

1 **Measuring congruence between electronic monitoring and**
2 **logbook data in Australian Commonwealth longline and gillnet**
3 **fisheries**

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14

15 **Abstract**

16 Electronic monitoring (EM) has the capacity to collect fisheries-dependent data to support
17 fisheries management decision-making. Following successful pilot studies, EM was
18 introduced into several Australian Commonwealth fisheries in 2015, including the Eastern
19 Tuna and Billfish Fishery (ETBF) and the Gillnet, Hook and Trap (GHAT) sector of the
20 Southern and Eastern Scalefish and Shark Fishery (SESSF). We compared two years of EM
21 analyst and fisher-reported logbook data from the ETBF and GHAT sector to examine the
22 level of congruence in reporting of both retained and discarded catch and protected species
23 interactions. In general, congruence between EM analyst and fisher-reported logbook data
24 in both the ETBF and GHAT sector was higher for retained than for discarded catch, and
25 the ETBF had a higher level of data equivalency than the GHAT sector. Fishery-wide
26 estimates of congruence, however, concealed a large amount of variation among individual

27 and groups of species. EM analyst and fisher-reported logbook data were highly congruent
28 for some species (e.g. tunas, swordfish and gummy shark), but for others there were clear
29 taxonomic (e.g. escolar and rudderfish), identification (e.g. sharks, marlins) and reporting
30 (e.g. draughtboard shark and elephantfish) issues, which reduced overall congruence. There
31 was evidence of increased congruence through time, particularly for discarded bycatch
32 species in the GHAT sector, due presumably to increased manager feedback and
33 communication with fishers on their logbook reporting. While EM analyst and fisher-
34 reported logbook interactions with protected species in the GHAT sector were equivalent,
35 this was not the case for species other than seabirds in the ETBF. In the ETBF, a greater
36 number of interactions were reported by fishers in their logbooks, suggesting a need to
37 modify existing or install additional EM technology to improve on-board vision for the EM
38 analyst. It is important to review the performance of any integrated EM system through time
39 to ensure it is fulfilling the data requirements for the fishery and meeting the overall
40 objectives of the program.

41 **Key words:** *fisheries management, electronic monitoring, cameras, at-sea observers,*
42 *gillnet, longline, bycatch, discards, protected species*

43

44 **1. Introduction**

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

51 At-sea observers have traditionally been used to independently monitor commercial
52 fisheries and collect data for science, management and compliance purposes (McElderry,
53 2008). Depending on the objectives of the observer program, this may include data on catch
54 composition, fishing effort, vessel characteristics, protected species interactions, species
55 biology (i.e. length and age frequency) and the use of mitigation measures and devices.
56 Despite their versatility, scheduling and logistical difficulties associated with placing
57 observers on board vessels, as well as financial costs (Ames, 2005; Evans and Molony, 2011;
58 WCPFC, 2016), have often been implied as leading to lower than anticipated coverage levels
59 (Clarke et al., 2013; Williams et al., 2016), coverage that is non-representative of fishing
60 effort (Babcock and Pikitch, 2003; Gilman et al., 2017; Nicol et al., 2013) or simply
61 considered sub-optimal in meeting legislative or management objectives (Evans and
62 Molony, 2011; Gilman, 2011; Larcombe et al., 2016).

63 Over the last two decades, technological advancements in fisheries monitoring have led to
64 the implementation of electronic monitoring (EM) in a variety of fisheries as both a
65 replacement and supplement to at-sea observers (Larcombe et al., 2016; NMFS, 2017; Ruiz
66 et al., 2015). EM is a combination of hardware and software that collects records in an
67 automated manner, which is closed to external or manual input (Dunn and Knuckey, 2013).

68 On the vessel, EM technology consists of a central computer, combined with several gear
69 sensors and video cameras that are capable of monitoring and recording fishing activities
70 (McElderry, 2008; Ruiz et al., 2015). The records are stored and can be independently
71 reviewed later onshore by an EM analyst for both management and compliance purposes.
72 Typically, the footage is either used to census all, or review a proportion (which can then be
73 extrapolated or raised), of fishing effort to estimate catch composition and/or to audit a
74 proportion of fishing effort to verify fishing logbooks (Mangi et al., 2015). To improve
75 readability, we use the term *integrated EM system* in this paper to jointly describe the
76 technological (i.e. on-board camera and sensors) and logistical (i.e. on-shore analysis of
77 records) aspects of EM.

78 Historical fishery-dependent data collection tools in Australian Commonwealth fisheries
79 have included fishing logbooks, at-sea observers, catch disposal records (landing records)
80 and in-port sampling (Larcombe et al., 2016). More recently, an integrated EM system was
81 introduced in several fisheries by the Australian Fisheries Management Authority (AFMA)
82 as a replacement for at-sea observers from 1 July 2015. Two of these fisheries included the
83 Eastern Tuna and Billfish Fishery (ETBF) and the Gillnet Hook and Trap (GHAT) sector of
84 the Southern and Eastern Scalefish and Shark Fishery (SESSF). While the integrated EM
85 system in the GHAT sector was initially used as a replacement for at-sea observers when
86 fishing within the Australian Exclusive Economic Zone (EEZ), in September 2017, at-sea
87 observers were re-introduced primarily to collect biological data for ageing purposes
88 (AFMA, 2017c). Under the current program, AFMA uses the integrated EM system to
89 validate fisher-reported logbook information with an audit target of 10% of sets (defined
90 here as the haul of catch from a single set) from each vessel. This audit includes an analysis

91 of catch composition, discards and interactions with protected species¹ (AFMA, 2015a).
92 Through the auditing process and accompanying feedback to fishers, AFMA aims to
93 independently validate fisheries logbook information so that it can be trusted (or not) as a
94 source of data for assessing and managing fisheries. This aspiration to validate logbook
95 reporting is due to the acknowledgement by AFMA that fisher-reported logbook data can be
96 inaccurate, particularly for discarded and protected species (Larcombe et al., 2016). For
97 example, Macbeth et al. (2018) identified systemic issues with respect to the accuracy of
98 fisher reporting of sharks when comparing at-sea observer and fisher-reported logbook data
99 in an Australian demersal shark longline fishery, while Hamer et al. (2008) highlighted
100 significant underreporting in fisher-reported logbooks of short-beaked dolphin (*Delphinus*
101 *delphis*) encirclements and mortalities in an Australian sardine fishery. Inaccuracies in the
102 logbook can be caused by underreporting or non-reporting of catches and/or
103 misrepresentation of the species composition of catches (Macbeth et al., 2018). These
104 inaccuracies can be a result of *inter alia*, variation in species identification competency
105 among skippers, high catch volumes and species richness making it logistically difficult to
106 accurately record all catch, and fears of compliance action and/or increased regulation
107 because of reporting interactions with protected species (Mangi et al., 2016; Sampson,
108 2011).

109 Various pilot studies and trials have indicated that integrated EM systems in both longline
110 (e.g. ETBF) and gillnet (e.g. GHAT) fisheries are capable of *inter alia*, independently
111 verifying catch composition and monitoring interactions with protected species (Ames et al.,
112 2007; Lara-Lopez et al., 2012; McElderry, 2008; McElderry et al., 2003; Stanley et al.,

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”

113 2015). Furthermore, there is evidence that integrated EM systems, when used as an audit
114 tool, can improve both the accuracy and timeliness of fisher-reported logbook data
115 (Larcombe et al., 2016; Stanley et al., 2011).

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

135 The greatest risk for the AFMA EM Program not meeting its key objectives would be if the
136 EM analyst has difficulty recording all retained and discarded catch and protected species
137 interactions, which would be observed by fishers in their audit report (through reduced

138 numbers of individuals reported by EM relative to logbook) and potentially create a
139 disincentive for fishers to accurately report in the future. Therefore, it is important to identify
140 where discrepancies in data reporting occur, and to determine how the integrated EM system
141 could be modified or fisher-logbook reporting improved to increase congruence in the future
142 and ensure that the data requirements for the fisheries, and overall objectives of the AFMA
143 EM program, are being met.

144

145 **2. Methods**

146 *2.1 Description of fisheries*

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

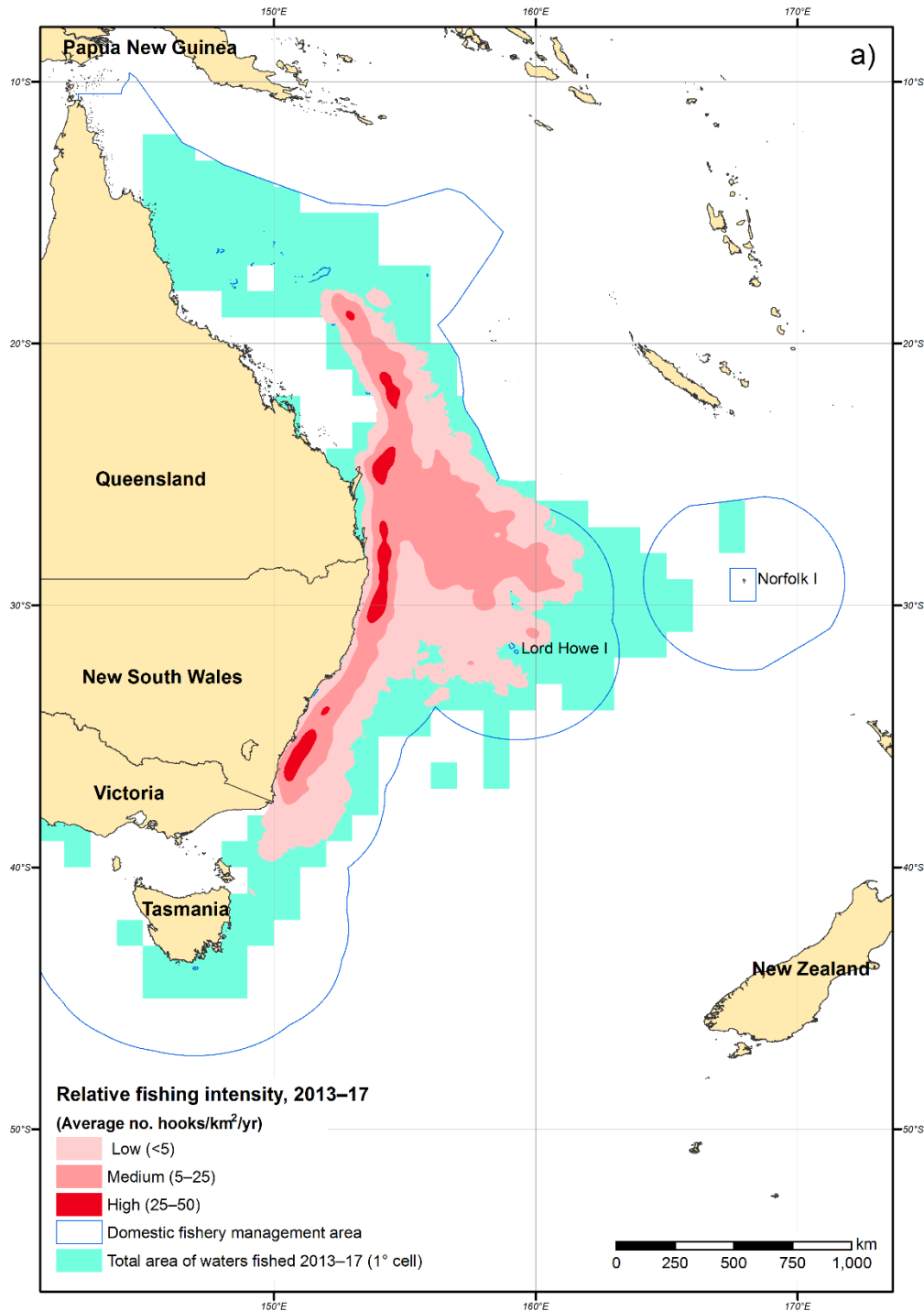
156 The GHAT sector is a demersal trap, gillnet, demersal longline, dropline and auto-longline
157 fishery that operates in waters south of the New South Wales – Victorian border, around
158 Tasmania and west to the South-Australian-Western Australian border targeting gummy
159 shark (*Mustelus antarcticus*)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

162 than 50 days in the previous or current fishing season must have operational EM technology
163 installed, while manual longline vessels must have fished for more than 100 days.

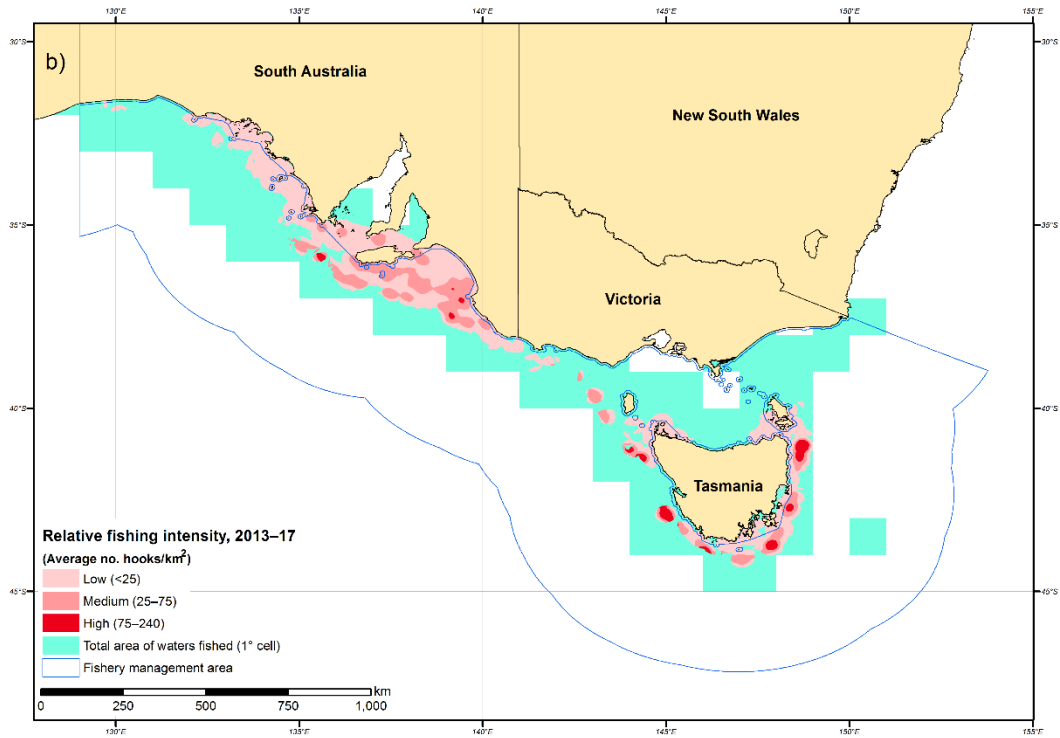
164 In both fisheries, AFMA instructed fishers to accurately record all catch composition
165 (retained and discarded) in their daily fishing logbook, along with any interactions with
166 protected species. These requirements have not changed in the years prior to and during the
167 operation of the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

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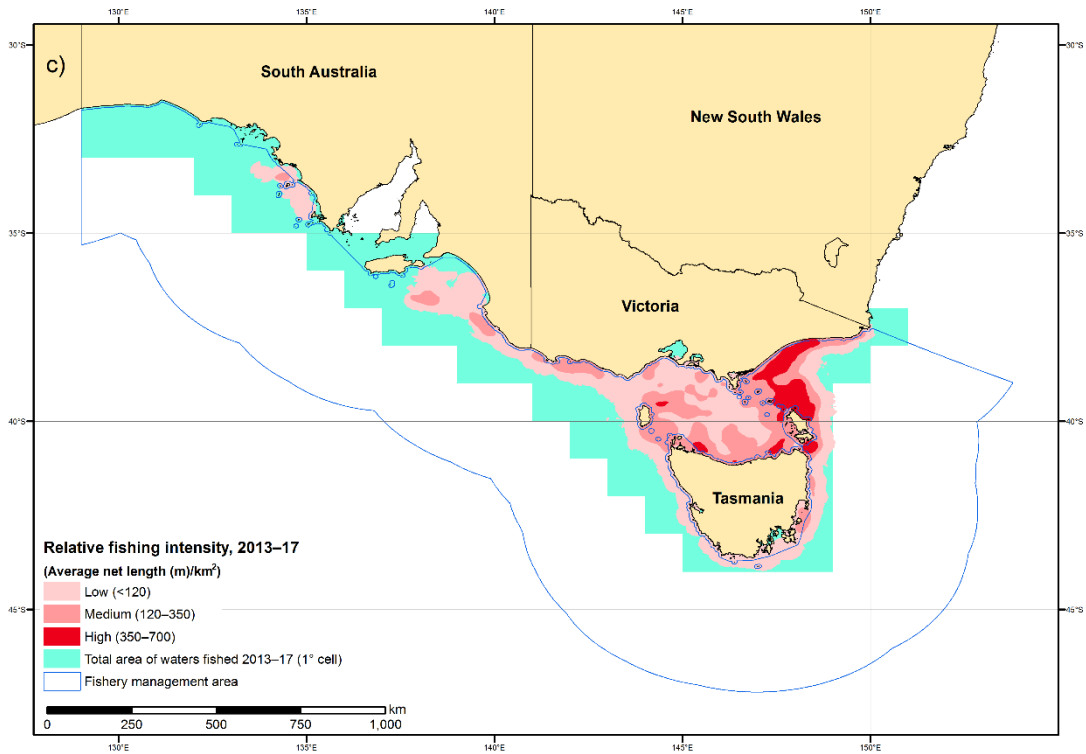
168 **Figure 1.** Area and relative fishing intensity in the: (a) eastern tuna and billfish fishery (b) line sector
 169 of the gillnet hook and trap and; (c) gillnet sector of the gillnet hook and trap between 2013 and 2017
 170 calendar years.



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175 2.2 *Electronic monitoring service provider*

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

191 2.3 *Data collection*

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

197 All data were collated and aggregated by set and the total number of species (individual or
198 species group) caught as reported by both the EM analyst and fisher in their logbook. Species

199 were classified based on their role in the fishery – target, byproduct and bycatch (see Table
200 1). Target species were those species identified by AFMA (AFMA, 2017a), while byproduct
201 species were those that were retained for sale more often than discarded (total numbers) in
202 the 2015/16 fishing season. All other species were classified as bycatch, as they were
203 discarded more often than retained in 2015/16. As fishers in the GHAT sector were only
204 required to record in their logbook the estimated weight (not count) of individual species up
205 until April 2016, there were several records with missing count data. Records that contained
206 both weight and count data were used to calculate the average weight of an individual
207 species and then used to estimate the number of individual species caught for those records
208 with only estimated weight data. All subsequent data analysis was undertaken using R
209 (version 3.2.0).

210 *2.4 Data analysis*

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

$$217 \quad [1] \quad EM \sim L * Y + \varepsilon$$

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

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

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

$$228 \quad [2] \quad D^2 = \frac{(\text{Null deviance} - \text{Residual deviance})}{\text{Null deviance}}$$

229

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

233 The regression slope, y-intercept and standard deviation of the residuals were estimated and
234 the fitted model was compared to the expected 1:1 relationship (slope of 1, y-intercept of 0).

235 Where the confidence intervals encompassed or approached 0 for the intercept and 1 for the
236 slope, the data reported from EM and logbooks were considered to be congruent (Pineiro et
237 al., 2008). The main effect of Y and the interaction between L and Y were used to evaluate
238 whether the intercept and/or the slope of the relationship between EM and logbook data
239 varied between years respectively.

240

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

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

243

244 To explore the difference in reporting for individual species and interactions with protected
 245 species, we calculated the percentage difference in reported catches from fishers in their
 246 logbook and EM analysts rather than use GLMs, because the number of observations were
 247 too low and variance too high. The percentage difference was calculated as the difference
 248 between the number of individuals reported by the EM analyst and by fishers in logbooks
 249 divided by the number of individuals reported by the method with the greatest number. For
 250 example, if fishers reported 38 individuals in their logbook and the EM analyst reported 53

251 individuals across one set, the percentage difference would be $(38 - 53)/53 = -0.28$ or -28%,
252 meaning that the EM analyst reported 28% more individuals than fishers in their logbook
253 for that set. While a multitude of studies use at-sea observers as a standard of comparison
254 for measuring congruence (Ames et al., 2007; Briand et al., 2017; Chavance et al., 2013;
255 Ruiz et al., 2015), we felt that using the higher-reported number of individuals from either
256 method was more appropriate given there should be no incentive for either to over-report
257 total numbers and both the fisher-reported logbook and EM analyst (and at-sea observer)
258 data have their own unique suite of errors (Kindt-Larsen et al., 2012) and there is no true
259 standard of reference or precise benchmark from which to measure accuracy (Ames et al.,
260 2007; Ruiz et al., 2015).

261

262 **3. Results**

263 *3.1 Fishery*

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

274 In contrast, congruence between EM analyst and fisher-reported logbook data in the GHAT
275 (gillnet, auto-longline and set-longline) sector was not high for both retained and discarded
276 catch (Table 2 and Figures 2c and 2d). On average, the EM analyst reported greater numbers
277 of retained and discarded individuals per set than were reported in logbooks. This was
278 particularly evident for discarded individuals, with zero or very small catches reported in
279 logbooks when larger catches were reported by the EM analyst (Figure 2d and
280 Supplementary Material – Figure S1c and S1d). However, for both retained and discarded
281 catch, there was evidence of significant improvement in congruence in 2016/17 relative to
282 2015/16. Model fits, particularly for discarded catch ($D^2 = 0.20$) were poor, however,
283 indicating that there was a large amount of deviance that was not accounted for by the model.

284 *3.2 Species group (target, byproduct and bycatch)*

285 For retained target species in both the ETBF and GHAT (gillnet, auto-longline and set-
286 longline) sector, congruence between EM and fisher-reported logbook data was high (Table
287 3 and Figures 3a and 3b). On average, it was not possible to detect a difference in reported
288 retained target species between fisher-reported logbooks and the EM analyst in both
289 fisheries. For retained byproduct species, the congruence was not as high as for target species
290 in both the ETBF and GHAT sector (Table 3 and Figures 3c and 3d). Fishers in both the
291 ETBF and GHAT sector reported more individuals in their logbook, on average, than the
292 EM analyst, when reporting more than approximately 10 and 9 catch items in the ETBF and
293 GHAT sector respectively in 2015/16 (Supplementary Material – Figure S2c and S2d).
294 While there was no significant difference in congruence between years in the GHAT sector,
295 there was a slight improvement in the ETBF in 2016/17. For retained bycatch species, the
296 model fit in the ETBF was poor ($D^2 = 0.14$) (Table 3), and there was a large number of sets
297 for which fishers reported 0 or 1 catch items in their logbook, but the EM analyst reported
298 catches up to 43 catch items (Figure 4e and Supplementary Material – Figure S2e). In the
299 GHAT sector, the EM analyst reported greater numbers of retained bycatch species than was
300 reported by fishers in their logbooks but there was a significant improvement in congruence
301 in 2016/17 relative to 2015/16 (Figure 3f).

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

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

322

323 **Table 2.** Summary statistics and estimated parameter outputs from the GLM regression between EM
 324 analyst and logbook reporting for fishery-level comparison of sets (N = number of sets observed, D²
 325 = deviance explained by the model).
 326

Fate	Fishery	N	D ²	Parameters	Estimates	Confidence Intervals		P-value
						2.5%	97.5%	
Retained	ETBF	745	0.91	Intercept	5.03	3.54	6.71	<0.001
				Logbook	1.01	0.96	1.06	<0.001
				Year	-3.69	-5.60	-1.89	<0.001
				Logbook*Year	-0.01	-0.08	0.05	0.77
	GHAT	1110	0.57	Intercept	73.14	53.94	95.06	<0.001
				Logbook	0.55	0.35	0.77	<0.001
				Year	-46.92	-70.86	-24.85	<0.001
				Logbook*Year	0.36	0.10	0.61	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	1110	0.20	Intercept	81.36	67.64	96.76	<0.001
				Logbook	0.50	0.15	1.02	0.05
				Year	-26.94	-44.85	-9.91	0.003
				Logbook*Year	0.36	-0.20	0.77	0.20

327

328

329 **Table 3.** Summary statistics and estimated parameter outputs from the GLM regression between
 330 EM analyst and logbook reporting for groups of retained species by set (N = number of sets
 331 observed, D² = deviance explained by the model).

Fishery	Role	N	D ²	Parameters	Estimates	Confidence Intervals		P-value
						2.5%	97.5%	
ETBF	Target	733	0.92	Intercept	3.30	2.38	4.35	<0.001
				Logbook	1.01	0.96	1.05	<0.001
				Year	-2.81	-3.95	-1.73	<0.001
				Logbook*Year	0.01	-0.05	0.06	0.86
	Byproduct	669	0.80	Intercept	2.03	1.30	2.94	<0.001
				Logbook	0.76	0.66	0.87	<0.001
				Year	-1.63	-2.60	-0.81	0.003
				Logbook*Year	0.06	-0.08	0.19	0.45
	Bycatch	745	0.14	Intercept	3.11	2.40	3.95	<0.001
				Logbook	0.81	0.34	1.50	0.01
				Year	-1.08	-2.02	-0.22	0.02
				Logbook*Year	0.02	-0.77	0.76	0.95
GHAT	Target	1054	0.96	Intercept	1.44	0.65	2.46	0.006
				Logbook	0.95	0.92	0.98	<0.001
				Year	0.78	-0.42	1.86	0.24
				Logbook*Year	0.02	-0.02	0.07	0.26
	Byproduct	968	0.64	Intercept	2.17	1.23	3.37	<0.001
				Logbook	0.72	0.60	0.85	<0.001
				Year	0.05	-1.33	1.29	0.95
				Logbook*Year	-0.10	-0.24	0.05	0.22
	Bycatch	1109	0.56	Intercept	43.06	29.48	59.80	<0.001
				Logbook	0.68	0.31	1.20	0.002
				Year	-25.24	-43.14	-9.67	0.003
				Logbook*Year	0.38	-0.19	0.85	0.14

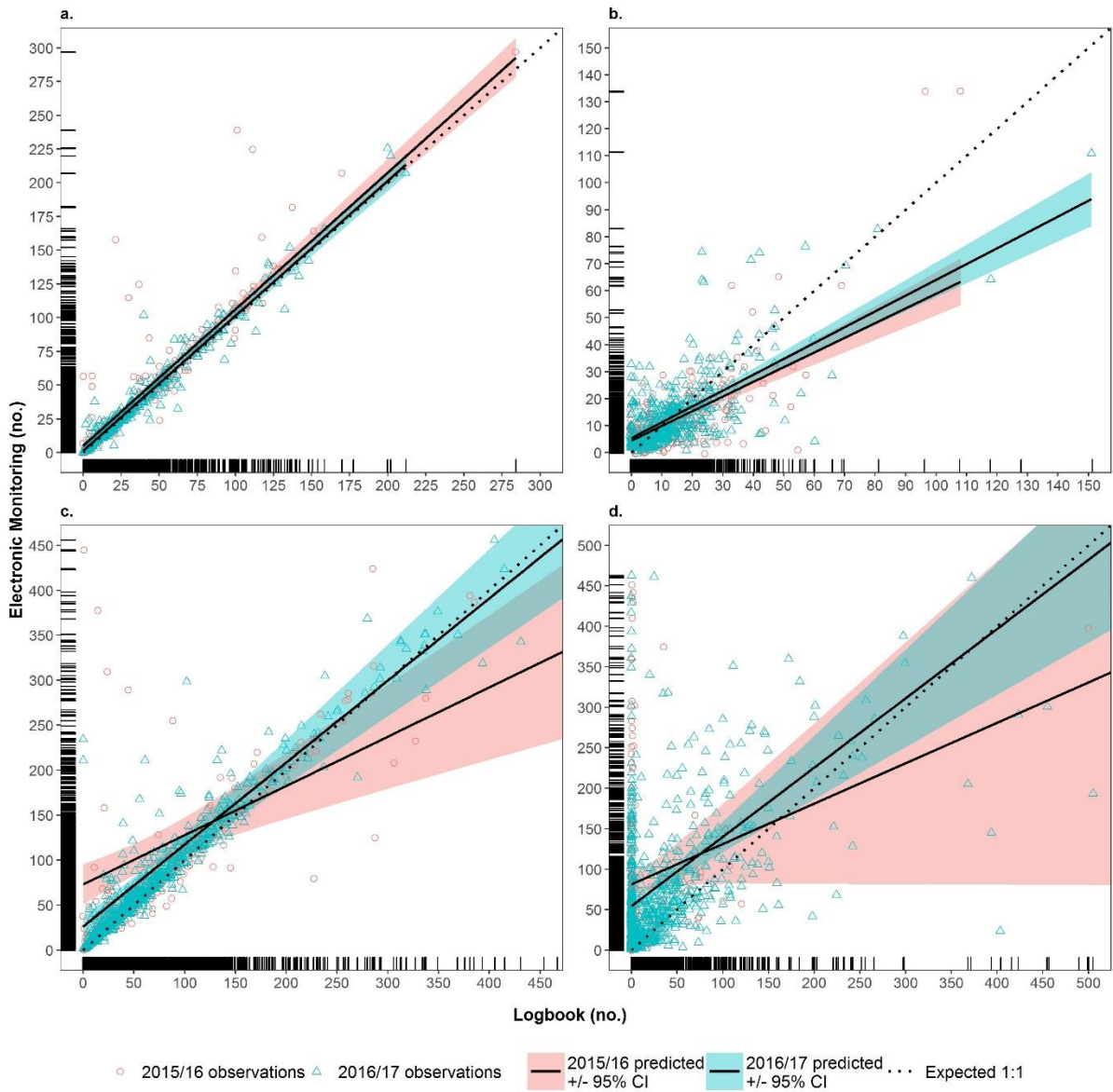
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333 **Table 4:** Summary statistics and estimated parameter outputs from the GLM regression between
 334 EM analyst and logbook reporting for groups of discarded species by set (N = number of sets
 335 observed, D^2 = deviance explained by the model).

Fishery	Role	N	D^2	Parameters	Estimates	Confidence Intervals		P-value
						2.5%	97.5%	
ETBF	Target	732	0.46	Intercept	0.68	0.50	0.90	<0.001
				Logbook	0.29	0.24	0.35	<0.001
				Year	-0.24	-0.48	-0.03	0.04
				Logbook*Year	0.11	0.02	0.19	0.02
	Byproduct	671	0.54	Intercept	0.18	0.10	0.29	0.001
				Logbook	0.52	0.43	0.64	<0.001
				Year	0.01	-0.12	0.12	0.90
				Logbook*Year	-0.37	-0.49	-0.26	<0.001
	Bycatch	745	0.36	Intercept	5.48	4.24	6.87	<0.001
				Logbook	0.46	0.32	0.61	<0.001
				Year	0.49	-1.16	2.06	0.56
				Logbook*Year	0.11	-0.06	0.28	0.20
GHAT	Target	1054	0.14	Intercept	0.52	0.31	0.72	<0.001
				Logbook	0.17	-0.05	0.40	0.13
				Year	-0.16	-0.39	0.08	0.19
				Logbook*Year	0.04	-0.20	0.27	0.76
	Byproduct	968	0.29	Intercept	2.56	1.59	3.85	<0.001
				Logbook	0.60	0.19	1.26	0.04
				Year	-0.62	-2.05	0.61	0.37
				Logbook*Year	0.09	-0.60	0.58	0.78
	Bycatch	1109	0.21	Intercept	78.41	64.82	93.72	<0.001
				Logbook	0.56	0.17	1.14	0.04
				Year	-26.84	-44.52	-10.09	0.003
				Logbook*Year	0.35	-0.26	0.81	0.24

336

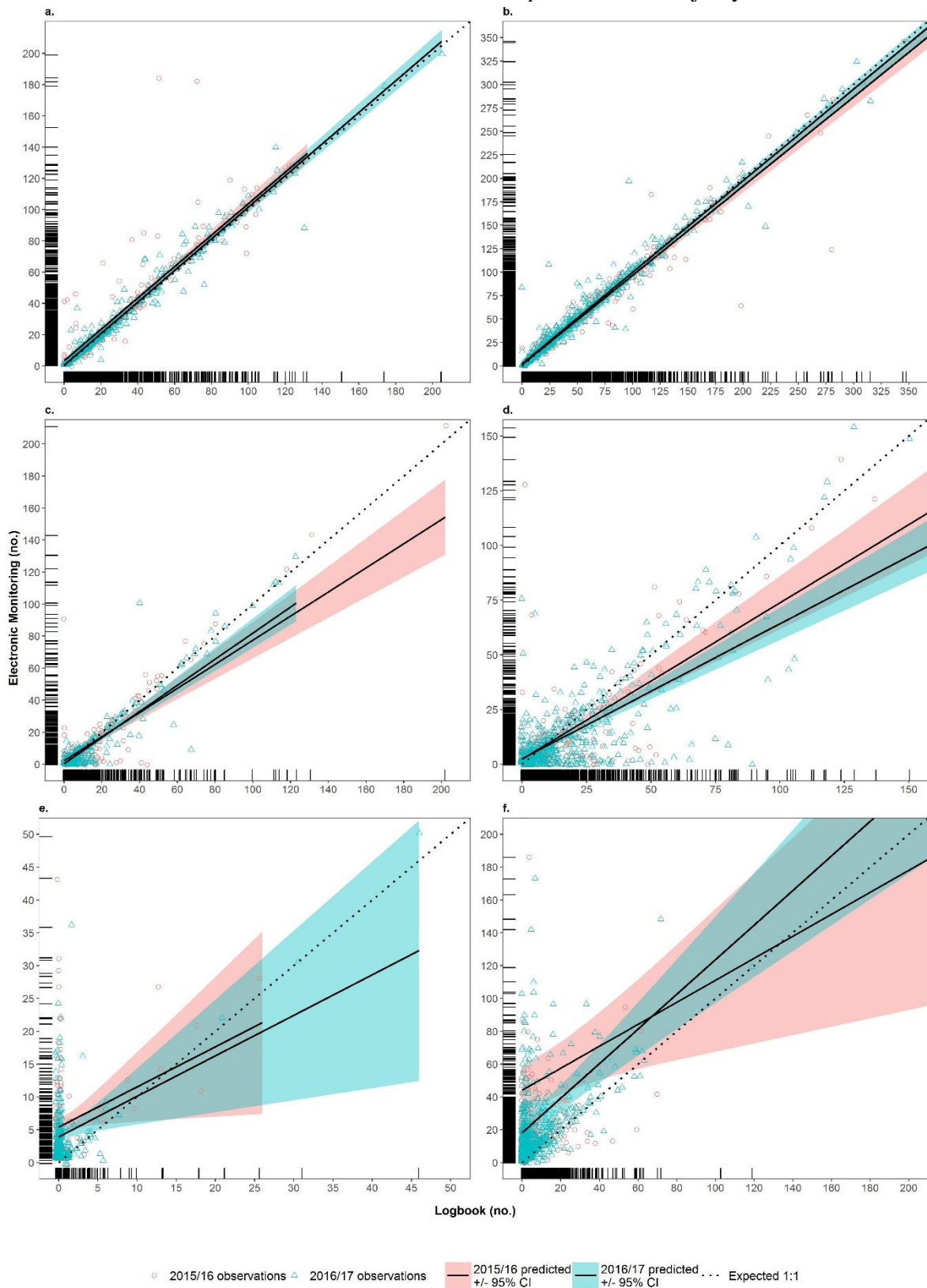
337 Figure 2: Estimated regression for 2015/2016 (solid black line with red shading)
 338 2016/2017 (solid black line with blue shading) and equal 1:1 relationship (dotted black line) between EM analyst and
 339 logbook reporting of individuals retained (a) and discarded (b) in the ETBF and retained (c) and
 340 discarded (d) in the GHAT (gillnet, auto-longline and set-longline) sector. Note Figure 2c and 2d have
 341 been truncated to eliminate extreme values and to reveal patterns in the majority of data.



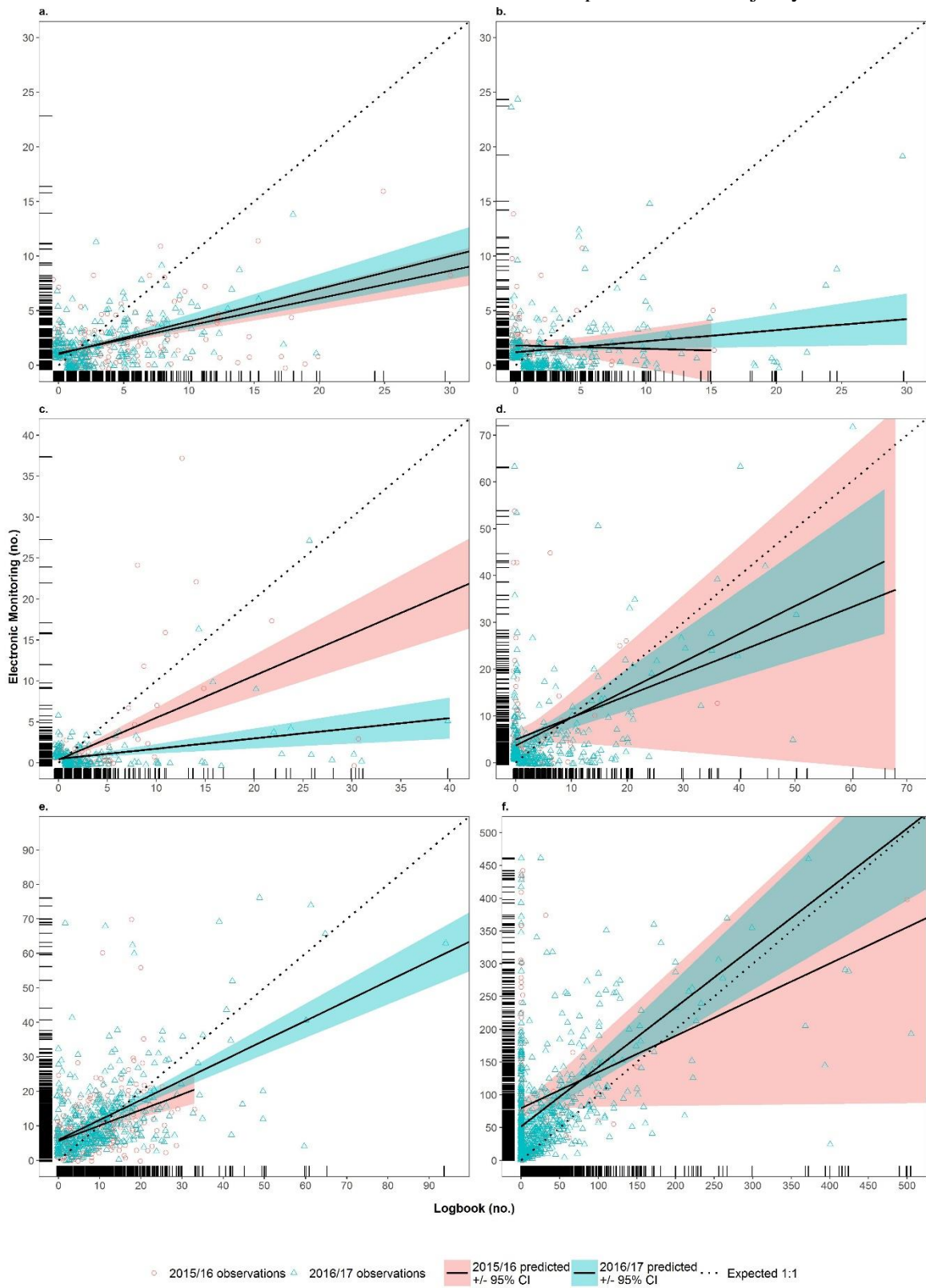
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344 Figure 3: Estimated regression for 2015/2016 (solid black line with red shading)
 345 2016/2017 (solid black line with blue shading) and equal 1:1 relationship (dotted black line) between EM analyst and
 346 logbook reporting of retained target (a, b), byproduct (c, d) and bycatch (e, f) in the ETBF (left side)
 347 and GHAT (gillnet, auto-longline and set-longline) sector (right side). Note Figure 3b, 3d and 3f have
 348 been truncated to eliminate extreme values and to reveal patterns in the majority of data.



350 Figure 4: Estimated regression for 2015/2016 (solid black line with red shading)
 351 2016/2017 (solid black line with blue shading) and equal 1:1 relationship (dotted black line) between EM analyst and
 352 logbook reporting of discarded target (a, b), byproduct (c, d) and bycatch (e, f) in the ETBF (left side)
 353 and GHAT (gillnet, auto-longline and set-longline) sector (right side). Note Figure 4a, 4c, 4e and 4f
 354 have been truncated to eliminate extreme values and to reveal patterns in the majority of data.



356 3.3 Individual species

357

358 The examination of congruence at a fishery and species group level (Figures 2, 3 and 4) using
359 GLMs, concealed a large amount of variation among individual species when examined using
360 the percentage difference analysis.

361 For species commonly retained in the ETBF (Figure 5a, Table 5), congruence was high (within
362 16%), with the only exceptions escolar (*Lepidocybium flavobrunneum*) and rudderfish
363 (*Centrolophus niger*), with substantially more of the former reported by the EM analyst and
364 the latter by fishers in their logbook (Figure 5a, Table 5).

365 There was a large amount of variation for species commonly discarded in the ETBF, with some
366 species having high mean discard numbers per set in the logbook, while others had higher
367 numbers when reported by the EM analyst (Figure 5b, Table 6). For example, there were 174
368 sets in 2016/17 where the EM analyst reported a total of 538 snake mackerel (*Gempylus*
369 *serpens*) discarded, compared to fisher-reported logbooks where only 314 were reported as
370 discarded (Table 6). In most cases, snake mackerel were reported either in large numbers by
371 the EM analyst and not in logbooks or vice versa. Many discarded species were reported in
372 higher numbers by fishers in their logbook than by the EM analyst, which suggests that either
373 the EM technology is not always capable of recording the capture of these species, or the EM
374 analyst is having difficulties in identifying them to a species level. This was particularly the
375 case for sharks (e.g. Blue Shark (*Prionace glauca*) and Bronze Whaler (*Carcharhinus*
376 *brachyurus*) and non-retainable marlin species (e.g. Blue Marlin (*Makaira nigricans*)) that are
377 likely to be cut off the line and not brought on board (Figure 5b, Table 6).

378 In the GHAT, retained target and byproduct species, including gummy shark (*Mustelus*
379 *antarcticus*), school shark (*Galeorhinus galeus*) and snapper (*Chrysophrys auratus*) were

380 reported in comparable numbers by both fisher-reported logbooks and the EM analyst (Figure
381 6a, Table 5). However, there was variability in the numbers reported by both fisher-reported
382 logbooks and EM analyst for all other retained species. For example, common (*Pristiophoridae*
383 *cirratus*) and southern (*Pristophorus nudipinnis*) sawsharks and boarfishes (*Caproidae spp.*)
384 were reported in higher mean numbers per set in logbooks than by the EM analyst, while
385 elephantfish (*Callorhinchus milii*) were reported in higher mean numbers per set by the EM
386 analyst than reported in logbooks. Sawsharks and sixgill and sevendgill sharks unspecified,
387 which were two grouped categories were also reported more by the EM analyst, suggesting
388 that the EM analyst was having issues identifying these sharks to a species level.

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

397

398 **Table 5.** Total numbers of top twelve retained species (as listed in Figure 5a and 6a) reported by fishers
 399 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 (<i>Thunnus alalunga</i>)	3507	4038	6204	6504
	Yellowfin tuna (<i>Thunnus albacares</i>)	2570	2701	2907	2947
	Mahi Mahi (<i>Coryphaena hippurus</i>)	1919	1636	880	977
	Southern Bluefin tuna (<i>Thunnus maccoyii</i>)	809	813	1943	1946
	Bigeye tuna (<i>Thunnus obesus</i>)	992	1083	1476	1464
	Broadbill swordfish (<i>Xiphias gladius</i>)	731	852	1709	1763
	Rudderfish (<i>Centrolophus niger</i>)	407	0	517	4
	Ray's bream (<i>Brama australis</i>)	69	148	683	602
	Striped marlin (<i>Kajikia audax</i>)	120	117	260	268
	Escolar (<i>Lepidocybium flavobrunneum</i>)	138	667	151	750
	Wahoo (<i>Acanthocybium solandri</i>)	68	83	71	84
Shortbill spearfish (<i>Tetrapturus angustirostris</i>)	42	41	60	68	
GHAT	Gummy shark (<i>Mustelus antarcticus</i>)	17763	17342	36442	36994
	Common sawshark (<i>Pristiophorus cirratus</i>)	992	374	3687	1826
	Elephantfish (<i>Callorhynchus milii</i>)	1567	2125	2985	3833
	School shark (<i>Galeorhinus galeus</i>)	894	884	1396	1388
	Southern sawshark (<i>Pristiophorus nudipinnis</i>)	467	20	1711	304
	Boarfishes (grouped category)	501	188	1399	218
	Broadnose shark (<i>Notorynchus cepedianus</i>)	429	154	783	652
	Draughtboard sharks (mixed) (grouped category)	271	4	574	1
	Sawsharks (grouped category)	1	853	493	3261
	Snapper (<i>Pagrus auratus</i>)	102	80	326	422
	Blue morwong (<i>Nemadactylus valenciennesi</i>)	139	33	240	8
Sixgill and sevengill sharks (grouped category)	36	326	233	655	

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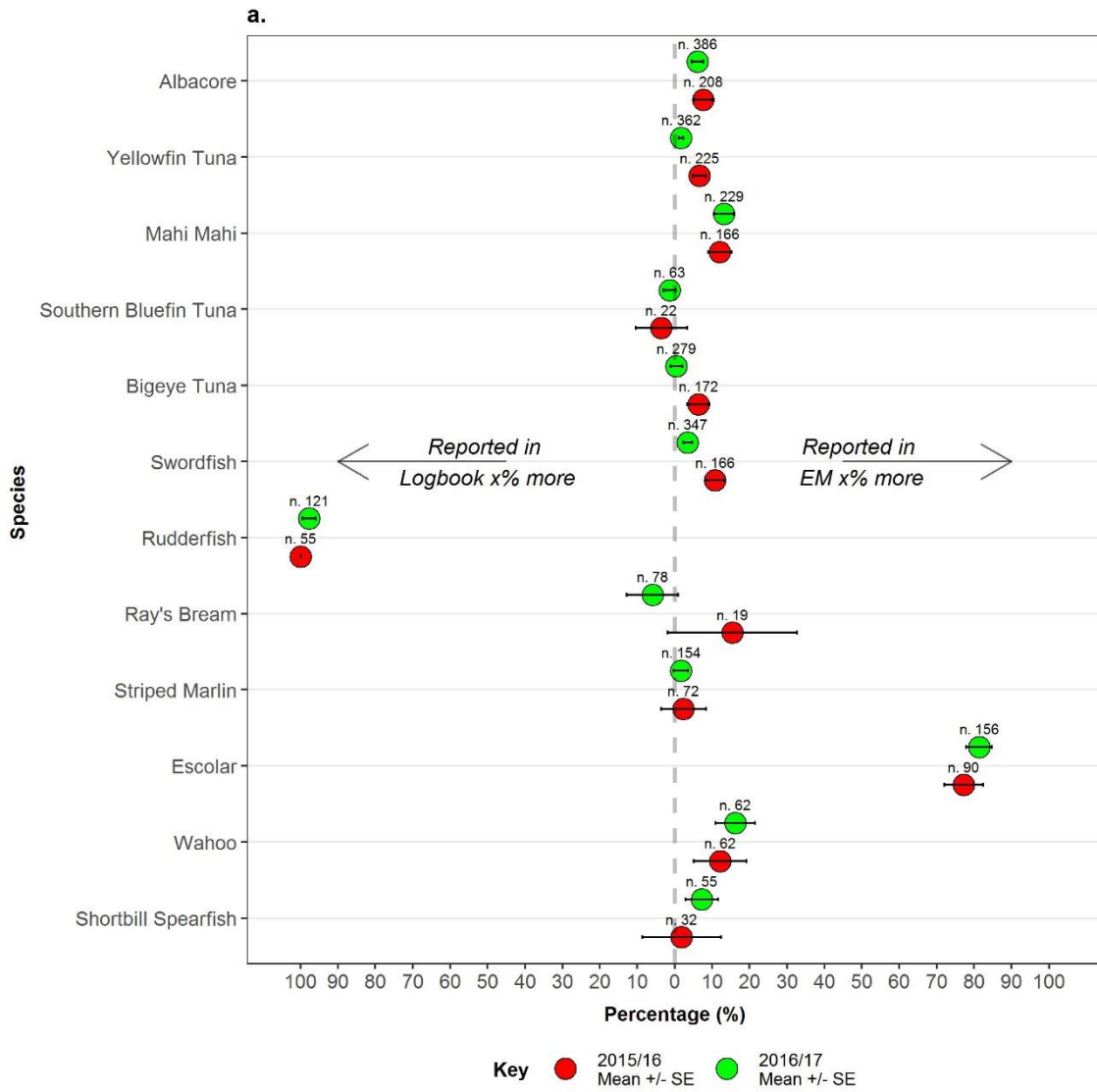
402 **Table 6.** Total numbers of top twelve discarded species (as listed in Figure 5b and 6b) reported by
 403 fishers in logbooks and by the EM analyst in the ETBF and GHAT (gillnet) sector in 2015/16 and
 404 2016/17.

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

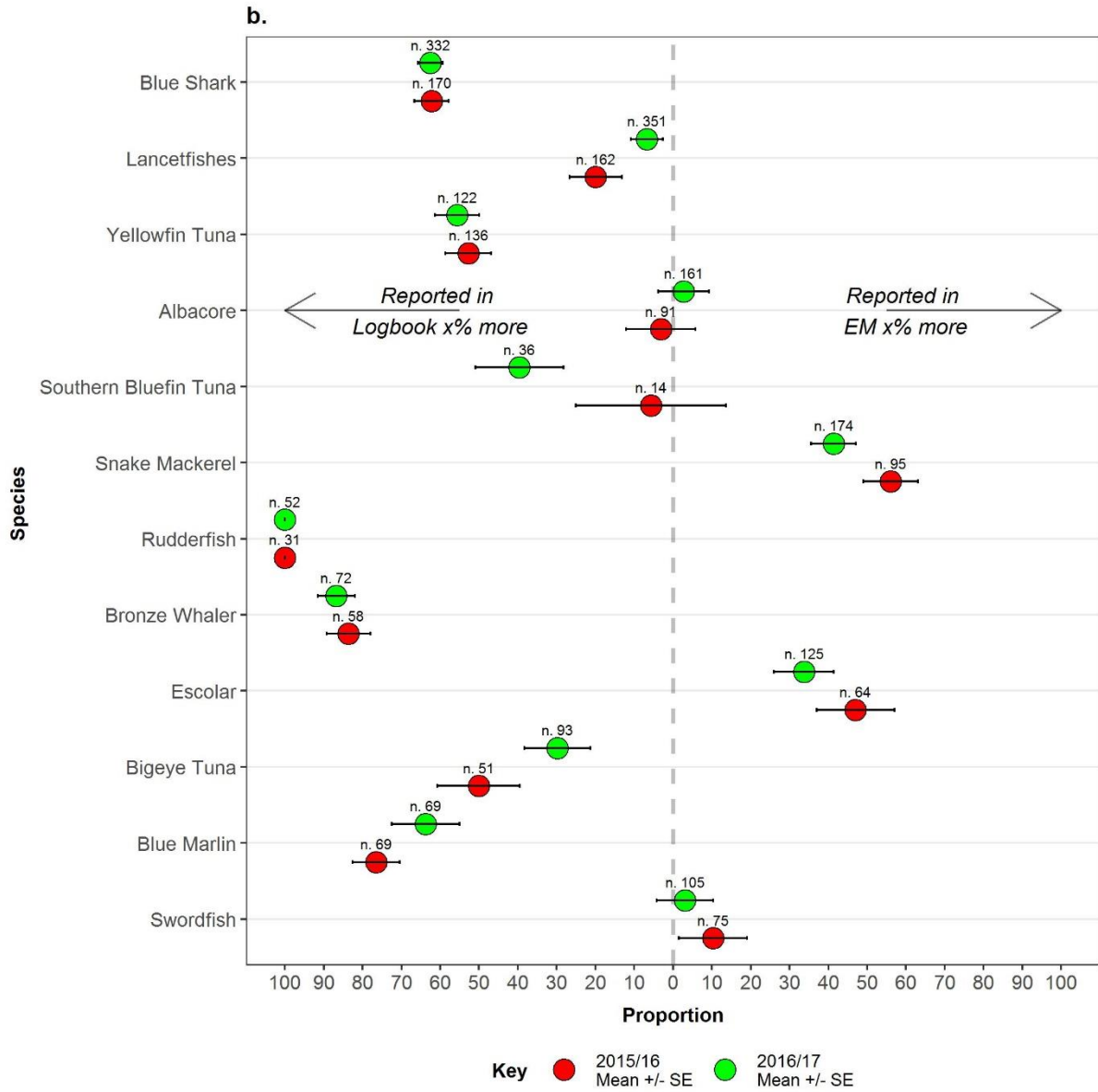
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407 **Figure 5.** Proportional difference in individual species reported as (a) retained and (b) discarded in the
 408 ETBF by fishers in logbook and EM analyst across all sets in 2015/16 and 2016/17 financial years.
 409 Species are ordered by top twelve reported (a) retained and (b) discarded species from 2015/16 and
 410 2016/17 logbook data. The number above the mean is the total shots audited where that species was (a)
 411 retained or (b) discarded.



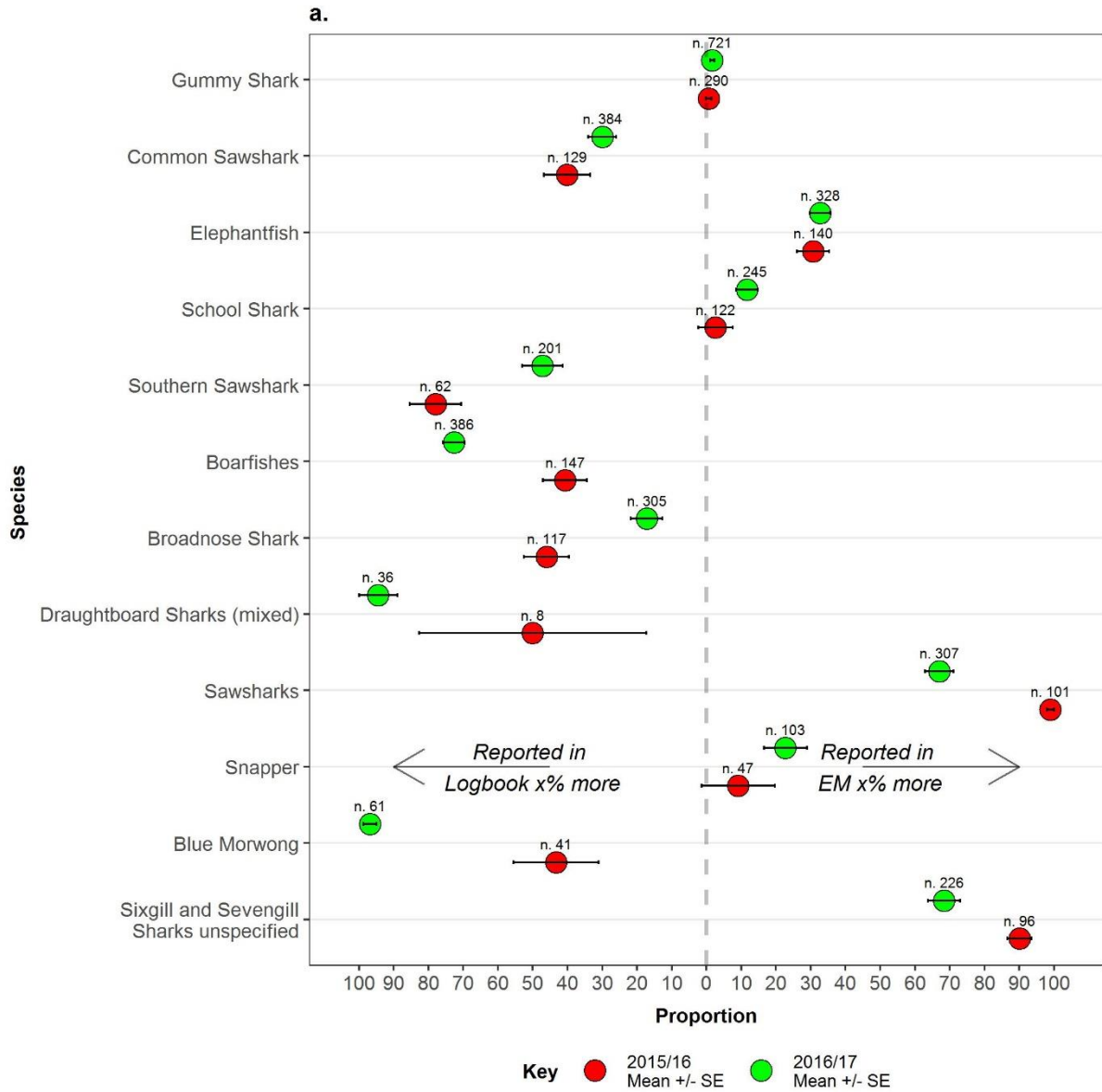
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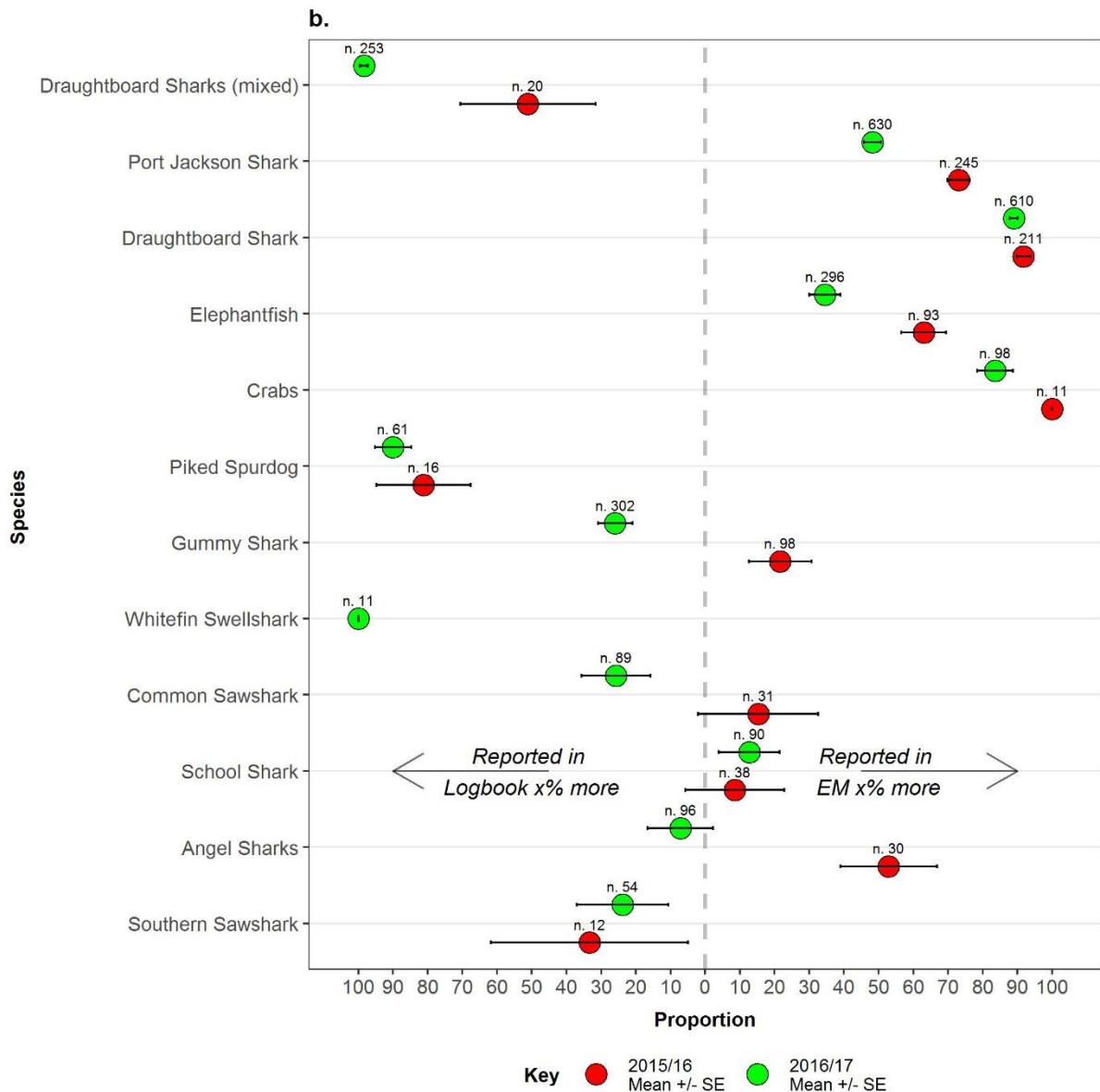
414

415 **Figure 6.** Proportional difference in individual species reported as (a) retained and (b) discarded in the
 416 GHAT (gillnet) by fishers in logbook and EM analyst across all sets in 2015/16 and 2016/17 financial
 417 years. Species are ordered by top twelve reported (a) retained and (b) discarded species from 2015/16
 418 and 2016/17 logbook data. The number above the mean is the total shots audited where that species was
 419 (a) retained or (b) discarded.



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422

423 *3.4 Protected species interactions*

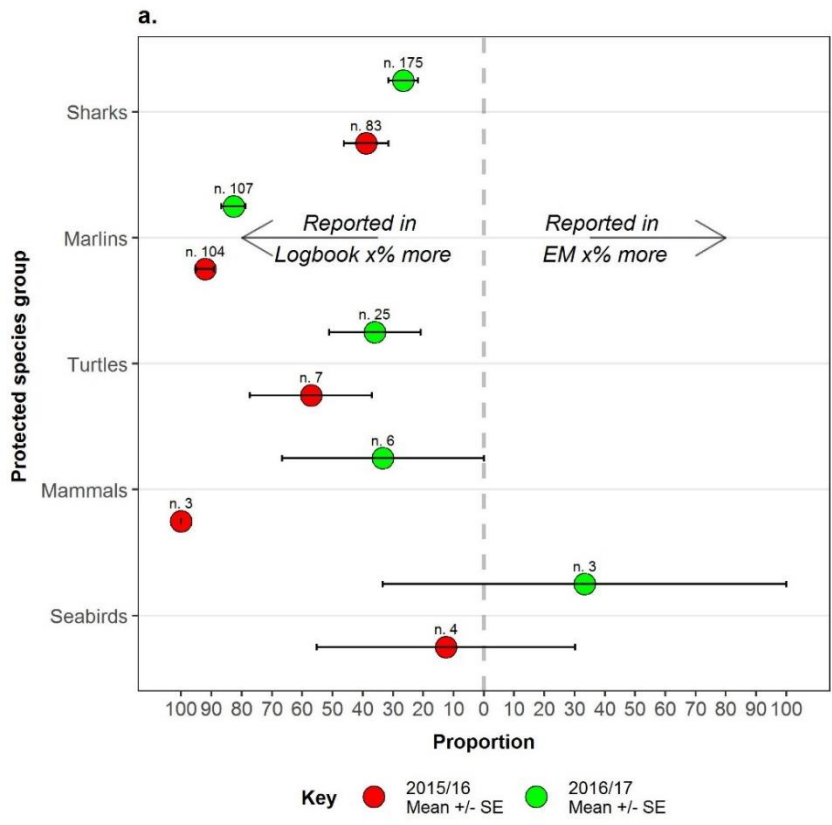
424 The results comparing the mean number of protected species interactions reported across all
 425 sets by both the EM analyst and fishers in the logbook are displayed in Figure 7. Apart from
 426 seabirds in the ETBF, it is evident that some protected species interactions are being missed by
 427 the EM analyst with fishers in their logbooks consistently reporting higher numbers. There was
 428 however, a slight improvement in overall congruence in 2016/17 relative to 2015/16 (Figure
 429 7). In the GHAT (gillnet) sector, the mean level of congruence ranged from 0 to 33% more
 430 interactions reported by the EM analyst than reported in the logbook (Figure 7). The small

431 sample size of interactions with protected species resulted in relatively large standard errors,
432 which all overlapped with zero, except for sharks in 2015/16. This indicates that it was not
433 possible to detect a difference between the EM analyst and fisher-reported logbooks in the
434 number of reported interactions with protected species.

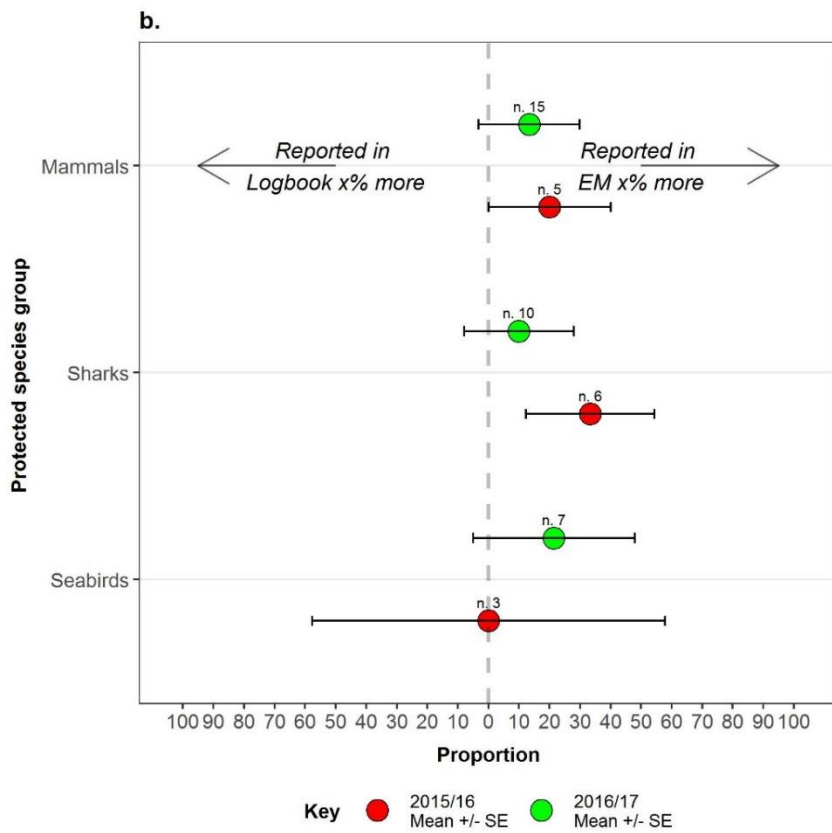
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436 **Figure 7.** Comparison of logbook to EM analyst reporting in 2015/16 and 2016/17 by set for
 437 interactions with protected and no-take species (i.e. wildlife) in the ETBF and GHAT (Gillnet only)



438



439

440

441 **4. Discussion**

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

455 In Australia, an integrated EM system was introduced (as an audit tool) in several
456 Commonwealth commercial fisheries in 2015, including the ETBF and GHAT sector with the
457 main aim to validate logbook information through reviewing 10% of all sets (100% of all gillnet
458 sets for protected species interactions in the Australian Sea Lion Management Zones) for both
459 retained and discarded catch, as well as monitor interactions with protected species (AFMA,
460 2015a, 2017b). In the ETBF and the auto-longline sector of the GHAT there are also additional
461 requirements for monitoring the deployment of seabird mitigation devices (e.g. tori lines)
462 (AFMA, 2015a). We reviewed the overall level of data congruence between the EM analyst
463 and logbook reported retained and discarded catch and interactions with protected species from
464 the first two years of operation to determine whether the AFMA EM program was meeting its

465 key objective of “increased confidence in data quality achieved through cross validation with
466 data captured in logbooks and observer records” (AFMA, 2015a).

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

476 On average, catches reported by the EM analyst and by fishers in their logbook were more
477 similar for longline than gillnet fishing gear. The higher congruence for longline than gillnet
478 fisheries may have been due to method in which fish are landed (van Helmond et al., 2015). In
479 the GHAT sector, catch is brought on deck or to the sorting station via the net roller, and in
480 some instances multiple individuals of more than one species can be brought onto a vessel
481 simultaneously. Conversely, in the ETBF, catch is brought on deck one individual at a time
482 during hauling. Increases in the number of species landed simultaneously can reduce the
483 performance of integrated EM systems (McElderry, 2008). For example, Bartholomew et al.
484 (2018) reported that EM analysts had difficulty in distinguishing between individuals when the
485 catch exceeded 15 individuals on deck in Peruvian small-scale gillnet fisheries. Similarly, the
486 ability of fishers to record all species in their logbooks is highly dependent on the fishing
487 method used and the number and diversity of species. For example, in the gillnet component
488 of the GHAT sector, an integrated EM system trial found that the length of time available for
489 at-sea observers to identify and count catch as it was landed in the net was restricted by the

490 need for fishing operations to continue (Lara-Lopez et al., 2012). Furthermore, the gear
491 selectivity and overall species richness in the ETBF is considerably less than in the GHAT
492 sector. In the past, the GHAT sector has reported catching approximately 210 species,
493 compared with approximately 90 species in the ETBF. Prior to the integrated EM system
494 implementation, it was common for the GHAT logbooks to have insufficient space for fishers
495 to report all bycatch species (AFMA, 2015b). Reporting the full species composition of catches
496 may therefore be more difficult for fishers in the GHAT sector relative to the ETBF, which
497 may be a reason why congruence was lower for both retained and discarded species. Therefore,
498 it is critical that either a mechanism is developed to increase the ability for fishers to
499 expediently record high volumes of mixed catch in their logbook without reducing operational
500 efficiency, or AFMA increases the tolerance levels for logbook reported discards if the costs
501 of comprehensive reporting (in terms of time and changes to operational practices) are
502 considered prohibitive.

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

511 The comparison of total retained and discarded catches between the EM analyst and fisher-
512 reported logbooks by fishery concealed a large amount of variation among individual and
513 groups of species. While the reporting of retained target species in the ETBF and GHAT sector
514 by fishers in their logbook and the EM analyst were equivalent, there were large discrepancies

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

519 It was evident that some species, particularly those discarded could not be identified by the EM
520 analyst in both fisheries, leading to them being grouped into more general species categories,
521 including, *inter alia*, unknown or other, tuna (mixed), sharks (mixed), sawsharks (mixed), and
522 marlin, spearfish and sailfish. In the ETBF for example, 46% of discarded tuna species were
523 grouped into the tuna (mixed) category by the EM analyst, while this proportion was even
524 higher (76%) for marlins, spearfish and sailfish species. Likewise, in the GHAT sector, 46%
525 of discarded gummy and school sharks were grouped into the hound sharks category, while
526 56% of angel shark species were grouped into the angel sharks category. The grouping of
527 species into more general categories by the EM analyst was similarly observed by Ames (2005)
528 in a comparison of at-sea observer and EM data in the Alaskan Pacific halibut longline fishery.

529 In the ETBF, there were some clear taxonomic issues in regard to the reporting of escolar and
530 rudderfish, which led to the EM analyst reporting them as escolar and fishers reporting them
531 as rudderfish in their logbook. Anecdotal evidence also points to similar issues in the logbook
532 reporting of snake mackerel and escolar in the ETBF, with some fishers incorrectly reporting
533 them as escolar (Trent Timmiss [AFMA], pers. comm. 2018). Differentiating the species of
534 smaller sized tuna (e.g. juvenile bigeye and yellowfin) from video footage was also challenging
535 in the ETBF integrated EM system trial and among pilot studies on tropical tuna purse seiners
536 in the Indian and Atlantic Oceans (e.g. Briand et al., 2017), which may explain why higher
537 numbers of discarded bigeye and yellowfin tunas were reported in logbooks than by the EM
538 analyst (Larcombe et al., 2016). In other integrated EM system trials and pilot studies, EM
539 analysts have also had trouble distinguishing similar looking species, such as rockfish

540 (McElderry et al., 2003). The inability to correctly identify individuals to a species level is a
541 challenge for integrated EM systems to resolve, as precise taxonomic identification is critical
542 for assessing fish stocks (Ruiz et al., 2015; Vecchione et al., 2000).

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

558 There are several factors to consider in order to improve species identification. Firstly, it is
559 important that EM analysts are familiar with target, by-product and bycatch species of the
560 specific fishery and ideally have on-board (i.e. at-sea observer) experience in the fishery prior
561 to reviewing any footage (Chavance et al., 2013). Alternatively, with time, difficulties with
562 species identification could be resolved through automated computer recognition software
563 (Storbeck and Daan, 2001). Secondly, additional cameras can be placed on-board vessels to
564 cover a larger proportion of fishing operations. In the GHAT sector, there is a particular need

565 to affix an additional camera to cover both sides of specific vessels to capture the discarding
566 of individuals. Thirdly, image quality and therefore species identification could be improved
567 by having stringent protocols in place to manage and maintain equipment on board the vessel
568 as advocated by van Helmond et al. (2015), as well as an automated warning system, which
569 alerts the skipper when image quality is poor and there is a need to clean the camera lens.

570 Failure of the EM analyst and/or the fisher to detect the capture of some species likely
571 contributed to some of the variation between EM and logbook data. In the ETBF, for instance,
572 shark and marlin species, along with marine turtles, were reported in greater numbers in
573 logbooks than by the EM analyst. This could be due to these species being cut off (i.e. in the
574 case of sharks to avoid potential injury to the crew) or dropping off the line before entering the
575 camera's field of view, thus preventing detection by the EM analyst. This was observed during
576 the integrated EM system pilot study in the ETBF and the Alaskan Pacific halibut longline
577 fishery (Ames et al., 2007; Ames et al., 2005; Larcombe et al., 2016). Ruiz et al. (2015) also
578 noted that EM analyst estimates for shark species in a tropical purse seine fishery were
579 significantly lower than at-sea observer estimates, while Bartholomew et al. (2018) found that
580 EM analysts only captured turtle interactions 50% of the time in Peruvian small-scale gillnet
581 fisheries. Conversely, in a Danish integrated EM system trial, porpoise bycatch was reported
582 in higher numbers by the EM analyst than in logbooks, as they dropped out of the net before
583 being observed by the fishers, but cameras were placed appropriately to capture these
584 interactions (Kindt-Larsen et al., 2012).

585 To improve the possibility of shark species and marine turtles being detected and correctly
586 identified by the EM analyst, there is a need to improve existing camera location, orientation
587 and image quality (i.e. resolution, frame rate, cleaning). While there was modification to
588 existing cameras and the addition of wide-angle cameras to some vessels in 2016/17 by AAP
589 and AFMA, there is clearly still a need for ongoing refinements as each vessel's configuration

590 and catch handling processes are unique. AFMA could also work with fishers to develop a
591 standardised approach for handling species that would improve the view for the EM analyst
592 and their ability to accurately identify catch items (Anon, 2016; Briand et al., 2017; McElderry,
593 2008; Piasente et al., 2012; Ruiz et al., 2015). For example, requesting fishers to bring all
594 species in proximity of the hauling station camera prior to being cut off the line or released.
595 However, safety concerns need to be considered, as changes to handling practices could have
596 adverse health and safety consequences for the crew.

597 Fishers could also have failed to record all of the species retained or discarded in their logbook.
598 In the GHAT sector, for instance, the EM analyst in both years reported over 30% more retained
599 elephantfish (*Callorhinchis milli*) than was reported in the logbook by fishers. In the GHAT
600 sector, there were also many discarded species that were either not reported or reported in low
601 numbers in the logbook relative to the EM analyst. Initially this is likely to have been
602 influenced by the change in logbook, with fishers not required to report counts of discarded
603 catch (only weights) for the first ten months of the AFMA EM program. This could also have
604 been a result of fishers either not observing species capture or simply a decision to not record
605 them as observed by Kindt-Larsen et al. (2012) in a Danish EM trial. AFMA has recognised
606 there is a need to continually educate fishers on the importance of accurate reporting of
607 discarded catch in their logbook and these efforts may have led to an improvement in
608 congruence in the GHAT sector between EM analyst and logbook data for discarded bycatch
609 species in 2016/17 relative to 2015/16. A similar result was also evident during the second year
610 of an EM trial in the New England groundfish fishery, where a timely feedback loop between
611 EM analysts and fishers improved both the consistency of their logbook reporting and the
612 relative accuracy of their weight estimates, which resulted in increased congruence between
613 EM analyst and fisher-reported logbook data (Anon, 2016). Given various studies have
614 confirmed that some fishers are poor at identifying species and underreport discards in their

615 logbook (Faunce, 2011; Macbeth et al., 2018; Mangi et al., 2016; Nakano and Clarke, 2006),
616 there is a clear need for AFMA to continually educate fishers on the importance of accurate
617 reporting of catch composition and fishing activities in their logbook to reduce the likelihood
618 that management decisions will be based on biased estimates of fishing mortality. A specific
619 case in point is for elephantfish (*Callorhinchis milli*), where prior to 2018, AFMA used logbook
620 estimates of retained catch (which according to this study were over 30% underreported) in the
621 CPUE standardisations to inform total allowable catch (TAC) setting.

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

636

637 **5. Conclusion**

638 Integrated EM systems have the capability to collect a diversity of fishery-dependent data that
639 can be analysed to reduce uncertainty and make informed management decisions. This study
640 has shown that congruence was highest in both longline and gillnet fisheries for retained target
641 species, but declined for discarded species, particularly those classified as byproduct and
642 bycatch. The integrated EM system also had difficulty recording captures of species such as
643 sharks, marlins and marine turtles in the ETBF, which are usually released or drop off the line
644 outside the camera's field of vision, as well as identifying many commonly discarded species
645 in both fisheries to a species level, resulting in their grouping. Consequently, in order to fulfil
646 the current objectives of the AFMA EM program, the existing camera configurations may need
647 to be reviewed or additional cameras affixed to the vessel with the aim to improve the field of
648 vision for the EM analyst. This is already an ongoing practice for AAP and AFMA, with wide-
649 angle cameras introduced on a number of vessels in 2016/17 in order to resolve blind-spots
650 (Trent Timmiss [AFMA], pers. comm.). Furthermore, while the integrated EM system has
651 previously been shown to be effective at improving logbook reporting of both retained and
652 discarded catch, as well as protected species in the ETBF (Larcombe et al., 2016), this may not
653 have occurred to the same extent in the GHAT sector, with an increase in logbook reporting
654 only initially observed for protected species (AFMA, 2017b). This indicates a continual need
655 to remind fishers of the importance of comprehensive logbook reporting and to investigate
656 whether this could be further improved through, for example, modification of existing
657 management incentives (e.g. evaluation standards for logbook auditing) or increased timeliness
658 of the feedback loop between EM analysts and fishers, which has shown to improve logbook
659 reporting (Anon, 2016). Furthermore, if EM technology is not perceived as a legitimate data
660 collection tool among GHAT sector fishers (i.e. acceptance of the applied regulations as
661 justified and reasonable (Jentoft, 2000; Nielsen, 2003)) then continual communication of the
662 benefits (e.g. individual accountability and access to previously closed areas) could be critical

663 in ensuring long-term cultural change. The need to improve logbook reporting of discards,
664 particularly bycatch species, in the GHAT sector has already elicited a management response
665 from AFMA in terms of heightened communication with fishers, which has improved overall
666 reporting in 2016/17 relative to 2015/16. Given the abundance and diversity of species in the
667 GHAT sector relative to the ETBF, it may be that increased tolerances for logbook reporting
668 of discarded species or allowances for grouping of species are required in the formulation of
669 any quantitative evaluation standards for auditing by AFMA. Similarly, the purchase of
670 additional cameras to identify species such as sharks, marlins and marine turtles in the ETBF,
671 which are usually released or drop off the line may be unwarranted if incentives for fishers to
672 continue to accurately report their capture remain durable.

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

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