CCSBT-ERS/1905/14
(ERSWG Agenda Item 5.3)

Marine Policy 104 (2019) 135–145

Contents lists available at ScienceDirect

Marine Policy

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

Changes in logbook reporting by commercial fishers following the implementation of electronic monitoring in Australian Commonwealth fisheries

Timothy J. Emery*, Rocio Noriega, Ashley J. Williams, James Larcombe

Australian Bureau of Agricultural and Resource Economics (ABARES), Department of Agriculture and Water Resources (DAWR), GPO Box 858, Canberra, ACT, 2601, Australia

ARTICLE INFO

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

ABSTRACT

Technological advancement has allowed for consideration of electronic monitoring (EM) as a tool for improving the accuracy of logbook data and/or increasing the quantity of fishery-dependent data collected. In Australia, an integrated EM system was implemented in several managed fisheries, including the Eastern Tuna and Billfish Fishery (ETBF) and the Gillnet Hook and Trap (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) from 1 July 2015. We compare logbook data from the first two years of EM operation to the previous six years, to measure changes in reported nominal catch and discard per unit effort (CPUE and DPUE) and interactions with protected species per-unit-effort (IPUE). We observed no significant increase in CPUE between non-EM (2009–2014) and EM (2015 and 2016) years for any species group in both the ETBF and GHAT. In contrast, DPUE increased significantly during the EM years for target, byproduct and bycatch species in the ETBF and for target species in the GHAT sector. There was a significant increase in the IPUE for seabirds, marine mammals and turtles in the ETBF and for dolphins and pinnipeds in the GHAT sector. While not discounting possible environmentally-driven shifts in availability and abundance, as well as individual vessel effects, the weight of evidence suggests the use of an integrated EM system has led to significant changes in logbook reporting of discarded catch and protected species interactions, particularly in the ETBF. Assuming this supposition is valid, we identify fishery-specific factors that might have influenced reporting behaviour.

1. Introduction

The collection and analysis of fishery-dependent and independent data is required to inform fishery management decision-making [1]. Of crucial importance is the accurate accounting of fishery-dependent removals (i.e. fishing mortality) [2]. One of the most utilised practices for collecting these types of data is through logbooks, where fishers are required (often as a condition of their fishing licence) to report on their daily fishing activities [3]. However, there are valid concerns about the quality and reliability of fisher-reported logbook data [2–6]. Studies measuring the precision of logbook data, often through direct comparisons to at-sea observer data, have identified inaccuracies caused by under-reporting or non-reporting of catch and/or misrepresentation of the species composition of catches [5]. For example, in an examination of catch rates for blue shark (*Prionace glauca*), Walsh et al. [7] found that underreported catches in fisher-reported logbooks were due to fishers being too busy to report incidental catches. In a similar study examining the catch rates for blue marlin (*Makaira nigricans*), Walsh et al. [8] observed that fisher-reported logbooks tended to over-report catches due to fishers misidentifying striped marlin (*Tetrapturus audax*) and shortbill spearfish (*Tetrapturus angustirostris*) as blue marlin.

In Australian Commonwealth fisheries, fishers are required to complete catch and effort information for each operation in their logbook, which includes information on retained and discarded catch and interactions with protected species. These data are used in scientific analyses, such as catch standardisations that provide the Australian Fisheries Management Authority (AFMA) with information to meet its legislative objectives under the *Fisheries Management Act 1991*. Historically, AFMA has used at-sea observer programs as a way of verifying fisher-reported logbook data through the at-sea observer's ability to collect a range of data on catch (both retained and discarded) and effort (gear characteristics and their utilisation), as well as recording interactions with protected species. However, the increasing financial and logistical costs associated with AFMA's at-sea observer

* Corresponding author. 7 London Circuit, Canberra, ACT, 2601, Australia.
E-mail address: timothy.emery@agriculture.gov.au (J. Larcombe).

https://doi.org/10.1016/j.marpol.2019.01.018
Received 2 October 2018; Received in revised form 17 January 2019; Accepted 17 January 2019
0308-597X/

program [9], as well as ongoing data quality issues present in fishing logbooks [10] prompted AFMA to investigate more cost effective ways of monitoring fishing operations and verifying logbook data. Electronic monitoring (EM) technologies were identified as a potential cost effective tool that could aid in improving the accuracy of logbook data without the limitations associated with at-sea observer programs (e.g. non-random placement of at-sea observers on fishing vessels) [11–13], while also allowing for greater monitoring coverage of fishing activities [14].

EM is a combination of hardware and software that collects and transmits records in an automated manner that is closed to external or manual input [15]. On the vessel, EM technology consists of a central computer combined with several gear sensors and video cameras that are capable of monitoring and recording fishing activities [16,17]. The footage is stored on a hard drive on the vessel and can be independently 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 [13].

Internationally, EM has proven to be a reliable and accurate method to independently verify catch composition on-board longline, purse seine and gillnet vessels, and to monitor interactions with protected species and the use of bycatch mitigation devices [16–21]. As a result, EM is often presented as one of the solutions to improving the accuracy of logbook catch reporting and reducing uncertainty through increasing the quantity and quality of data available [13,22]. The reliability of EM has led to it being implemented in the Canadian British Columbia groundfish hook-and-line fishery [19,23], Alaskan groundfish and halibut hook-and-line and pot fisheries [24,25], and Australian longline and gillnet fisheries [10]. To improve readability, we use the term *integrated EM system* in this paper when discussing in unison the technological (i.e. on-board camera and sensors) and logistical (i.e. on-shore analysis of records) aspects of EM.

On 1 July 2015, AFMA implemented integrated EM systems in several of its managed fisheries, including the Eastern Tuna and Billfish Fishery (ETBF) and the Gillnet Hook and Trap (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF). As a result, at-sea observers were initially phased out when fishing within the Australian exclusive economic zone (EEZ) in both fisheries, but were reintroduced in the GHAT from September 2017 to primarily collect biological data for ageing purposes [26]. Biological data continues to be collected through an established in-port sampling program in the ETBF. Under the current program, AFMA uses the integrated EM system to validate fisher-reported logbook information with an audit target of 10% of hauls (fishing events) from each vessel. This audit includes an analysis of catch composition, discards and interactions with protected species[1] [10]. Through the auditing process and accompanying feedback to fishers, AFMA aims to independently evaluate the veracity of fisheries logbook information as a source of data for assessing and managing fisheries.

The aim of this study was to evaluate whether the use of an integrated EM system as an auditing tool with an accompanying vessel feedback system has led to changes in logbook reporting behaviour in the ETBF and GHAT. To achieve this, we examined whether there was any significant difference in logbook-reported catch per unit effort (CPUE), discard per unit effort (DPUE) or protected species interactions per unit effort (IPUE) pre- or post-EM implementation. A similar analysis was recently undertaken by Gilman et al. [27], comparing logbook-reported mean catch and discard rates from pelagic longline vessels fishing in the Palau exclusive economic zone (EEZ) with and without EM technology installed on-board. However, there was no established auditing and feedback system in the pilot study, despite the potential for punitive action to be taken against vessels for non-compliance, which is in contrast to our case study. In our analysis, what we expected was not dissimilar from the established "observer effect", whereby fishers are known to alter their behaviour in the presence of at-sea observers, or in this case, on-board cameras [6,12]. Having observed evidence of increased DPUE and IPUE post-EM implementation, we identify fishery-specific factors that might have influenced changes in logbook reporting behaviour. This study provides an important insight into the ability of integrated EM systems, when used as an audit tool, to lead to improvements in logbook reporting behaviour.

2. Methods

2.1. Description of fisheries

The ETBF is (for the most part) a pelagic longline fishery that operates within the Australian EEZ and adjacent high seas waters targeting yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alulunga*), broadbill swordfish (*Xiphias gladius*) and striped marlin (*Tetrapturus audux*). The ETBF operates from Cape York, east and south to the Victorian – South Australian border, including waters around Tasmania and the high seas of the Pacific Ocean [28] (Fig. 1a). In 2017, there were a total of 39 longline and two minor line vessels active in the ETBF [29]. In the ETBF, vessels that have fished more than 30 days in the previous or current fishing season must have operational EM technology installed.

The GHAT is a demersal trap, gillnet, demersal longline, dropline and auto-longline fishery that operates in waters south of the New South Wales – Victorian border, around Tasmania, and west to the South-Australian-Western Australian border targeting gummy shark (*Mustelus antarcticus*) [30] (Figs. 1b and 1c)). The gillnet and hook sectors of the GHAT both had 38 active vessels in the 2016/2017 fishing season [29]. In the GHAT sector, gillnet and auto line boats that have fished more than 50 days in the previous or current fishing season must have operational EM technology installed, while manual longline vessels must have fished for more than 100 days.

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

2.2. Data analysis

To examine changes in nominal CPUE, DPUE and IPUE in the ETBF and gillnet sector of the GHAT, we collated reported logbook data from the first two financial years of EM implementation (2015/16 and 2016/17) and compared this to the previous six financial years (2009/10 to 2014/15) for target, byproduct, bycatch and protected species. While we analysed financial year data, to improve readability we hereafter use the first calendar year when referring to them in this paper (e.g. 2015/16 = 2015).

We chose to exclude the line (auto and manual longline) sector of the GHAT from this analysis due to the small number of trips audited by EM analysts in 2015 and 2016 relative to the gillnet sector. So hereafter all mention of the GHAT relates solely to the gillnet sector.

Retained and discarded species were classified based on their role in the fishery – target, byproduct and bycatch (see Table 1). Target species were those identified by AFMA [28], which are nearly always retained, but occasionally discarded if not a marketable size or condition, or if catch quotas are reached. Byproduct species were those that were retained more often than discarded (total numbers) in the 2015 fishing season. All other species were classified as bycatch, as they were

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

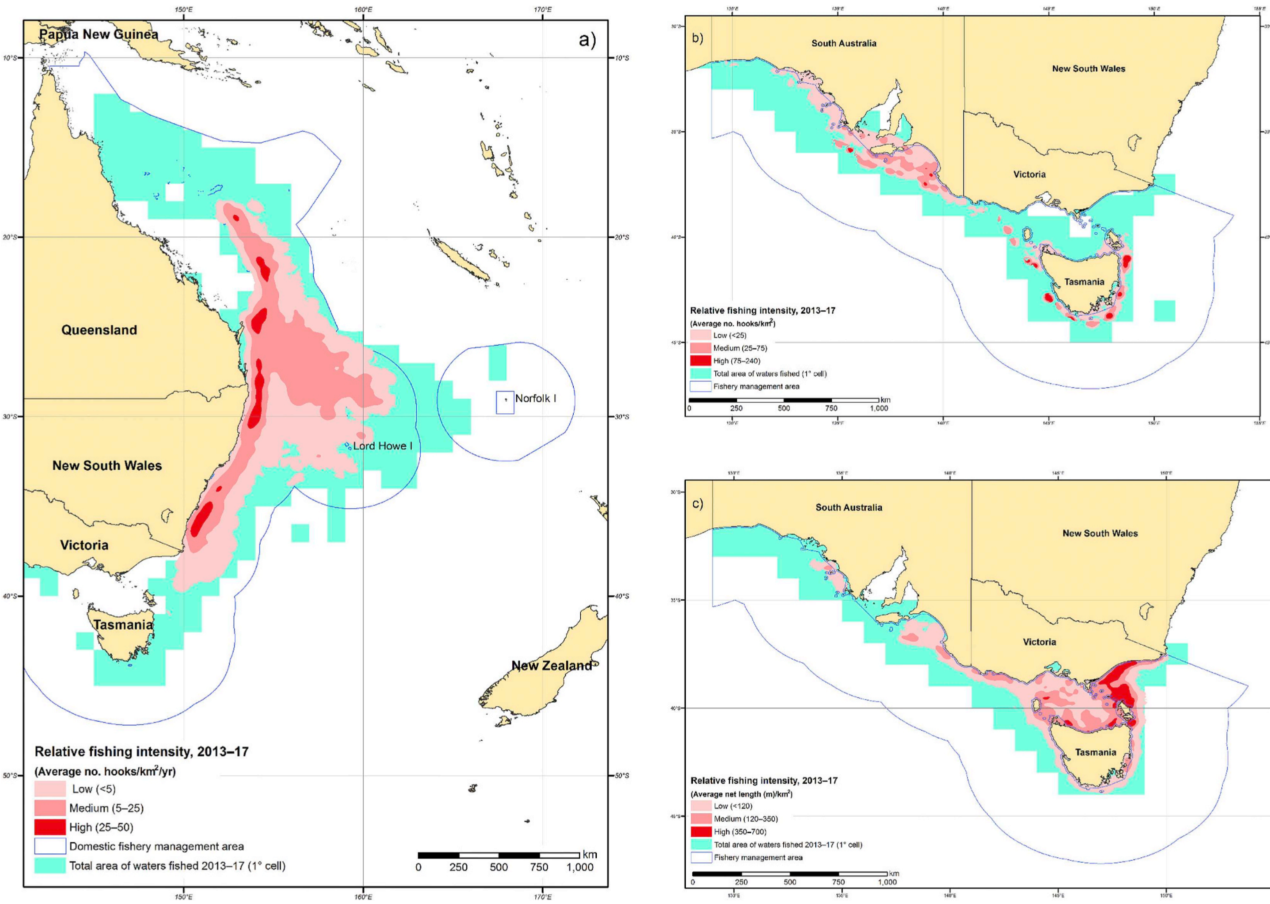

Fig. 1. Area and relative fishing intensity in the: (a) eastern tuna and billfish fishery (b) line sector of the gillnet hook and trap and; (c) gillnet sector of the gillnet hook and trap between 2013 and 2017 calendar years.

discarded more often than retained in 2015. It is important to note that this could mean some species classified as byproduct in this study, could be likewise classified as bycatch, and vice versa using alternative methods of classification. Protected species were combined into groups for analysis including: seabirds, marine turtles, marine mammals and sharks. In the GHAT, the marine mammal group was further divided into dolphins and pinnipeds given the historical significance of both groups interacting with the gillnet sector.

Nominal CPUE, DPUE and IPUE were calculated by dividing the total number of species retained, discarded or interacted with by the unit of effort, which in the ETBF was per 1000 hooks and for the GHAT was per 1000 m gillnet length. As fishers in the GHAT were only required to record in their logbook the estimated weight (not count) of discarded species up until April 2016, there were several records with missing count data. Records that contained both weight and count data were used to calculate the average weight of an individual species and then used to estimate the number of individual species discarded for those records with only estimated weight data.

We calculated nominal CPUE, DPUE and IPUE for vessels that had fished every year during the selected period (2009–2016) in each fishery to reduce the overall variability caused by vessels entering and exiting the fishery. A total of 16 of 59 vessels (27%) in the GHAT and 28 of 66 vessels (42%) in the ETBF fished in all years. For the GHAT, we chose to only include fishing grounds within Bass Strait, rather than the entire fishery, to reduce the effects of spatial variability in fishing activity caused by management changes (mainly fishing closures for pinnipeds), which were more prevalent in the western area of the fishery, off South Australia, during the selected period.

Initial linear regression showed serious violations of homogeneity, so we applied a generalised least squares (GLS) approach following Zuur et al. [31]. Using GLS, we defined a variance structure that allowed for modelling different residual variation for CPUE, DPUE and IPUE per EM and non-EM year. The Akaike information criterion (AIC) was lower for the model using the different variances per EM and non-EM years. Significance was justified at $p < 0.01$, with a higher level of confidence chosen for this study to reduce the likelihood of Type I errors (false positives). All analyses were conducted using R (version 3.2.0).

3. Results

A summary of the results of the analysis for each species group in both fisheries is provided in Table 2. For the ETBF, there was no significant difference detected in logbook reported nominal CPUE between non-EM (2009–2014) and EM (2015 and 2016) years for target and byproduct species, but a significant decrease was observed for bycatch species (Table 2 and Fig. 2). Conversely, there was a significant increase in logbook reported nominal DPUE for all species groups (target, byproduct and bycatch) in the ETBF (Table 2 and Fig. 2). In the GHAT, there was no significant difference in logbook reported nominal CPUE for any species group when comparing non-EM to EM years (Table 2 and Fig. 3), while for logbook reported nominal DPUE, we detected a significant increase between non-EM and EM years for target species (i.e. gummy shark (*Mustelus antarcticus*)) only (Table 2 and Fig. 3).

Except for sharks, there was a significant increase in the nominal IPUE for all protected species groups in the ETBF between non-EM and EM years (Table 3, Fig. 4). The logbook reported least square mean interaction rate for marine turtles increased significantly from 0.002 to 0.012 per 1000 hooks between non-EM and EM years, while for seabirds it increased significantly from 0.0006 to 0.0054 per 1000 hooks.

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

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

In the GHAT, there was no significant difference in the nominal IPUE for both sharks and seabirds between non-EM and EM years, but there was a significant increase for marine mammals (pinnipeds and dolphins) (Table 3, Fig. 5). The logbook reported least square mean interaction rate for pinnipeds and dolphins increased significantly from 0.0001 to 0.0012 and 0.0002 to 0.0022 respectively per 1000 m of gillnet between non-EM and EM years.

4. Discussion

Commercial fishers often have logbook reporting requirements attached to their fishing licence [3,32,33]. The consistency and accuracy of fisher-reported logbook data, however, has been an ongoing concern in Australian and other international fisheries [6,34,35], with various validation studies identifying inherent biases [3–5,7,8,36]. Globally, fisher-reported retained and discarded catch numbers and weights from logbooks are used as the principle source of information in catch standardisations and stock assessments, the results of which underpin management decisions [7,8,37]. Consequently, it is important to ensure that fisher-reported data are accurate, or at least the deficiencies and uncertainties in the data are understood, to enable assessments to capture uncertainties through sensitivity analyses for the delivery of robust scientific advice to fishery managers [8].

One of the main reasons that AFMA introduced an integrated EM system in various Australian Commonwealth fisheries was to improve the accuracy of fisher-reported logbook data [10,38]. Achieving this objective with broad fishery coverage would provide more confidence in estimates of standardised catch rates used to index abundance of target species, total fishing mortality (through a more accurate estimate of discards), as well as the number of interactions with protected species. We analysed fisher-reported logbook data to determine whether significant changes in CPUE, DPUE and IPUE have occurred between non-EM and EM years. We took a weight of evidence approach to answering the question as to whether the introduction of an integrated EM

Table 2
Summary statistics and estimated parameter estimates from the GLS regression comparing logbook reported CPUE and DPUE for species groups between EM and non-EM years across vessels that fished all years in both the ETBF and GHAT (gillnet).

Fishery	Fate	Species Group	Parameters	Estimates	Confidence Intervals		P-value
					0.5%	99.5%	
ETBF	Retained (CPUE)	Target	Intercept	19.70	17.71	21.68	< 0.001
			Non-EM Years	−0.36	−2.79	2.07	0.70
		Byproduct	Intercept	7.73	5.43	10.02	< 0.001
			Non-EM Years	−1.37	−3.78	1.04	0.14
		Bycatch	Intercept	0.25	0.10	0.41	< 0.001
			Non-EM Years	0.31	0.06	0.56	0.002
	Discarded (DPUE)	Target	Intercept	1.37	0.94	1.80	< 0.001
			Non-EM Years	−0.67	−1.15	−0.19	< 0.001
		Byproduct	Intercept	0.93	0.65	1.20	< 0.001
			Non-EM Years	−0.54	−0.84	−0.23	< 0.001
		Bycatch	Intercept	6.88	4.43	9.33	< 0.001
			Non-EM Years	−3.77	−6.35	−1.19	< 0.001
GHAT	Retained (CPUE)	Target	Intercept	14.61	12.52	16.69	< 0.001
			Non-EM Years	−1.89	−4.36	0.58	0.05
		Byproduct	Intercept	4.66	3.54	5.79	< 0.001
			Non-EM Years	0.14	−1.09	1.38	0.76
		Bycatch	Intercept	1.90	1.13	2.67	< 0.001
			Non-EM Years	0.23	−0.80	1.26	0.57
	Discarded (DPUE)	Target	Intercept	0.19	0.09	0.29	< 0.001
			Non-EM Years	−0.12	−0.23	−0.01	0.01
		Byproduct	Intercept	0.39	0.14	0.63	< 0.001
			Non-EM Years	0.12	−0.30	0.54	0.46
		Bycatch	Intercept	1.98	0.44	3.51	0.001
			Non-EM Years	0.17	−1.91	2.26	0.83

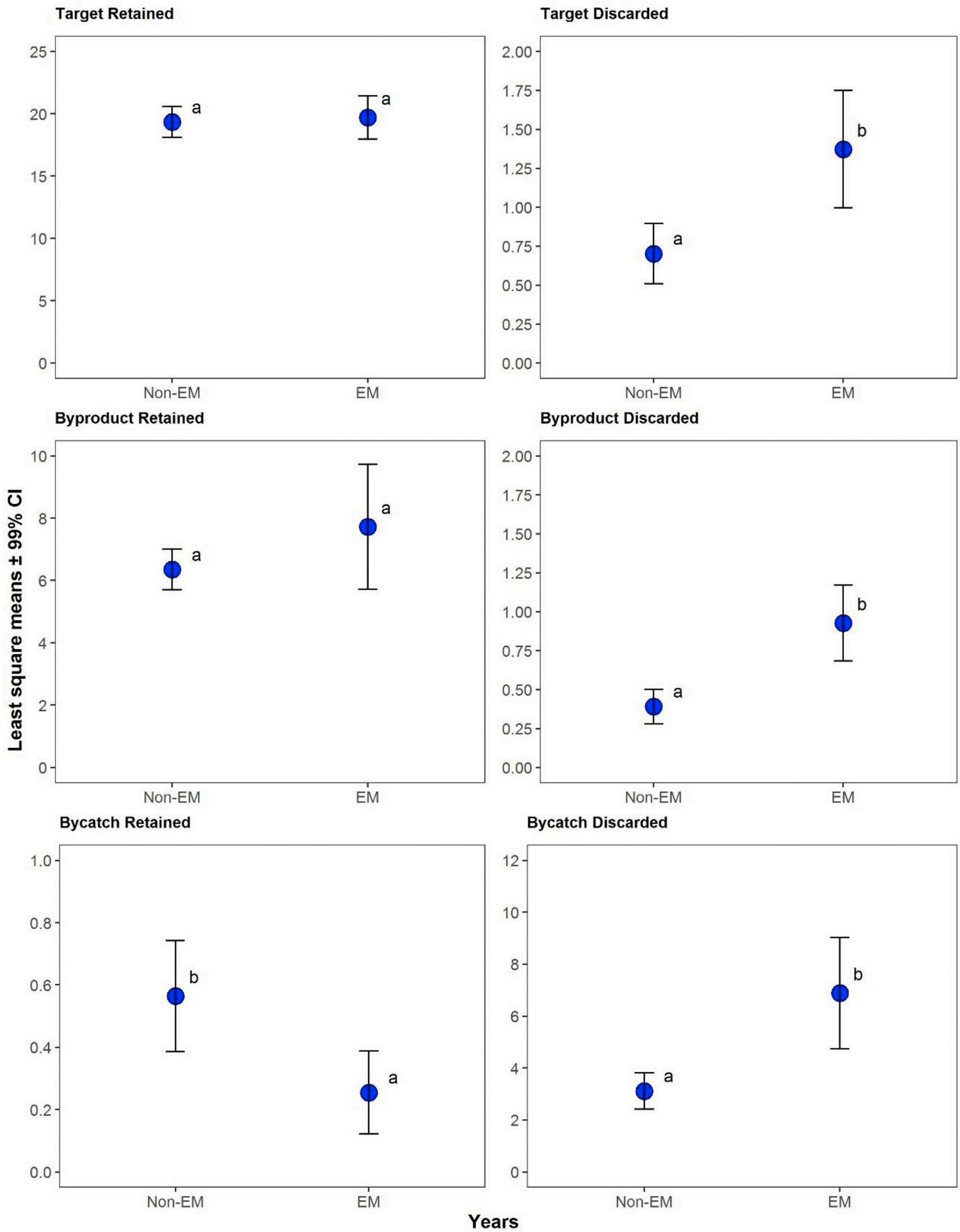

Fig. 2. Least square means ± 99% CI of catch and discard per unit effort (CPUE and DPUE) (no. individuals retained and discarded per 1000 hooks) by ETBF vessel that fished all years in EM (2015 and 2016) and non-EM (2009–2014) years for target and discarded species groups. Means not sharing a letter are significantly different at $p < 0.01$ (Tukey-adjusted comparisons).

system has led to changes in logbook reporting among fishers in the ETBF and GHAT.

Results from this study illustrate disparate changes in logbook-reported CPUE, DPUE and IPUE among species groups and fisheries when comparing non-EM to EM years. Predictably, there was no significant increase observed in the logbook-reported CPUE for target, byproduct and bycatch species in either fishery, which in the absence of shifts in environmental conditions and fleet behaviour would be expected, given that the number and weight of retained target, byproduct and bycatch species in both fisheries are independently verified upon landing (through catch disposal records). It makes sense, therefore, that retained catch would be accurately recorded by fishers in logbooks [38]. There was a significant decrease in retained bycatch species in the ETBF, but this was driven by a reduction in the overall retention of

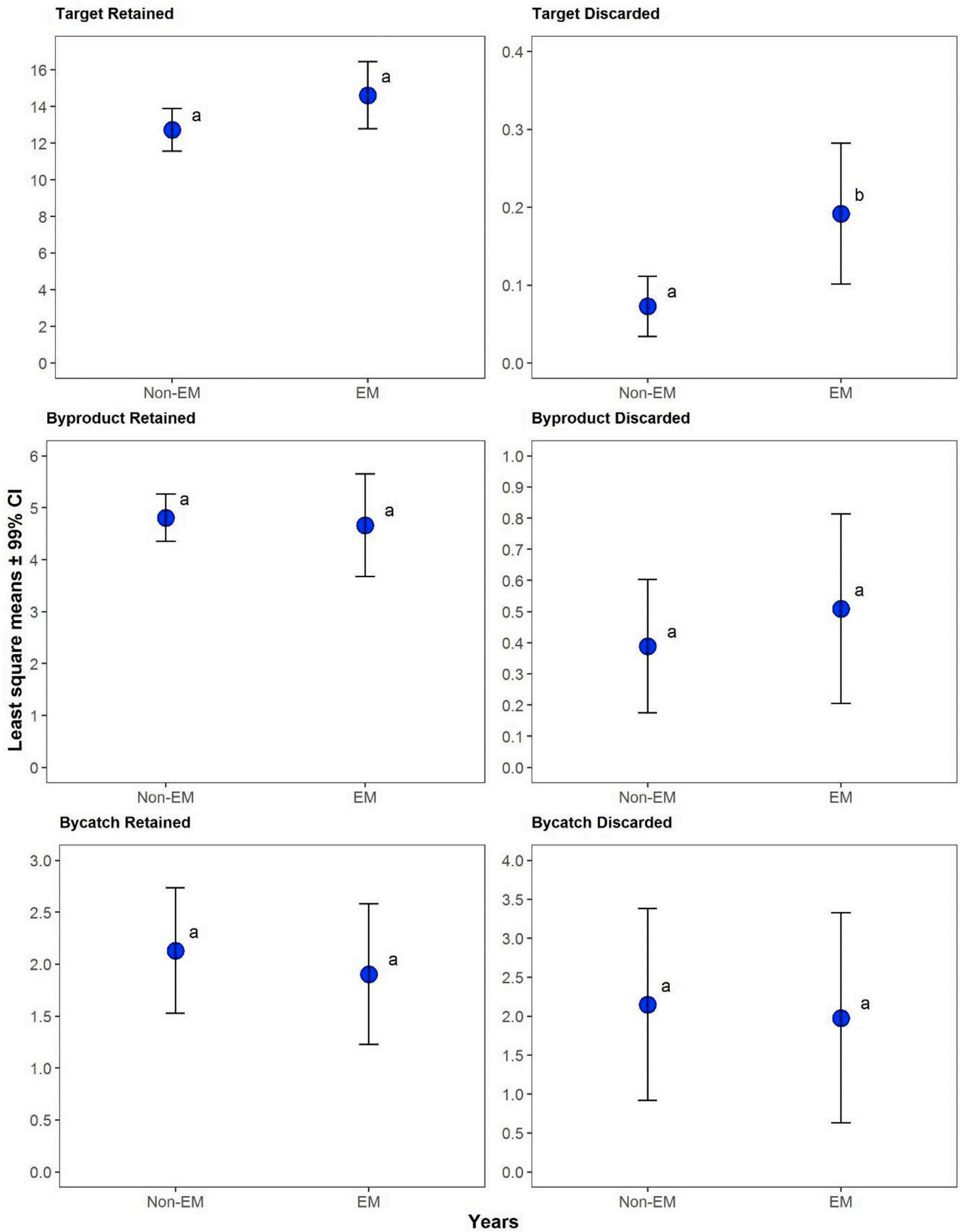

Fig. 3. Least square means ± 99% CI of catch and discard per unit effort (CPUE and DPUE) (no. individuals retained and discarded per 1000 hooks) by GHAT (gillnet) vessel that fished all years in EM (2015 and 2016) and non-EM (2009–2014) years for target and discarded species groups. Means not sharing a letter are significantly different at $p < 0.01$ (Tukey-adjusted comparisons).

escolar (*Lepidocybium flavobrunneum*) and various shark species through time, which is likely to have been market-driven.

The increase in logbook reported DPUE for all species groups in the ETBF and for target species in the GHAT lends some support to prevailing evidence in the literature that discards are often misreported or underreported in logbooks by fishers in the absence of EM systems [4,38]. The logbook-reported DPUE for target species in the ETBF and the GHAT increased significantly between non-EM and EM years. This was due to greater amounts of bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alalunga*) and striped marlin (*Kajikia audax*) in the ETBF (Appendix – Figure A1) and gummy shark in the GHAT being recorded by fishers as discarded. In the ETBF, the logbook reported DPUE of byproduct and bycatch species also significantly increased in the EM years. For byproduct species this was mainly driven by greater numbers

Table 3
Summary statistics and estimated parameter estimates from the GLS regression comparing logbook reported IPUE for protected species between non-EM and EM years across vessels that fished all years in the ETBF and GHAT (gillnet) sector.

Fishery	Protected Species Group	Parameters	Estimates	Confidence Intervals		P-value
				0.5%	99.5%	
ETBF	Marine Turtles	Intercept	0.012	0.007	0.016	< 0.001
		Non-EM Years	−0.01	−0.014	−0.005	< 0.001
	Seabirds	Intercept	0.005	0.001	0.01	0.002
		Non-EM Years	−0.005	−0.009	−0.000	0.007
	Sharks	Intercept	0.33	0.234	0.425	< 0.001
		Non-EM Years	0.11	−0.037	0.260	0.06
	Marine Mammals	Intercept	0.002	0.001	0.004	< 0.001
		Non-EM Years	−0.002	−0.004	−0.001	< 0.001
GHAT (gillnet)	Seabirds	Intercept	0.002	−0.001	0.005	0.06
		Non-EM Years	−0.002	−0.005	0.001	0.07
	Sharks	Intercept	0.003	0.002	0.004	< 0.001
		Non-EM Years	0.002	0.000	0.004	0.01
	Pinnipeds	Intercept	0.001	0.000	0.002	< 0.001
		Non-EM Years	−0.001	−0.002	−0.000	< 0.001
	Dolphins	Intercept	0.002	0.001	0.003	< 0.001
		Non-EM Years	−0.002	−0.003	−0.001	< 0.001

of rudderfish (*Centrolophus niger*) and mahi mahi (*Coryphaena hippurus*) being recorded as discarded, while for bycatch species this was a result of a greater number of sharks being recorded as discarded, (e.g. blue shark) [See also, 38].

It is possible that the significantly higher DPUE observed for some groups of species in the ETBF and GHAT could have been driven by changes in environmental conditions, or increases in total abundance or availability (e.g. movements of fish or changes in the size of the resource in response to trends in annual recruitment). Similarly, it is possible that it could have been driven by changes in individual vessel effects (e.g. changes to targeting practices or catchability through time). However, we believe it is unlikely that availability and catchability would have increased for all these species groups simultaneously during the EM years particularly given that catch landings across the time period have been consistent, suggesting that there has not been any significant environmental changes that would influence the results. Furthermore, in both the ETBF and GHAT, there have been no marked changes in effort distribution through time (Appendix – Figure A2 and A3). Therefore, it seems more likely that the significant increases in DPUE, particularly in the ETBF at least, were driven by changes in logbook reporting behaviour as a result the implementation of an integrated EM system.

This supposition is supported by the large number of studies documenting historical underreporting of discarded target, byproduct and bycatch species in fisher-reported logbooks in the ETBF and GHAT [39–43]. For example, Braccini et al. [42] reported that in Bass Strait, elephantfish (*Callorhinchus milii*) are underreported by GHAT fishers in their logbooks, while Bromhead et al. [43], in a comparison of ETBF at-sea observer and logbook reported DPUE between 1997 and 2004, identified significantly higher at-sea observer DPUE for species such as albacore, yellowfin tuna (*Thunnus albacares*), escolar and blue shark. Similarly, Bruce et al. [39] estimated that the level of underreporting of shortfin mako (*Isurus oxyrinchus*) and porbeagle (*Lamna nasus*) sharks in the ETBF between 1998 and 2011 was between 23 and 28% depending on the estimation method applied. Underreporting of discarded sharks in longline fisheries has previously been highlighted as the reason why there is a preference to use at-sea observer data in assessments for the Western and Central Pacific Fisheries Commission (WCPFC) [44,45].

There was also a significant increase in logbook-reported IPUE for some protected species groups in both the ETBF and GHAT. In the ETBF, the IPUE for seabirds, marine turtles and marine mammals increased significantly in the EM years, while in the GHAT, only the IPUE for marine mammals - dolphins and pinnipeds, increased significantly in the EM years. As previously mentioned, it is not possible to discount possible increases in abundance, availability, or individual vessel effects driving this change. However, we consider it unlikely that these effects would be solely responsible for the observed significant increases in IPUE, given the low productivity (e.g. slow growth, late maturation and low fecundity) of the protected species groups [46] which would not support significant and rapid changes in abundance, and the documented historical underreporting of interactions in both fisheries [41,43].

This supposition is again supported by various international studies suggesting that interactions with protected species are underreported in logbooks [27,47–50]. For example, in a comparison of at-sea observer and logbook data in an Australian sardine fishery, Hamer et al. [51] identified significant underreporting in logbooks of short-beaked dolphin (*Delphinus delphis*) encirclements and mortalities, with fishers only reporting 3.6% of the encirclements and 1.9% of the mortalities recorded by at-sea observers during the same period. Specifically in the ETBF, both AFMA [41] and Phillips et al. [52] highlighted underreporting of seabird interactions in fisher-reported logbooks, while in the GHAT, Goldsworthy et al. [53] observed significant historical underreporting of pinniped interactions in fisher-reported logbooks of gillnet vessels fishing in waters off South Australia. The Goldsworthy et al. [53] study led to AFMA implementing closures off South Australia around threatened Australian sea lion (*Neophoca cinerea*) colonies and increasing the level of monitoring (i.e. through at-sea observers and EM technology for vessels fishing in the area) [54]. The increased levels of monitoring revealed that dolphin interactions had also been systematically unreported in logbooks, with 27 reported in 2010/11 compared to a total of 13 in the preceding four years combined [55]. The observed increase in the number of dolphin interactions off South Australia, which followed increased monitoring sets a precedent for explaining the significant increase in pinniped and dolphin IPUE observed in the GHAT in Bass Strait following the implementation of an integrated EM system.

The absence of any significant increase in logbook-reported DPUE for byproduct and bycatch species as well as the observed increase in logbook-reported IPUE for marine mammals in the GHAT may be explained to some extent by the planning design and implementation of the integrated EM system by AFMA. In the GHAT, the initial focus, and one of the main drivers of EM implementation, was to improve reporting of protected species interactions, particularly dolphins and sea lions [56]. The communication of this specific objective at meetings with industry may have led to increased reporting, and subsequent

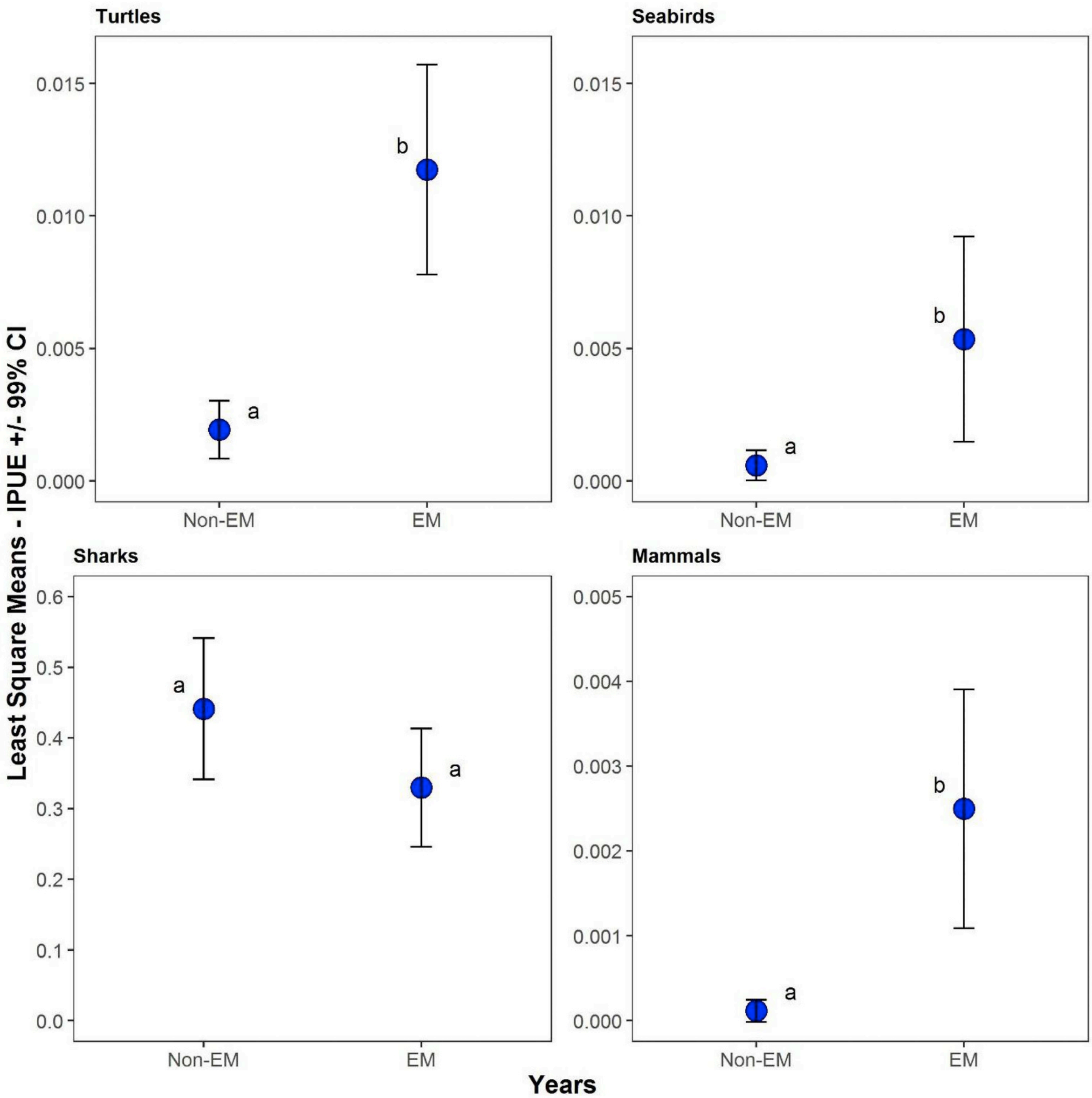

Fig. 4. Least square means ± 99% CI of protected species interaction per unit effort (IPUE) (no. individuals interacted with per 1000 hooks) by ETBF vessel that fished all years in EM (2015/16 and 2016/17) and non-EM (2009/10 to 2014/15) years for groups of protected species. Means not sharing a letter are significantly different at $p < 0.01$ (Tukey-adjusted comparisons).

increase in logbook IPUE for marine mammals during the EM years. In contrast, improving the reporting of discarded catch was not prioritised initially, with managers informing industry six months after EM implementation that they would tolerate incomplete reporting of discarded species in logbooks, with the expectation that discards were an approximation only [57]. While this informal offer probably originated from AFMA acknowledging that the fishery needed some time to adjust to new reporting requirements and guidelines for conduct, it may have influenced the incentive for fishers to report all of their discarded catch initially [57]. It is important to note, however, that this initial tolerance for recording discarded catch is no longer accepted, and AFMA has placed increasing focus on educating GHAT fishers to improve their reporting of all discarded catch. Furthermore, for the first 10 months following implementation of the integrated EM system, GHAT fishers were not required to report counts of discarded catch (only weights) while waiting for a revised logbook, which would have also influenced incentives to report discards.

In a similar analysis of nominal mean catch and discard rates from fisher-reported logbooks, Gilman et al. [27] observed no significant difference between longline vessels fishing in the Palau EEZ with and without EM technology installed. While this finding contrasts with our current study, it is important to note that contrary to the Australian EM program, there was no random auditing of logbook data or vessel feedback system implemented for those vessels fishing in the Palau EEZ, as it was a pilot study. Therefore, in taking a weight of evidence approach to our results, it is likely that significant increases in logbook-reported DPUE and IPUE during the EM years were caused to some extent by the random auditing mechanism and vessel feedback system instituted by AFMA influencing the individual reporting behaviour of fishers. This seems particularly the case in the ETBF, where an absence of any significant increase in CPUE but a concurrent increase in DPUE for target, byproduct and bycatch species along with most protected species groups was observed.

This perceived success of the AFMA EM program, which is still in its infancy, is made even more significant considering the current lack of any evaluation standards for logbook reporting. The implementation of

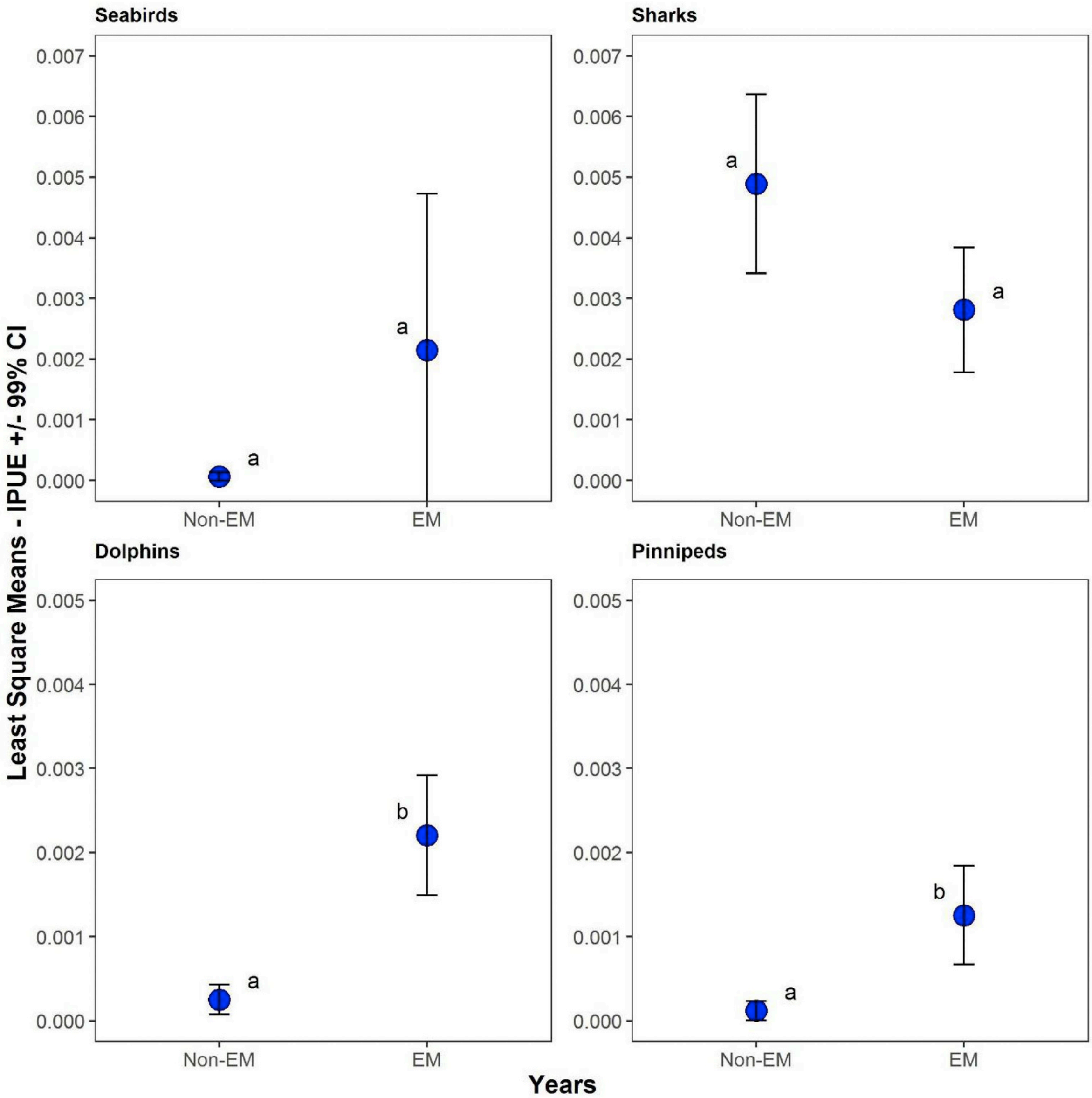

Fig. 5. Least square means ± 99% CI of protected species interaction per unit effort (IPUE) (no. individuals caught per 1000 m of gillnet) by GHAT (gillnet) vessel that fished all years in EM (2015/16 and 2016/17) and non-EM (2009/10 to 2014/15) years for groups of protected species. Means not sharing a letter are significantly different at $p < 0.01$ (Tukey-adjusted comparisons).

any integrated EM system that is used as an auditing tool should be accompanied by a logbook reporting evaluation standard, with associated sanctions or penalties (such as requirements for full review of EM imagery, or carriage of an at-sea observer at a fisher's own expense) for unsatisfactory performance, to create greater incentives to improve self-reporting in logbooks. This is currently implemented in the groundfish hook-and-line fishery in British Columbia [19,23] for unsatisfactory reporting of discards. A similar system has been instituted in the ETBF to manage the discarding of southern bluefin tuna caught during their annual migration up the Australian east coast. Only those fish that are classified as “alive and vigorous” can be released and if this is not complied with, operators will be required to carry an at-sea observer in future trips at their own expense [58]. While no overarching incentive scheme or logbook reporting evaluation standard has been implemented in the AFMA EM program to date, it is currently being considered (Gerner, M. [AFMA], pers. comm. 2018); and consequently, an opportunity exists to potentially observe further improvements in the accuracy of logbook reporting through time.

5. Conclusion

The accuracy of fishery-dependent logbook data is an important issue for fisheries managers when accounting for total fishing mortality. In the two years following the implementation of an integrated EM system, there was a significant increase in the DPUE for target, by-product and bycatch species, and a significant increase in the IPUE for seabirds, marine turtles and mammals in the ETBF. In the GHAT, there was a significant increase in the DPUE for target species, as well as the IPUE for marine mammals. While it is impossible to discount environmentally-driven shifts in availability or abundance and individual vessel effects influencing the results, the weight of evidence suggests there has likely been a shift in logbook reporting incentives among fishers in the EM years compared to the previous six years, particularly in the ETBF. As such, this study provides insight into reasons for differences in logbook reporting among both fisheries and how this could be improved in the future through the institution of quantitative evaluation standards for auditing fisher logbooks. Prescribing tolerances for logbook reporting, as similarly undertaken in Canadian fisheries [23], may further increase logbook reporting performance through facilitating certainty among industry as to AFMA's expectations. This could lead to a permanent "observer effect", in which fishing and logbook reporting behaviour changes fleet-wide, instead of on individual vessels or trips that are randomly selected to carry an at-sea observer [12,59].

In addition to the benefits associated with probable improvements in the accuracy of logbook reporting, the integrated EM system has also allowed AFMA to ensure operators comply with additional domestic and international legislation in relation to bycatch handling or marine pollution, which was previously unable to be policed effectively. Equally, the integrated EM system provides industry with the opportunity to demonstrate to the community that their fishing practices are best practice and aligned with public expectations about fisheries sustainability, theoretically acquiring a "social licence to operate" [60,61]. It could also assist industry in achieving third party certification (e.g. Marine Stewardship Council [MSC]), or to obtain export approval under the Australian *Environment Protection and Biodiversity Conservation Act 1999*. Individually, it also allows industry to be accountable for their fishing practices and allow compliant fishers to access areas previously restricted or closed, such as in the GHAT off South Australia due to interactions with protected species. These are all enhancements to the existing management framework, which when coupled with possible improvements in the accuracy of logbook reporting, should reassure the public owners of the resource that AFMA are meeting their legislative objective of ensuring accountability to the Australian community in the management of fisheries resources.

Acknowledgments

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.01.018.

References

[1] FAO, FAO Technical Guidelines for Responsible Fisheries 4: Fisheries Management, Food and Agricultural Organisation of the United Nations, Rome, 1997.
[2] H. Nakano, S. Clarke, Filtering method for obtaining stock indices by shark species from species-combined logbook data in tuna longline fisheries, Fish. Sci. 72 (2006) 322–332.
[3] D.B. Sampson, The accuracy of self-reported fisheries data: Oregon trawl logbook fishing locations and retained catches, Fish. Res. 112 (2011) 59–76.
[4] S.C. Mangi, S. Smith, T.L. Catchpole, Assessing the capability and willingness of skippers towards fishing industry-led data collection, Ocean Coast Manag. 134 (2016) 11–19.
[5] W.G. Macbeth, P.A. Butcher, D. Collins, S.P. McGrath, S.C. Provost, A.C. Bowling, et al., Improving reliability of species identification and logbook catch reporting by commercial Fishers in an Australian demersal shark longline fishery, Fish. Manag. Ecol. 25 (2018) 186–202.
[6] C.H. Faunce, A comparison between industry and observer catch compositions within the Gulf of Alaska rockfish fishery, ICES J. Mar. Sci. 68 (2011) 1769–1777.
[7] W.A. Walsh, P. Kleiber, M. McCracken, Comparison of logbook reports of incidental blue shark catch rates by Hawaii-based longline vessels to fishery observer data by application of a generalized additive model, Fish. Res. 58 (2002) 79–94.
[8] W.A. Walsh, R.Y. Ito, K.E. Kawamoto, M. McCracken, Analysis of logbook accuracy for blue marlin (Makaira nigricans) in the Hawaii-based longline fishery with a generalized additive model and commercial sales data, Fish. Res. 75 (2005) 175–192.
[9] M. Piasente, B. Stanley, T. Timmiss, H. McElderry, M. Pria, M. Dyas, Electronic Onboard Monitoring Pilot Project for the Eastern Tuna and Billfish Fishery. FRDC Project 2009/048, Australian Fisheries Management Authority, Canberra, 2012, p. 104.
[10] AFMA, Australian Fisheries Management Authority Electronic Monitoring Program: Program Overview, Australian Fisheries Management Authority, Canberra, ACT, 2015, p. 26.
[11] R.T. Ames, G.H. Williams, S.M. Fitzgerald, Using digital video monitoring systems in fisheries: application for monitoring compliance of seabird avoidance devices and seabird mortality in Pacific halibut longline fisheries, NOAA Technical Memorandum NMFS-AFSC, vol. 152, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Seattle, Washington, 2005, p. 93.
[12] H.P. Benoît, J. Allard, Can the data from at-sea observer surveys be used to make general inferences about catch composition and discards? Can. J. Fish. Aquat. Sci. 66 (2009) 2025–2039.
[13] S.C. Mangi, P.J. Dolder, T.L. Catchpole, D. Rodmell, N. de Rozarieux, Approaches to fully documented fisheries: practical issues and stakeholder perceptions, Fish Fish. 16 (2015) 426–452.
[14] GSGislason&Associates, Benefits and costs of e-monitoring video technologies for Commonwealth fisheries, GSGislason & Associates Ltd., Vancouver, Canada, 2007, p. 50.
[15] S. Dunn, I. Knuckey, Potential for e-reporting and e-monitoring in the western and central Pacific tuna fisheries. WCPFC10-2013-16_rev1: Secretariat of the Pacific Community (SPC) and the Western and Central Pacific Fisheries Commission, WCPFC, 2013, p. 67.
[16] H. McElderry, At sea observing using video-based electronic monitoring, Background Paper Prepared by Archipelago Marine Research Ltd. For the Electronic Monitoring Workshop July 29–30, 2008. Seattle WA, Held by the North Pacific Fishery Management Council, the National Marine Fisheries Service, and the North Pacific Research Board: the Efficacy of Video-Based Monitoring for the Halibut Fishery, 2008.
[17] J. Ruiz, A. Batty, P. Chavance, H. McElderry, V. Restrepo, P. Sharples, et al., Electronic monitoring trials on in the tropical tuna purse-seine fishery, ICES J. Mar. Sci. 72 (2015) 1201–1213.
[18] H. McElderry, J. Schrader, J. Illingworth, The Efficacy of Video-Based Monitoring for the Halibut Fishery, Fisheries and Oceans, Canada, 2003, p. 79.
[19] R.D. Stanley, T. Karim, J. Koolman, H. Mc Elderry, Design and implementation of electronic monitoring in the British Columbia groundfish hook and line fishery: a retrospective view of the ingredients of success, ICES J. Mar. Sci. 72 (2015) 1230–1236.
[20] R.T. Ames, B.M. Leaman, K.L. Ames, Evaluation of video technology for monitoring of multispecies longline catches, N. Am. J. Fish. Manag. 27 (2007) 955–964.
[21] A. Lara-Lopez, J. Davis, B. Stanley, Evaluating the Use of Onboard Cameras in the Shark Gillnet Fishery in South Australia, Australian Fisheries Management Authority, Canberra, Australia, 2012, p. 65.
[22] A.T.M. van Helmond, C. Chen, J.J. Poos, How effective is electronic monitoring in mixed bottom-trawl fisheries? ICES J. Mar. Sci. 72 (2015) 1192–1200.
[23] R.D. Stanley, H. McElderry, T. Mawani, J. Koolman, The advantages of an audit over a census approach to the review of video imagery in fishery monitoring, ICES J. Mar. Sci. 68 (2011) 1621–1627.
[24] NPFMC, 2017 Electronic Monitoring Pre-implementation Plan: EM Workgroup Recommendation to Council, September 2016, North Pacific Fishery Management Council, 2016, https://static1.squarespace.com/static/563cfe4fe4b0b371c8422a54/t/5834f48d9de4bbe7ab9b36a2/1479865493471/C3+2017+EM+Pre-Implementation+Plan+9-13-16+%282%29.pdf.
[25] J. Viechnicki, Electronic monitoring available for smaller fishing boat. KFSK Community Radio, https://www.kfsk.org/2017/08/10/electronic-monitoring-available-smaller-fishing-boats/2017.
[26] AFMA, South East Management Advisory Committee (SEMAC) Meeting 31 - Meeting Minutes 1-2 November 2017, Australian Fisheries Management Authority, Canberra, Australia, 2017, p. 35.
[27] E. Gilman, E. Schneiter, C. Brown, M. Zimring, C. Heberer, Comparison of Fisheries-dependent Data Derived from Electronic Monitoring, Logbook and Port Sampling Programs from Pelagic Longline Vessels Fishing in the Palau EEZ. TNC Indo-Pacific Tuna Program, (2018), p. 14.
[28] AFMA, Eastern Tuna and Billfish Fishery: Management Arrangements Booklet 2017/18, Australian Fisheries Management Authority, Canberra, 2017, p. 48.
[29] H. Patterson, J. Larcombe, S. Nicol, R. Curtotti, Fishery Status Reports 2018, Australian Bureau of Agricultural and Resource Economics, Canberra, 2018.
[30] AFMA, Southern and Eastern Scalefish and Shark Fishery: Management Arrangements Booklet 2017, Australian Fisheries Management Authority, Canberra, 2017, p. 93.
[31] A.F. Zuur, E.N. Ieno, N.J. Walker, A.A. Saveliev, G.M. Smith, Mixed Effects Models and Extensions in Ecology with R, Springer, 2009.
[32] J.T. Watson, A.C. Haynie, P.J. Sullivan, L. Perruso, S. O'Farrell, J.N. Sanchirico, et al., Vessel monitoring systems (VMS) reveal an increase in fishing efficiency following regulatory changes in a demersal longline fishery, Fish. Res. 207 (2018) 85–94.
[33] F. Jensen, N. Vestergaard, Asymmetric information and uncertainty: the usefulness of logbooks as a regulation measure, Ecol. Econ. 63 (2007) 815–827.
[34] S. Pascoe, I. Herrero, S. Mardle, Identifying Misreporting in Fisheries Output Data Using DEA, Seventh EU productivity and efficiency workshop, Oviedo, Spain, 2001.
[35] M.D. Camhi, Conservation status of pelagic elasmobranchs, in: M.D. Camhi, E.K. Pikitch, E.A. Babcock (Eds.), Sharks of the Open Ocean: Biology, Fisheries and Conservation, Blackwell Publishing Ltd., Oxford, 2008, pp. 397–417.
[36] S. Collins, An Evaluation of Australian Fishing Zone (AFZ) Squid Logbook Data and Samples Collected by AFZ Observers. Hobart, Marine Laboratory, Department of Sea Fisheries, Tasmania, 1988, p. 24 (Tasmania).

[37] J. Pope, Input and output controls: the practice of fishing effort and catch management in responsible fisheries, in: K.L. Cochrane (Ed.), A Fisheries Manager's Guidebook: Management Measures and Their Application, Food and Agricultural Organization of the United Nations, Rome, Italy, 2002, pp. 75–94.
[38] J. Larcombe, R. Noriega, T. Timmiss, Catch reporting under e-monitoring in the Australian Pacific longline fishery, Report for the 2nd Meeting of the Electronic Reporting and Electronic Monitoring Intersessional Working Group, Bali, Indonesia, August 2016, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, Australia, 2016, p. 20.
[39] B. Bruce, C. Ashby, P. Bolton, S. Brouwer, R. Campbell, K. Cheshire, et al., Shark futures: a synthesis of available data on mako and porbeagle sharks in Australasian waters, Current Status and Future Directions, CSIRO and FRDC, 2013, p. 151.
[40] R. Campbell, Summary of Logbook and Observer Data Pertaining to the Catch of Blue Sharks off Eastern Australia WCPFC Scientific Committee, Ninth Regular Session, Pohnpei, Federated States of Micronesia, CSIRO Marine and Atmospheric Research, 2013, p. 28.
[41] A.F.M.A. Eastern, Tuna and Billfish Fishery Management Advisory Committee (Eastern Tuna MAC) 75, Australian Fisheries Management Authority, Canberra, ACT, 2009.
[42] J.M. Braccini, M.P. Etienne, S.J.D. Martell, Subjective judgement in data subsetting: implications for CPUE standardisation and stock assessment of non-target chondrichthyans, Mar. Freshw. Res. 62 (2011) 734–743.
[43] D. Bromhead, J. Ackerman, S. Graham, M. Wight, Byproduct: Catch, Economics and Co-occurrence in Australia's Pelagic Longline Fisheries, Bureau of Rural Sciences, Canberra, Australia, 2006, p. 182.
[44] T. Lawson, Estimation of catch rates and catches of key shark species in tuna fisheries of the western and central Pacific Ocean using observer data, WCPFC-SC7-2011/EB-IP-02. Noumea, New Caledonia: Secretariat of the Pacific Community, 2011.
[45] D. Bromhead, S. Clarke, S. Hoyle, B. Muller, P. Sharples, S. Harley, Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications, J. Fish Biol. 80 (2012) 1870–1894.
[46] J.A. Musick, Ecology and conservation of long-lived marine animals, Am. Fish. Soc. Symp. 23 (1999) 1–10.
[47] J.K. Baum, R.A. Myers, D.G. Kehler, B. Worm, S.J. Harley, P.A. Doherty, Collapse and conservation of shark populations in the Northwest Atlantic, Science 299 (2003) 389–392.
[48] A.J. Read, P. Drinker, S. Northridge, Bycatch of marine mammals in U.S. And global fisheries, Conserv. Biol. 20 (2006) 163–169.
[49] NOAA, Evaluating bycatch: a national approach to standardized bycatch monitoring programs, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2004, p. 108.
[50] D.J. Hamer, Operational Interactions between Marine Mammals and Commercial Fisheries in Australian and South Pacific Waters: Characterisation and Options for Mitigation, The University of Adelaide, Adelaide, South Australia, 2012.
[51] D.J. Hamer, T.M. Ward, R. McGarvey, Measurement, management and mitigation of operational interactions between the South Australian Sardine Fishery and short-beaked common dolphins (Delphinus delphis), Biol. Conserv. 141 (2008) 2865–2878.
[52] K. Phillips, F. Giannini, E. Lawrence, N. Bensely, Cumulative Assessment of the Catch of Non-target Species in Commonwealth Fisheries: a Scoping Study, Bureau of Rural Sciences, Canberra, Australia, 2010.
[53] S.D. Goldsworthy, B. Page, P.D. Shaughnessy, A. Linnane, Mitigating seal interactions in the SRLF and the gillnet sector SESSF in south Australia, Report to the Fisheries Research and Development Institute, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia, 2010.
[54] AFMA, Regulation Impact Statement: Managing Interactions with Australian Sea Lions in the Gillnet Hook and Trap Sector of the Southern Eastern Scalefish and Shark Fishery, Australian Fisheries Management Authority, Canberra, Australia, 2013, p. 50.
[55] AFMA, Regulation Impact Statement: Managing Interactions with Dolphins in the Gillnet Hook and Trap Sector of the Southern and Eastern Scalefish and Shark Fishery, Australian Fisheries Management Authority, Canberra, Australia, 2011, p. 16.
[56] AFMA, South East Management Advisory Committee (SEMAC) Meeting No. 13: 15-16 October 2013 - Minutes, Australian Fisheries Management Authority, Canberra, Australia, 2013, p. 43.
[57] AFMA, Shark resource assessment group (SharkRAG), in: A.F.M. Authority (Ed.), Meeting No. 2 2015 18-19 November 2015: Minutes, 2015, p. 22 Canberra.
[58] AFMA, Information Package on SBT Longlining in the Area of the ETBF in 2016, Australian Fisheries Management Authority, Canberra, 2016, p. 8.
[59] C.H. Faunce, S.J. Barbeaux, The frequency and quantity of Alaskan groundfish catcher-vessel landings made with and without an observer, ICES J. Mar. Sci. 68 (2011) 1757–1763.
[60] S. Tracey, C. Buxton, C. Gardner, B. Green, K. Hartmann, M. Haward, et al., Super trawler scuppered in Australian fisheries management reform, Fisheries 38 (2013) 345–350.
[61] C. Cullen-Knox, M. Haward, J. Jabour, E. Ogier, S.R. Tracey, The social licence to operate and its role in marine governance: insights from Australia, Mar. Pol. 79 (2017) 70–77.