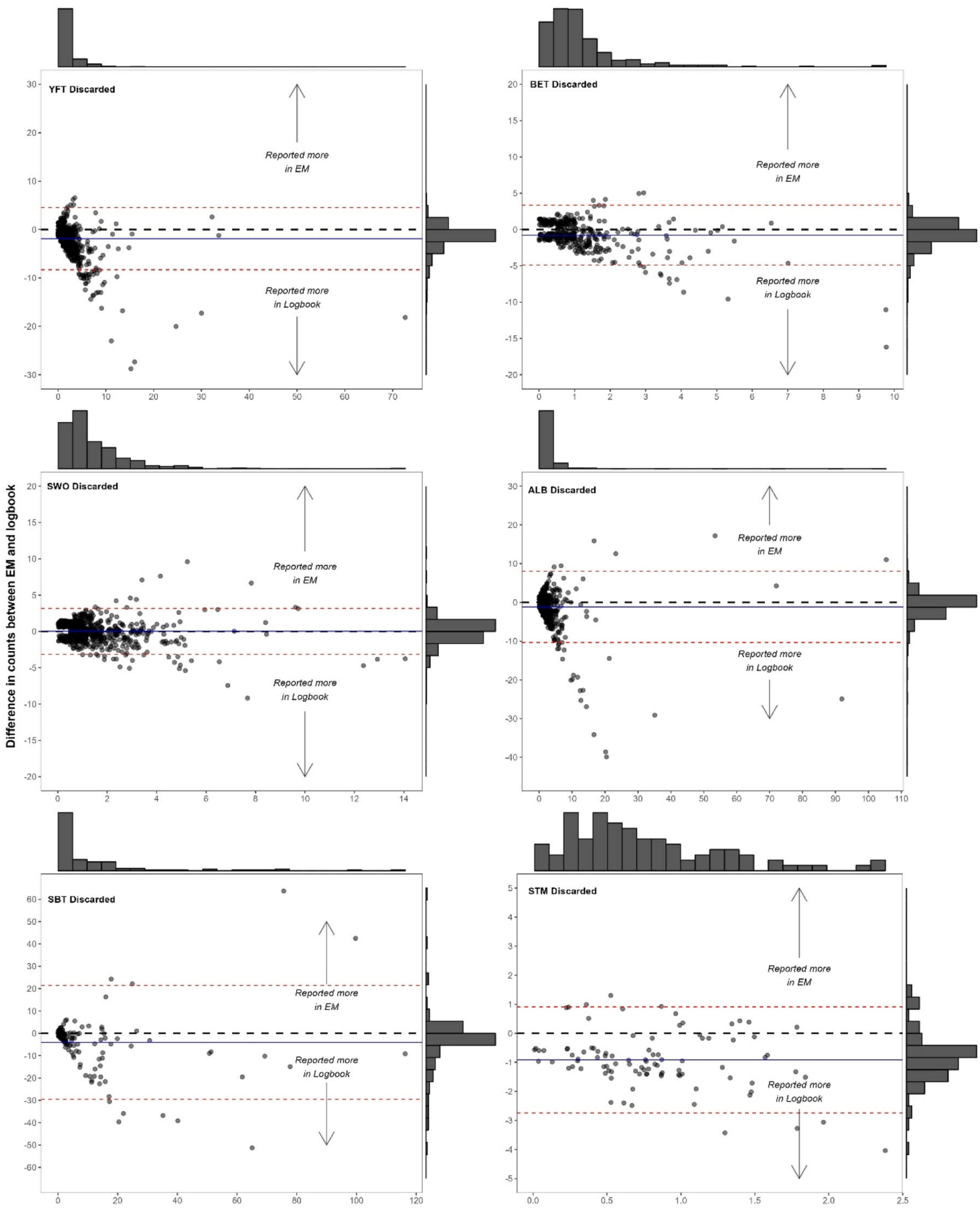

Fig. 4. Bland-Altman plots illustrating the mean difference in counts between EM and logbook recorded key discarded tuna and billfish species in the ETBF and average no. of discarded individuals per set. Solid blue lines represent the mean bias, red dotted lines represent the 95 % CI. The marginal histograms denote the frequency distribution of the X and Y variables.

depend on the magnitude of the measurement (i.e. average number discarded per set). In contrast, for yellowfin, albacore and bigeye tuna, there is a clear pattern, with the differences observed between EM and logbook reporting (skew towards logbook reporting more individuals) increasing as the average number of discarded individuals per set multiplies. This suggests that the congruence between the two data collection tools may vary for a particular species based on how many are being discarded in an average set.

To investigate whether the EM analyst was not observing individual discarded tuna species, or not able to identify them to a species level, the tuna species were grouped at a higher taxonomic level for analysis (Fig. 5). When examining discarded tuna (grouped) at a higher taxonomic level, overall congruence improved relative to the congruence observed for individual tuna species. This suggests the EM analyst was having difficulties in identifying discarded tuna to a species taxonomic level but was still observing tuna being discarded.

Only 12 %, 10 %, 25 % of all sets containing discarded bigeye tuna, yellowfin tuna and swordfish respectively had no difference in logbook and EM counts. When differences in discard counts between logbook and EM were observed in a single set, these were typically around ~1–5 individuals depending on the species but there was a clear skew in the frequency histograms towards logbooks reporting greater numbers discarded than EM (Fig. 4).

Vessel level analyses for retained catch indicated variation in average congruence between vessels for some species, but (with the exception of swordfish) that variation showed no consistent skew towards either data collection tool. For retained swordfish there were three vessels where EM analysts were recording much higher individuals per set than was recorded in the logbook (Table 3, Fig. 6) while numerous other vessels also showed a skew to EM, albeit to a lesser degree. For retained species there were some vessels (between 1 – 8 depending on the species) that had no difference in EM and logbook counts (i.e. perfect congruence over a 5-year period) (Table 3, Fig. 6).

Vessel level results for discarded catch indicated that not all vessels were skewed towards the logbook reporting more individuals than EM, which could be inferred from the fleet-level results for key tuna and billfish species. For example, two vessels had much higher EM counts of discarded yellowfin tuna than the rest of the fleet (Table 3, Fig. 7).

Table 3
Inter-vessel variation in fish counts as a proportion of the average catch (average of EM and logbook reported) per set for key tuna and billfish species in the ETBF.

Species	Fate	No vessels audited	Logbook counts > EM	Logbook = EM	EM counts > Logbook
Yellowfin tuna	Retained	41	11	5	25
	Discarded	31	29	0	2
Swordfish	Retained	38	2	5	31
	Discarded	23	11	1	11
Bigeye tuna	Retained	37	17	3	17
	Discarded	20	14	1	5
Southern bluefin tuna	Retained	14	5	2	7
	Discarded	8	7	0	1
Albacore tuna	Retained	41	9	1	31
	Discarded	29	16	2	11
Striped marlin	Retained	32	11	8	13
	Discarded	10	10	0	0

Similarly, there was a single vessel for both discarded bigeye tuna and southern bluefin tuna that had much higher EM counts than the rest of the fleet (Table 3, Fig. 7). Notably, while fleet-level statistics suggest high congruence of discarded swordfish, vessel level statistics identified several vessels with much higher EM counts than logbook (Table 3, Fig. 7). There was also a much lower number of vessels (between 0 and 2 depending on the species) that had no difference in EM and logbook counts (i.e. perfect congruence) (Table 3, Fig. 7), than occurred for retained species statistics. Of particular importance for managers was two to three vessels, which were serial non-reporters of discards across most species analysed.

3.2. Endangered, threatened and protected (ETP) species

A comparison of audited sets that interacted with an ETP species (Table 4, Fig. 8), found that a total of 45 %, 59 % and 55 % of all sets had no difference (between EM and logbooks) in counts for seabirds, marine mammals, and marine turtles, respectively. Where counts differed, there was no clear skew towards EM or logbook reporting more individuals than the other data collection tool. EM reported higher interaction

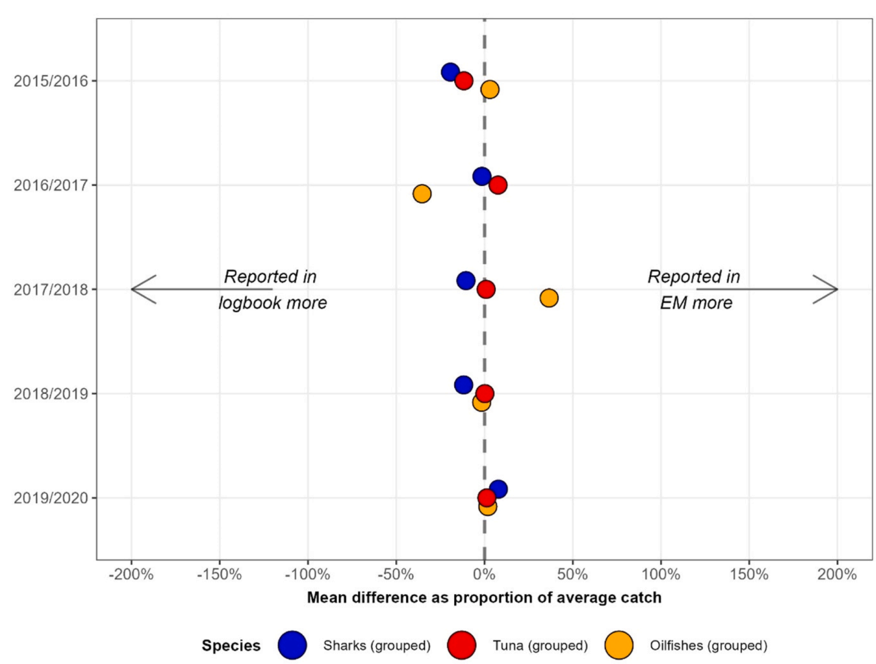

Fig. 5. The mean difference in discarded fish counts as a proportion of the average catch (average of EM and logbook reported) per set for discarded sharks (grouped), tuna (grouped) and oilfishes *Ruvettus spp*. (grouped) in the ETBF by financial year.

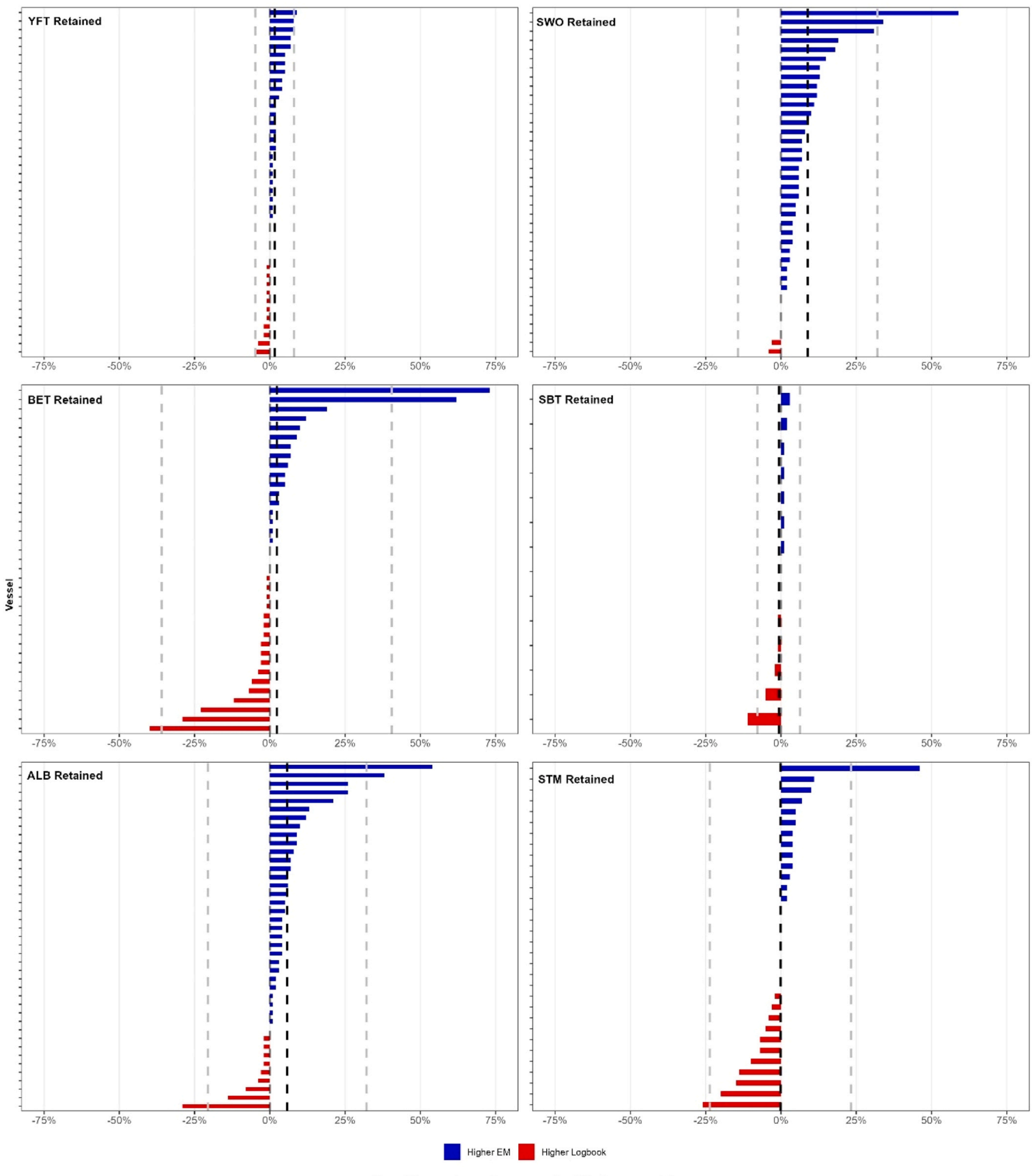

Fig. 6. The mean difference in counts as a proportion of the average catch of individual vessels for key retained tuna and billfish species in the ETBF. Note vessels were only included where the selected species was recorded as retained in ≥ 5 sets audited. Black dashed line is the fleet mean and grey dashed lines are 2*standard deviation (from the mean). A positive number indicates more were reported in EM and a negative number indicates more were reported in logbooks.

numbers (than logbooks) in a total of 29 %, 12 % and 19 % of all sets for seabirds, marine mammals, and marine turtles respectively.

For marine mammals, there were only two instances (from two different vessels) of EM reporting an interaction, which was not reported in the logbook (Fig. 8, Table 4). In contrast there were five instances of logbook reporting an interaction, which was not reported by EM from four different vessels (Table 4). For seabirds, there was 11 instances of EM reporting an interaction that was not reported in the logbook from 11 different vessels. In contrast there were 10 instances of logbook reporting an interaction, which was not reported by EM from six

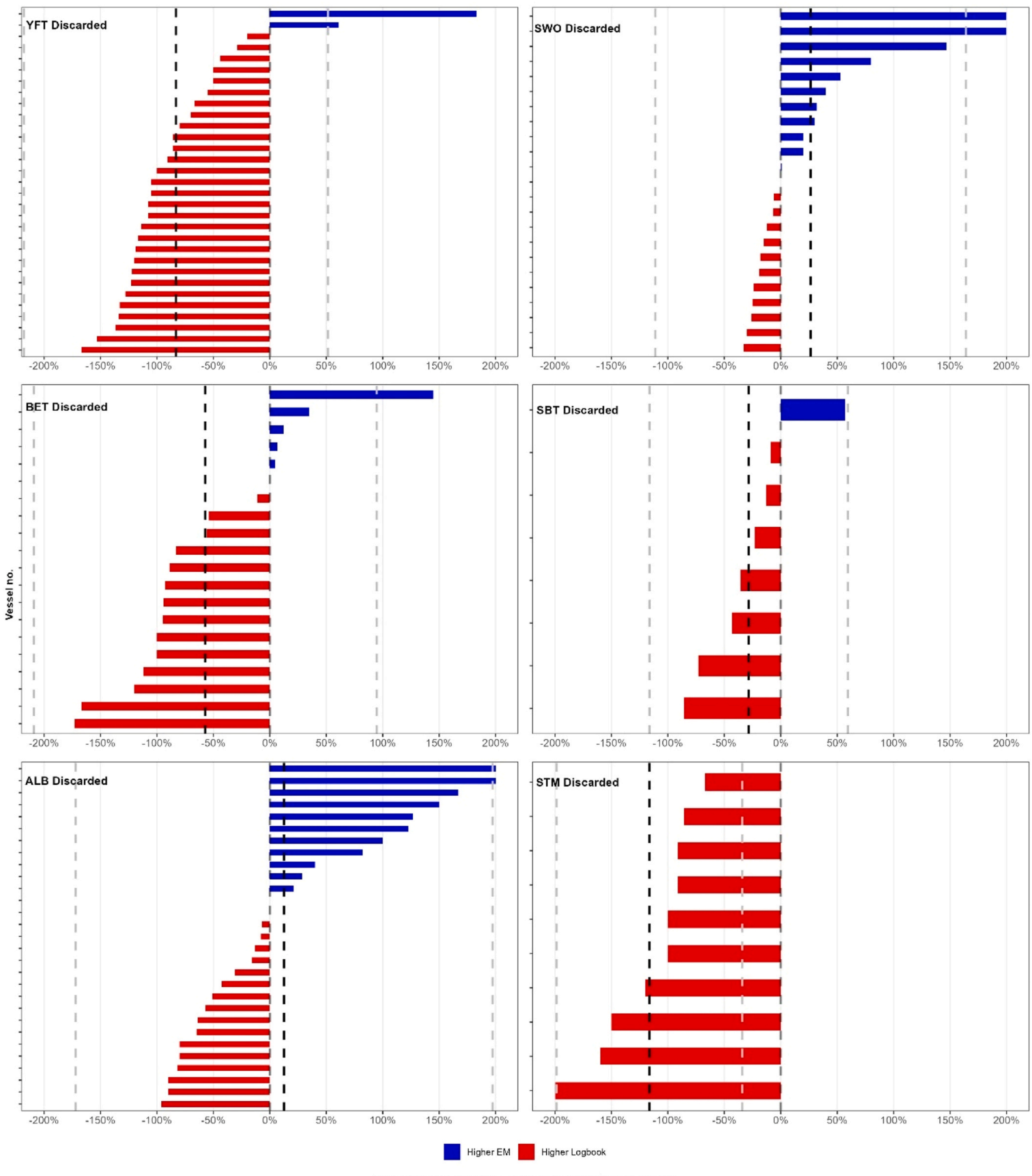

Fig. 7. The mean difference in counts as a proportion of the average catch of individual vessels for key discarded tuna and billfish species in the ETBF. Note vessels were only included where the selected species was recorded as discarded in ≥ 5 sets audited. Black dashed line is the mean and grey dashed lines are 2*standard deviation. A positive number indicates more were reported in EM and a negative number indicates more were reported in logbooks.

different vessels (Table 4). For marine turtles, there was 17 instances of EM reporting an interaction that was not reported in the logbook from 11 different vessels. In contrast there were 24 instances of logbook reporting an interaction, which was not reported by EM from 11 different vessels (Table 4).

Vessel level results identified variation in reporting (Fig. 9). Seven vessels had no differences in counts between EM and logbook (i.e. perfect congruence) (*FV3, FV5, FV10, FV12, FV13, FV21 and FV31*) across the five-year period. Conversely, there were some vessels where EM was reporting more individuals than the logbook and vice-versa. There was a

Table 4
The number of sets with differences in counts (where positive numbers = higher EM counts and negative numbers = higher logbook counts) across ETP groups in the ETBF.

TEP group	Difference in counts	No.
Seabirds	−2	2
	−1	8
	0	17
	+ 1	10
	+ 2	1
	No. audited sets	**38**
Marine mammals	−2	1
	−1	4
	0	10
	+ 1	2
	+ 2	0
	No. audited sets	**17**
Marine turtles	−2	0
	−1	24
	0	50
	+ 1	17
	+ 2	0
	No. audited sets	**91**

total of five vessels (*FV1, FV8, FV9, FV19 and FV24)* that had no reported interactions in the logbook, but EM analysts observed an interaction with ETP species across the five-year period (Fig. 9). Interestingly there was no overlap between the vessels that were poorly reporting of target species and discards and those non-reporting ETP interactions.

Reporting at the species level in the ETBF was mixed and it was clear that the EM analyst was having difficulty in identifying all interactions to a species level (Fig. 10). For marine turtles, while it seemed the EM analyst could identify leatherback turtles, there were more issues identifying hard-shelled marine turtles to a species level, resulting in them being classified as marine turtles (mixed). A similar result was also observed for seabirds and whales, where the EM analyst was more likely to label these interactions as birds or whales (mixed) respectively (Fig. 10).

Protected and no-take species of sharks (shortfin and longfin mako, porbeagle and silky shark) and marlins (blue and black marlin) were also assessed as part of this work (see, Emery et al., 2023) but the results were not included in this paper as it was evident the EM analyst was rarely, if ever, able to identify these sharks and marlins to a species level (noting they could still observe the interaction), with significantly higher numbers reported by fishers at the species level in their logbook across all years. This was previously reported in Emery et al. (2019b) and seemingly hasn't changed through time in the ETBF. This is likely due to the species being cut off (i.e., to avoid potential injury to the crew) or dropping off the line before the EM analyst is able to discern the key number of distinguishing features to appropriately identify it to a species level. It highlights one of the key limitations of EM (globally) that needs to be resolved so as to improve the collection of EM data on cut-offs/discards and this issue is not limited to solely pelagic longline fisheries (see, e.g. Forget et al. 2021).

4. Discussion and conclusions

The results of this work highlight the importance of assessing congruence between EM and logbook records at a vessel-level, rather

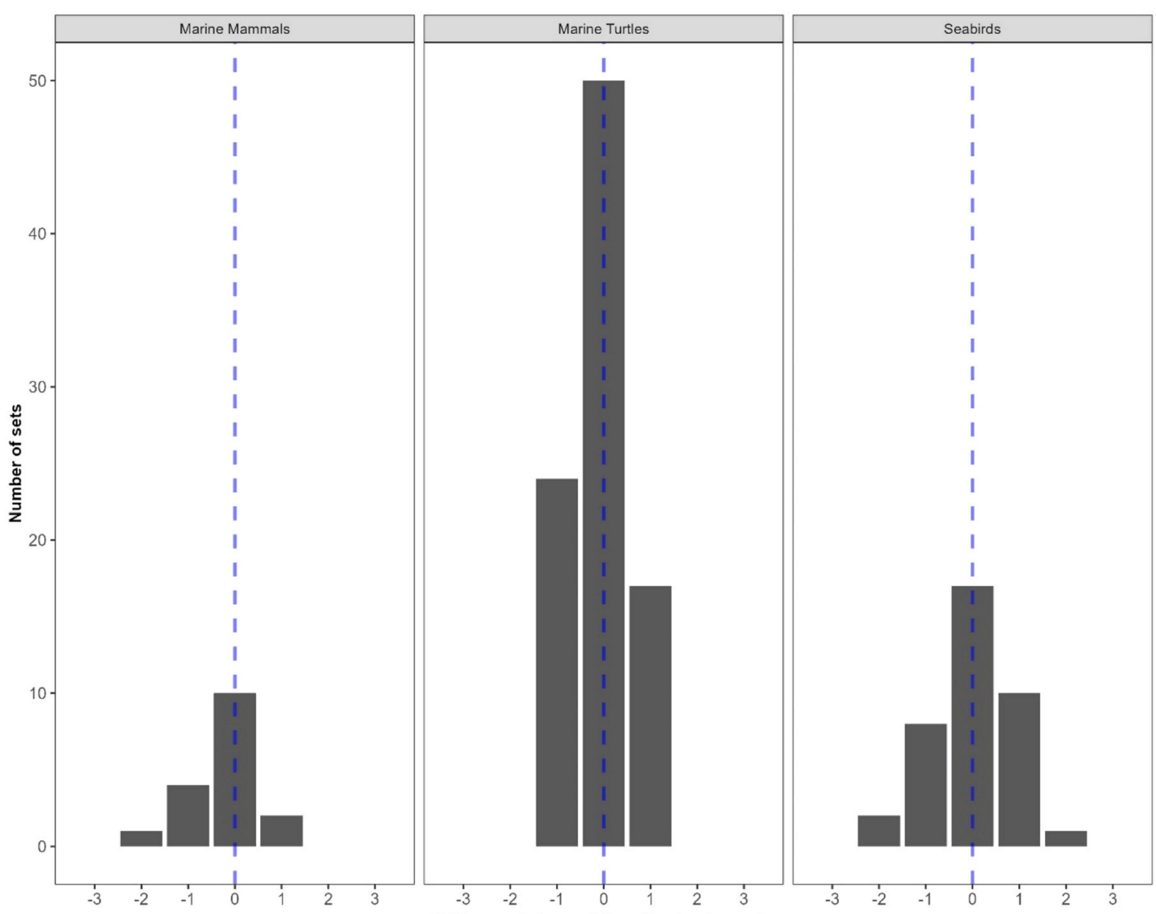

Fig. 8. Frequency histograms of the difference in counts between EM and logbook for individual sets across ETP groups in the ETBF (where positive numbers = higher EM counts and negative numbers = higher logbook counts).

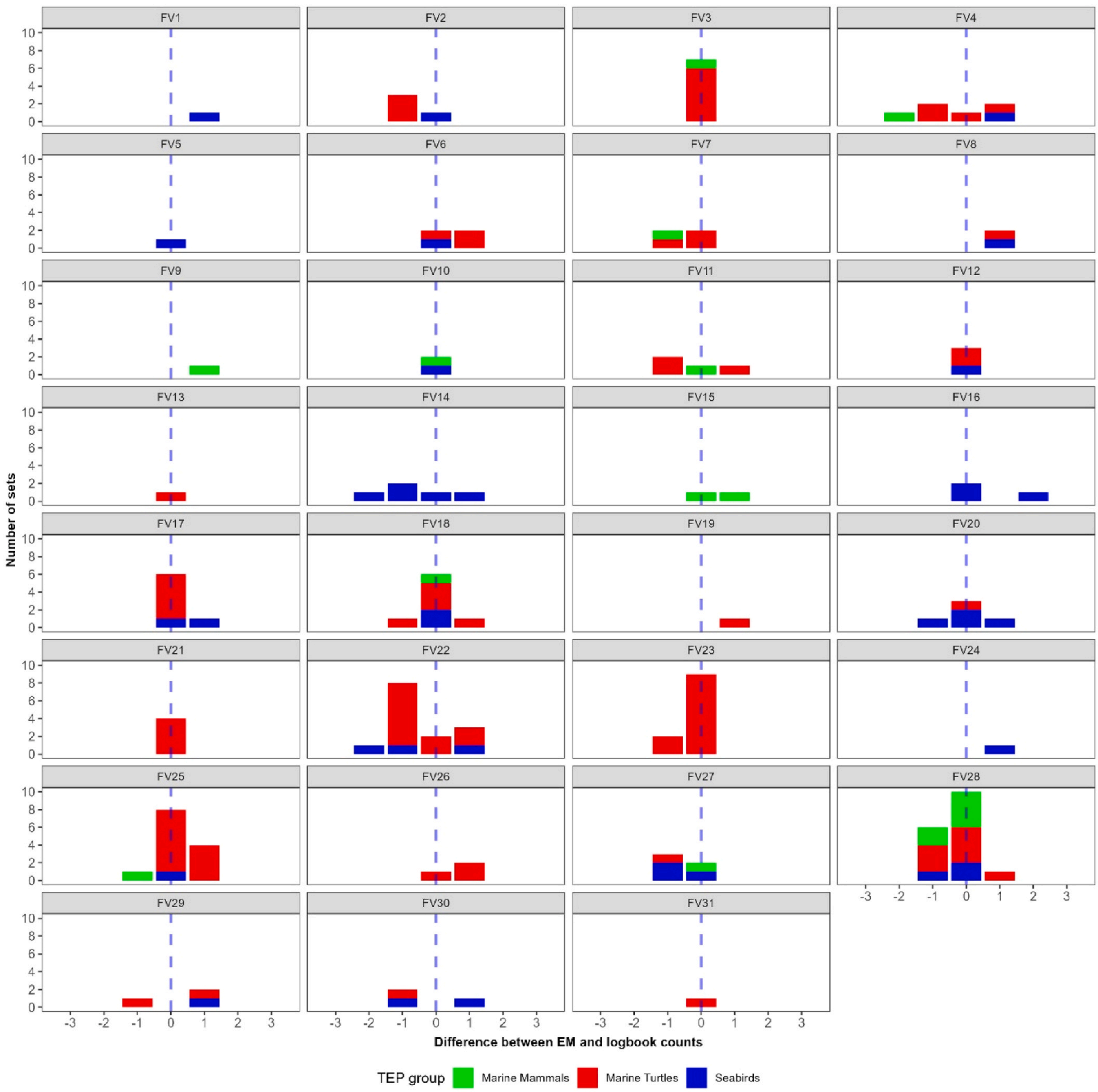

Fig. 9. Frequency histograms of the difference in counts between EM and logbook for individual sets across ETP groups in the ETBF by individual vessel (where positive numbers = higher EM counts and negative numbers = higher logbook counts).

than simply across the entire fleet. In this study, while EM and logbook reporting of some retained key tuna and billfish species appeared to be relatively similar at the fishery level when comparing mean differences in counts, once examined at the vessel level, it was evident some vessels had higher logbook counts and others had higher EM counts. In saying that it is also entirely possible in this scenario for each of the data collection tools to be underestimating the actual interactions, as we don't know the true value.

Disparity at the vessel level was even more pronounced for discarded key tuna and billfish species in contrast to discarded species groups (e.g. tuna grouped). While there was a clear skew towards logbook reporting higher discard numbers than EM at a fleet level, this was not reflective of all vessels in the fleet, with some vessels not reporting any discards, despite discards being reported by EM. This absence of reporting by a minority of vessels was also evident for ETP groups (e.g. seabirds), however, it wasn't the same group of vessels. It is not yet clear why these interactions were not being reported by fishers, nor why the non-reporting vessels differed between tuna/billfish and ETP species. There was much greater overlap in (the same) vessels non-reporting of discards across the different key tuna and billfish species. Notably, for both retained and discarded key tuna and billfish species and ETP species there was a small group of vessels that had perfect congruence across all audited sets over the five-year period.

We surmise that the disparity in congruence between logbook and EM in our study is likely to be driven by one or several factors including: (i) a skipper's skill in species identification and/or diligence in reporting, as well as handling/operational practices of catch/bycatch on deck, (ii) an EM analyst's skill in species identification, and; (iii) on-board

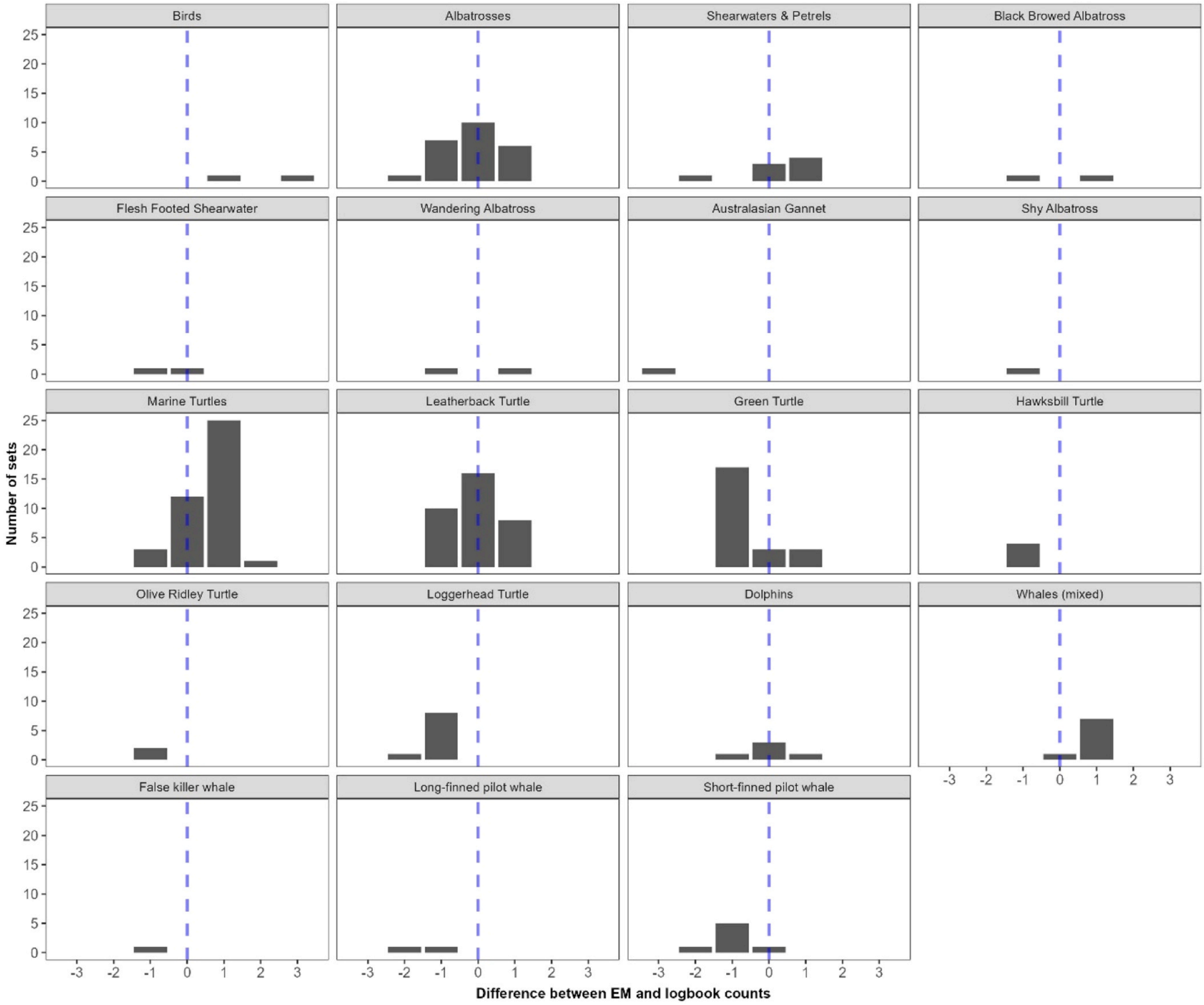

Fig. 10. Frequency histograms of the difference in counts between EM and logbook for individual sets across ETP species in the ETBF (where positive numbers = higher EM counts and negative numbers = higher logbook counts).

camera placement and vessel layout, particularly in the haul area. Each of these potential different drivers is discussed in more detail below.

Precise taxonomic identification is crucial to assessing fish stocks (Faunce, 2011; Ruiz et al., 2015), whether that be by stock assessment for key commercial species or ecological risk assessment methods for byproduct and bycatch species. A skipper's skill in identification of marine species will be influenced by their length of tenure, interest and experience in the fishery, coupled with the amount of education and training provided by the managing authority or industry and advocacy groups (e.g. the distribution of species identification guides for onboard the vessel). For retained catch of key tuna and billfish species in our study there are unlikely to be identification issues as all species were targeted and easily distinguishable. Similarly, given target species would be regularly processed in the hauling station area, they were more likely to be observed by multiple cameras, in good light conditions and visible to the EM analyst reviewing the footage (Emery et al., 2019b). The higher EM counts for retained catch of key tuna and billfish species, for several vessels in this study, were more likely due to a lack of diligence in logbook reporting. This result is not surprising when studies have highlighted the heterogeneity among fishers in respect to diligence in logbook reporting (Macbeth et al., 2018). Research undertaken prior to the introduction of EM, by Bromhead et al. (2005), comparing human observer and logbook data, identified significant potential under-reporting of both retained and discarded catch of a number of species (such as albacore and yellowfin tuna) in the ETBF at that time. While the introduction of EM subsequently led to improved logbook reporting, particularly of discards, in the fishery generally (Emery et al., 2019a), it's clear from this current vessel level study that some individual vessels still lack sufficient diligence in logbook reporting (as evidenced by higher EM reports of retained catch and discards).

Identification issues were likely more prevalent for discarded catch of key tuna and billfish species, with results skewed towards the logbook reporting more than EM at the fleet level. While heterogeneity in EM analyst skill in detecting and identifying discarded species is likely a contributing factor, further investigation identified that the EM analyst was often observing these individuals being discarded but was having difficulties in identifying them to a species level and subsequently reporting them at a higher taxonomic level (Emery et al., 2023). In practice, many of the discarded species in the ETBF are released without being brought on board the vessel, often to maximise the survivability of the animal being released. This means that it is often impossible for the EM analyst to observe the necessary number of distinguishing features to identify the animal to a species level. While simply a factor of being released in the water would restrict the EM analyst's view, these identification issues can often also arise due to poor image quality caused by external factors such as weather, waves and lighting, or the quality of the camera systems (Evans and Molony, 2011; Mangi et al., 2015; van Helmond et al., 2015; Wallace et al., 2013). A similar issue was observed by Briand et al. (2018) in French tropical tuna purse-seine fisheries where recording individuals to a species level was difficult when cameras were not near discard operations, or discard operations occurred outside the full view of the camera. Furthermore, when species are damaged (through depredation), and key distinguishing features are not observed from the available imagery, EM analysts are often instructed to group these damaged catch items up to the next taxonomic group during EM review (Carnes et al., 2019; Emery et al., 2023). It is hoped that camera placement will continue to improve through time, particularly as AFMA implements operational standards for EM hardware (AFMA, pers comm. 2025). AFMA will routinely update all Vessel Monitoring Plans (VMPs) to a similar standard to that which is required for vessels currently fishing in the Indian Ocean Tuna Commission (IOTC) area of competence. This describes the numbers of cameras, sensors, displays their position on board and settings, and key areas to be monitored for fishing activities, catch handling, species identification, fate and storage of the individuals (see: *IOTC Resolution 23/08*). AFMA will then have a greater understanding of camera placement on board and be able to confirm if system tampering events have occurred during video review (AFMA, pers comm. 2025). Despite the clear skew towards the logbook reporting more individual discarded tuna and billfish at the species level than EM (which improved when grouped at a higher taxonomic level), there was still significant inter-vessel variability in our study. Importantly, there was evidence of persistent non-reporting of discarded catch by a small number of vessels (2−3) in their logbooks, despite the EM analyst reporting discarded individuals. This is likely a result of a lack of diligence in logbook reporting.

A combination of factors, such as identification issues, reporting diligence, on-board camera placement and vessel layout were possibly responsible for the variation in congruence observed among vessels in reporting of ETP groups (i.e., seabirds, marine turtles, marine mammals). Accurate reporting is imperative to understand the magnitude of interactions with ETP species to ensure fishing is not likely to adversely affect their conservation status. However, in this study, for fishing operations where either EM and/or logbooks recorded an ETP interaction, there was a total of 55 %, 31 % and 45 % of all sets with differences in counts (i.e., $\pm$1–2 individuals) for seabirds, marine mammals, and marine turtles respectively. Importantly, there was again inter-vessel variation in reporting, with some vessels having perfect congruence (i.e., no difference in counts) and others where EM was reporting more individuals than the logbook. Interestingly, it was not the same vessels that had non-reporting or poor reporting of discards that had higher EM counts of ETP species. For seabirds, marine turtles, and marine mammals there was a total of 11, 11 and 2 vessels respectively (out of total 31 with audited sets) that had higher numbers of interactions being reported by EM compared to logbook. It is unclear why these interactions were not being reported in logbooks by these vessels. 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 being observed by the fishers, but cameras were placed appropriately to capture these interactions (Kindt-Larsen et al., 2012). While it is possible these differences may be caused by missed observations, its possibly less likely on longline vessels where the fishers will typically need to dehook or cut the line to enable ETP species to go free, and as such it could also be a result of incomplete or inaccurate logbook reporting, which has previously been shown to be an issue specifically for ETP species (e.g. Basran and Sigurðsson, 2021; Brown et al., 2021; Goldsworthy et al., 2010). There was also evidence for occasional instances where fishers reported ETP interactions that were missed by EM. This can occur for a range of reasons, including vessels not maintaining and cleaning cameras, gaps in data for key camera views due to system functionality issues, as well as short term weather conditions that prevented clear EM views.

It was evident that EM analysts were having difficulty in identifying all interactions to the species level for both key tuna and billfish and ETP species. For example, while it seemed that the EM analyst could identify leatherback turtles (due to clear distinguishing features), there were more issues identifying hardshell marine turtles to a species level, resulting in them being classified as marine turtles (mixed). This could be a result of most turtles being released without being bought on board the vessel as per turtle release guidelines. This was similarly observed in the Hawaiian longline fisheries by Carnes et al. (2019) with the EM analyst unable to identify hardshell turtles to a species level because they were unable to observe the necessary number of characteristics from the video footage. Although not included in this paper, shark species reporting congruence was analysed (Emery et al., 2023), with similar identification issues apparent for specific shark species (shortfin, longfin mako, silky and porbeagle shark), as well as blue marlin and black marlin, where the EM analyst was not able to identify these to a species level. For these species, significantly higher numbers were being reported at the species level by fishers in their logbook, which hasn't changed through time (Emery et al., 2023). This was likely due to the species being cut off in the water (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 either detection or identification by the EM analyst. 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 Carnes et al. (2019) observed a large number of "unknown catch events" being recorded by the EM analyst in Hawaiian longline fisheries, which they surmised were most likely shark interactions.

While it remains unclear if fishers are more adept at species identification of ETP species than the EM analyst, results suggest fishers are willing to report them to a species taxonomic level with more regularity than the EM analyst, who is required to observe the necessary number of distinguishing features from the video footage, before recording a species level ID. Therefore, what has become clear through numerous studies in the ETBF (e.g. Emery et al., 2023; Emery et al., 2019b) is that the EM data is unable to provide an insight into likely ETP species composition comparable to other data collection tools, perhaps with the exception of leatherback turtles. This has implications for species-specific reporting requirements and relevant analyses. Solutions to improving EM identification of discarded and ETP species that are cutoff or released in the water clearly need to be developed, where this doesn't compromise the survivability of the individual that was captured. One alternative implemented by AFMA to visually identifying seabird bycatch was requiring feather samples (from dead seabirds) to be collected by the crew for DNA analysis and precise species identification (Polanowski et al., 2023). Unfortunately, this program was ceased due to the health risks associated with the potential to contract avian influenzas when handling seabirds. Another possible, innovative solution is the use of underwater cameras in combination with overhead cameras on longline vessels. Trials in the Gulf of Mexico commercial reef fin fishery of a dedicated underwater camera indicated that it was a successful tool for capturing clearer images of released large (>2 m) sharks, with EM analysts able to improve individual species identification, determination, and fate by 34.4 % compared to traditional EM analyst review using overhead cameras (Neidig et al., 2024). For small (<2 m) sharks, the underwater camera, provided an additional view to use with the overhead camera for accurately documenting fate at discard (Neidig et al., 2024). Given the disparity observed in the congruence of reported discarded key tuna and billfish species and ETP species, it is important that managers confirm the key drivers through conducting further investigation and outreach, including via skipper/crew interviews, vessel inspections and discussions with EM reviewers. While we have discussed the most likely drivers here, in most cases, these cannot be confirmed without further information or investigation. For those cases, it is recommended that managers investigate and seek further information from stakeholders (EM providers, industry and scientists) to confirm these factors, which will then inform the subsequent management actions needed to improve congruency in the future. This should be undertaken at the vessel-level because there are many instances where only a small number of vessels have higher, or lower, logbook reported catch/discards levels (relative to EM reported levels), while the rest of the fleet display high congruency. Furthermore, examination of the skipper reporting practices, and specific configuration of EM systems found on vessels with high congruence, might in some cases inform advice and solutions for vessels with low congruence.

Importantly, while we have identified discrepancies in congruence between EM and logbook at the vessel level, it is not clear whether these differences are “acceptable” to managers. Generating prescribed tolerance levels for reporting of retained, discarded catch and ETP species' interactions through the development of quantitative evaluation standards, such as those established in Canadian fisheries (Stanley et al., 2011) are therefore an important step in ensuring individual accountability and improving management efficiency. For example, this can then be used to identify outperforming and underperforming vessels (in regards to both EM and logbook) for further investigation or corrective action and allow for the adoption of a risk-based approach to resource prioritisation (Parsa et al., 2020).

When quantitative evaluation standards are in place, and the vessel specific drivers of identified incongruences in data are identified (via follow-up skipper interviews, EM service provider discussions and vessel inspections), actions can be taken to resolve those issues and improve EM and logbook reporting. The nature of such actions will depend on the issues identified for each vessel. For example, for issues involving poor species identification in logbooks, managers can conduct further outreach activities to remind fishers about their reporting responsibilities and/or educate them in species identification/taxonomy. The implementation of feedback (communication) loops between EM analysts, managers and fishers on reporting standards and identification are important to improve performance.

The capability of EM analysts to accurately identify and determine the fate of species (retained/discarded) can also be improved, where necessary, through additional species identification training (including from qualified experts e.g. at sea observers, scientists) particularly for species for which identification is more difficult. Periodic audits can also be conducted on EM analyst reports (by secondary reviewers) to ensure consistency and maintenance of high-quality EM data through time. Where drivers of EM based species identification issues are vessel based (e.g. poor or obstructed camera angles, views, resolution), improvements can be achieved by adding/moving/modifying camera positions and angles on those vessels, ensuring vessels remove objects obstructing camera views, or requiring fishers to process and/or discard fish within view of the camera.

In conclusion, this work highlights the importance of assessing congruence at a vessel-level to identify vessels with general (i.e. universal) or specific (e.g. particular species) logbook or EM reporting deficiencies. However, it also emphasises the need for managers to investigate the underlying processes causing the difference in reporting between vessels within the fleet and using that knowledge to engage in targeted interventions that improve reporting behaviour and the ability of the EM analyst to observe interactions and identify species on the vessel. Ultimately this approach will improve data inputs for scientific analyses and the fisheries management decisions that rely on them.

CRediT authorship contribution statement

Mahdi Parsa: Writing – review & editing, Conceptualization. **Rocio Noriega:** Writing – review & editing, Conceptualization. **Trent Timmiss:** Writing – review & editing, Supervision. **Don Bromhead:** Writing – review & editing, Supervision. **Emery Timothy:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Tim Emery reports financial support was provided by Australian Fisheries Management Authority. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

The data that has been used is confidential.

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