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Comparing Electronic Monitoring and human observer collected fishery data in the tropical tuna purse seine operating in the Pacific Ocean

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Abstract

Electronic Monitory (EM) systems have been proven a valid tool for collecting fishery dependent data. They are being widely used in many fisheries as a complement or alternative to human observers to increase the monitoring coverage of fisheries. However, considering its wide application, following agreed minimum standard, it is important to compare the congruence between the information collected by EM and observers. We compared EM and observer data collected on 7 trips of tuna purse seiners in the Eastern and Central Pacific Ocean to analyze the similarity of fishing set type identification, estimation of tuna and bycatch catches between both monitoring systems. Overall EM was a valid tool to estimate the type of fishing set. Retained total catch of tunas by set was estimated by EM as reliable as that by observers/logbook. When comparing the information by set, EM estimation of the main species, such as skipjack and bigeye and the combination of bigeye/yellowfin, was proven to be less accurate but statistically similar to the estimates made by observers. For bycatch species, EM allows to identify main bycatch species as observers do. For large individuals, such as sharks, billfishes and, to a lower extent, large bony fishes, EM identified a similar overall number of individuals when considering all trips together. For sharks, which are the main bycatch issue in the FAD purse seine fishery, the congruence between EM and observer was high.

Introduction

The scientific advice and management recommendations on the status of any fish stocks are based upon the results of fisheries stock assessments which depend on the analyses

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of the available and appropriate fishery information (FAO, 1999). Fishery-dependent and independent data are, therefore, needed to estimate abundance of populations and exploitation rates exerted on those populations but also to monitor fishery interaction with non-target species (FAO, 1997). In addition to catch and effort fishery-dependent information collected through logbooks and/or port-sampling of commercial vessels, observer data is key to compile, complement and verify fishery activity information (McElderry, 2008). Observer programs have been widely established in fisheries to improve the scientific data collection of catch composition by species, catch and fishing effort, size composition of the catch, vessel and fishing gear characteristics, bycatch and discards and interactions with Endangered and Protected Species (ETP), biological information (e.g. otoliths for age determination and gonads for fecundity studies). The information collected is determined by the objectives of each observer program. Moreover, observer data is sometimes also used to verify compliance with management measures as a means to strengthen the Monitoring and Control Surveillance (MCS) system and to increase the transparency in the fisheries (Ewell, Hocevar, Mitchell, Snowden, & Jacquet, 2020). For example, it has been shown that catch statistics, and bycatch discards, are more accurately reported in the logbooks and that compliance with management measures is improved when observers are onboard (Morrell, 2019). Ideally, scientific observer programs should be separated from those for compliance in order to ensure that information is collected objectively without pressures on the observer (Nolan, 1999). However, in practice many observer programs cover both roles such as the observer programs established in the Inter-American Tropical Tuna Commission (IATTC) under the Agreement on the International Dolphin Conservation Program (AIDCP) and the Western Central Pacific Fishery Commission (WCPFC).

Observer coverage is very diverse between regional management bodies. For example, only 3 out of 17 Regional Fishery Management Organizations (RFMOs) investigated by Ewell et al. 2020 require 100 % of observer coverage on their large scale vessels. Although it has been shown that observer coverage requirements for bycatch species should be between 20 and 50 % or even larger for rare species (Babcock, Pikitch, & Hudson, 2003; NMFS, 2004), most of the fisheries worldwide have lower observer coverage. Similarly, for compliance purposes, 100 % of observer coverage may be needed. In tuna RFMOs, there is a 100 % requirement for human observers in large scale Purse Seiners (class 6 vessels) in the Inter-American Tropical Tuna Commission (IATTC) under the Agreement on the International Dolphin Conservation Program (IDCP) and the Western and Central Pacific Fisheries Commission - WCPFC (CMM 2018-01), and 100% for human and/or electronic monitoring systems in the International Commission for the Conservation of Atlantic Tunas - ICCAT (ICCAT, 2019). On the other hand, the Indian Ocean Tuna Commission (IOTC) requires the collection of independent data on fishing activity through human observers for 5 % of the operations for each gear type (Resolution 11-04). However, the observer coverage requirement for smaller purse seiners as well as other type of fishing vessels is between 5 and 10 % in tuna RFMOs, which is not enough to obtain reasonably accurate scientific data on fishing activity. There are, however, several difficulties to increase the human observer coverage on some of those fleets which are related to the difficulty in placing observers onboard small fishing vessels. These usually have to do with the high costs involved in observer placement, debriefing and data handling, and with the limited availability of space onboard as well vessel seaworthiness.

Electronic Monitoring could be a good alternative, and/or complement human observers, (i) to increase the observer coverage for avoiding many of the practical difficulties of placing human observers on board some of vessels (e.g. smaller than class 6 PS in IATTC); (ii) to improve monitoring increasing observation coverage onboard (a single person cannot follow all the activities onboard) and collecting new data; (iii) to calibrate and verify reporting from human observers; and (iv) to ensure observer's safety. Electronic monitoring (EM) using cameras and other sensors is a proven technology and has been widely used for various purposes on fishing vessels, primarily in industrial fleets. EM systems consist of active tracking of a vessel's position and activity, together with a system of cameras that record key aspects of the fishing operations. EM has been used extensively for this purpose to obtain reliable information on catches and their composition as well to monitor and collect data on bycatches of protected species (ETP).

EM pilot tests on tuna purse seiners and longline vessels, as well as in small-scale artisanal fisheries, in different regions have demonstrated the validity of this technology to improve the collection of fishery information (Bartholomew et al., 2018a; Emery, Noriega, Williams, & Larcombe, 2019b, 2019c; Emery et al., 2018; McElderry, 2008; Ruiz et al., 2015). In some places EM systems have been fully integrated as a fishery monitoring tool such as the case of the west coast of Canada and the USA (Jannot, Richerson, Somers, Tuttle, & McVeight, 2020; NOAA, 2017; van Helmond et al., 2019) and east coast of Australia for the tuna longline fishery (AFMA, 2015), where there is a significant level of EM acceptance by fishers and fishing management agencies. However, before considering the wide application of any EM in general, and particularly in tuna fisheries, minimum standard for the installation, collection and analysis of data are needed (Emery et al., 2018; van Helmond et al., 2019). Moreover, it is also important to compare the congruence between EM and observers collected fishery data to ensure capability, replicability and accuracy of the information collected through EM (e.g. same data fields and to be as accurate as observer information) to inform the stock assessment and management process (Emery et al., 2018; Gilman, De Ramón Castejón, Loganimoce, & Chaloupka, 2020; van Helmond et al., 2019).

Tropical tuna purse seiners operate in the tropical areas of the three Oceans targeting skipjack, yellowfin and bigeye with three main fishing strategies or set types: sets on tuna free schools, sets on drifting Fish Aggregating Devices (dFADs) and other floating objects, and sets on tuna school associated with dolphins); the latter only occurs in the eastern Pacific Ocean under the mandate of the Inter-American Tropical Tuna Commission (IATTC).

Thus, we aim to analyze the similarity between data collected using EM system, human observers and logbooks to determine whether EM systems are suitable to collect accurate and reliable fishery statistics with regards to (i) fishing set distribution, (ii) set types, (iii) estimation of total tuna catches and by species and (iv) estimation of bycatch of total bycatch and by species group. In short, we aim to determine whether EM is a viable monitoring tool to be applied to tuna Purse seiner fisheries in the Pacific Ocean.

Material and Methods

EM records, observer data, and logbook data were simultaneously collected during 7 trips, with a total of 155 purse seine sets, conducted in the eastern and western Pacific

Ocean by two different purse seine vessels (Aurora B and Rosita C) in 2017 (Table 1). These vessels do not perform dolphin sets.

Table 1.- Vessels and number of fishing sets by area performed during the study.

			Number of Sets			
Vessel.Name	Trip	Months	WCPFC	Overlap area	IATTC	Total
Aurora B.	1	February-March	8		6	14
Aurora B.	2	April-May	26		2	28
Rosita C	3	April-May	6		8	14
Aurora B.	4	June-July	5		15	20
Rosita C	5	August-October	0	4	38	42
Aurora B.	6	October-November	19		2	21
Aurora B.	7	November-December	9	1	6	16
			73	5	77	155

Electronic Monitoring

Satlink SeaTube EM (with central processing unit, digital video cameras, and type approved VMS receiver) was used. A 6-camera High Definition (1280 x 720 @ 24FPS) system was installed with three cameras located above on the working deck and three other ones mounted mid-line directly above the wet deck's fish loading conveyor belt system (Figure 1). HD high quality video data from all 6 cameras was recorded continuously 24/7 and stored on removable hard disk drives on the bridge. Each video image is stamped with the vessel's name, the date and time (GMT – 1-second accuracy) and the corresponding position (latitude and longitude to the nearest 0.00001˚).

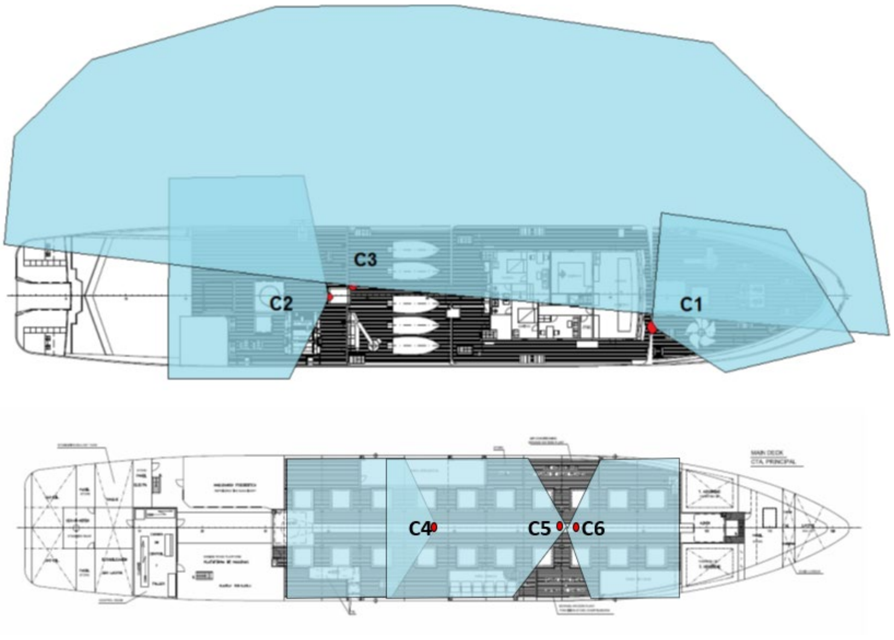

Figure 1.- Cameras onboard Rosita C and Aurora B.

The video images were reviewed by Digital Observer Services (DOS). EM images analysts reviewed data on fishing set (date, time and location), type of set (FAD and free school), and for each set the catch of target species, the bycatch and discards (including sex and size measurement when possible). The type of set was determined according to the behavior of the vessel when approaching the school/FAD, recording evidences of the presence of a FAD and the fish species composition of the catch. Weights of target tuna species catches, by species, were estimated by counting the number of brails and the fullness of each brail (the maximum brail and well capacity information was provided by the vessels operator). For a known well capacity, the brail capacity was calibrated based on the number of brails dropped into the well. The catch weight given to each brail were verified comparing the total weight of all brails dropped into a particular well and the total well capacity. This is the same procedures as it is made by observer onboard but using only information from video footage without auxiliary additional information used by observers (e.g. information from sonar or crew). Species composition was determined by identifying the species percentage in a known grid of the conveyor belt in the lower deck. Bycatch/discards (in numbers) were counted by reviewing images of the upper and lower deck cameras. EM analysts were instructed to record all retained catches, by-catches and discards (including the fate - dead or alive-) for all sets, however, camera positions and configuration was not designed for the detection and identification of small bony fish bycatch as the target species are rarely under 30 cm.

Observer Data

Spanish National Observer Program data collected, using IATTC – Agreement on the International Dolphin Conservation Program (AIDCP) observer program standards and forms, in both regions of the Pacific was used for the analysis. Although for the trips/sets in the WPO an additional observer from the WCPFC Regional Observer Program was also collecting information onboard, for this study only observer data from the Spanish observer program in both side of the Pacific was used. Using AIDCP observer program standards and forms, the observer collected information on fishing set date-time and location, type of fishing sets, retained catch and discards (both target and bycatch species).

Logbook data & cannery unloading data

Fishing vessels operating both in the eastern and western Pacific Ocean are required to complete and submit logsheet information on fishing set catch and catch and effort information to the IATTC and WCPFC, respectively. The main fishery information collected in the logbooks is the type of fishing activity including date-time and location of the fishing sets and the resulting information of the fishing sets about retained catch by species. For this analysis, only retained total catch by species was available from logbooks (Román, Cleridy, & Ureña, 2019).

All retained catch was delivered to a cannery in Manta or in Bangkok with a cargo vessel. Cannery information of sales by species was available for all trips, however, for the catch of the trips sold to Bangkok no species identification was available for fish < 1.8 kg (2 trips). Sales information of total retained catch was used to appraise the accuracy of EM/Observer and logbook information of total retained catch and by species.

Data analysis

Set type

Differences in set-type classification between the observer and EM was described by an exact binomial test (Conover, 1971) which estimates the set type categorization success probability. The identification of the set type (free-school and FAD) by the observer was considered accurate.

EM and observer catch/bycatch comparison

A Generalized Linear Model (GLM) was fitted to catch data for each fishing set to compare the variability between EM and observer estimates of total target species catch, total retained target species catch, total catch by species, total bycatch and main species group bycatch. The GLM approach was used to appraise overall correspondence between EM and observer estimates rather than as a predictive model (Freedman, 1997). GLM model formulation was:

$$EM \sim OBS + \varepsilon$$

or in the case that area/RFMO is used as factor

$$EM \sim OBS * RFMO + \varepsilon$$

Where EM and OBS are the estimates of catch (in metric tons, mt) and bycatch (in numbers) in each fishing set by Electronic Monitoring and Observers, respectively, RFMO is the Regional Fishery Management Organization where the fishing set occurred (the six sets in the overlap are were excluded from this analysis), and ε is the model error.

Model fit was also determined by the Deviance (D^2), considered a pseudo-R^2, for the GLM, estimated as follows:

$$D^2 = (\text{Null deviance} - \text{Residual deviance})/\text{Null deviance}$$

Where the null deviance is the deviance of the intercept only model and the residual deviance is the unexplained deviance of the final model (McFadden, 1974).

Catch data are continuous and positive and its variance increased with the mean and, hence, a gamma distribution was assumed for the error (McCullagh and Nelder, 1989). If the estimates between EM and the observer are the same, their relationship will follow a 1:1 relationship, expressed as a slope of 1 in a regression model (Piñeiro et al., 2008). The fitted model was compared to the expected 1:1 relationship (slope of 1, intercept of 0) using an identity link for GLM. When 95% confidence intervals of the estimated intercept and slope encompassed 0 and 1, respectively, the data estimated by EM was considered to be consistent with the observer estimates. Skunk (failed) sets, those where the tuna school manages to escape from the fishing operation, were omitted from the GLM analysis. This GLM approach was applied to total target catch, total retained target catch as well as total catch by species (Skipjack, Yellowfin and Bigeye). For total retained catch, to evaluate whether relationship between EM and observers varies depending on the RFMO area, a main effect of area and the interaction between observer estimate and area was included in the model.

For the bycatch, EM and observers count the individuals of each bycatch species, which are identified to the species level or group level. In this case, a GLM for total bycatch and bycatch by species groups (sharks, billfishes, large bony fishes and small bony fishes) with Poisson error distribution and identity link function was applied as recommended by McCullagh and Nelder, 1989. Similarly, the model outputs were compared to the expected 1:1 relationship. Fishing sets with bycatch observations (number >0) from either EM or observers were included in the analysis. The validation of the model fit and the adequacy of the error structure were checked by residual diagnostics.

The GLM for individual species was not possible due to the low number of observations. In this case, the bycatch number estimates by observer and EM is provided in Appendix 1.

All GLMs were performed using the packages stats and glm2 of the statistical software R (http:// www.r-project.org/) (Marschner, 2011).

Results

Trip overview and classification of sets

Seven trips were conducted on two tuna purse seine vessels, Aurora B and Rosita C, in 2017 fishing on High Seas of the eastern and western Pacific with the exception of 1 fishing set made in the Cook Islands EEZ (Figure 2). In total, 155 fishing sets were performed (Table 2) accounting for valid (positive) and skunk (e.g. failed operation with no or little capture) sets and EM and observers identified all of them (logbook information was only available for positive sets). Seventy nine out of 155 fishing sets (51 %) were performed in IATTC area, 71 (46%) in WCPFC area and 5 fishing sets (3 %) in the overlap area between IATTC and WCPFC. All valid sets were identified as FAD sets by EM/Observers and logbooks. There were some differences in the identification of the 6 skunk sets, with observers recording all of them as FADs sets while EM identified 3 out of 6 as free school sets. Moreover, EM identified a valid FAD sets with up to 0.5 metric tons of yellowfin while observers and logbooks considered it null. Thus, the probability of EM successfully identifying a FAD set, assuming that the observer correctly identified FAD set, was 98.1 % (p-value < 2.2e-16) for FAD sets and 42.8 % (p-value < 2.2e-16) for FAD sunk sets.

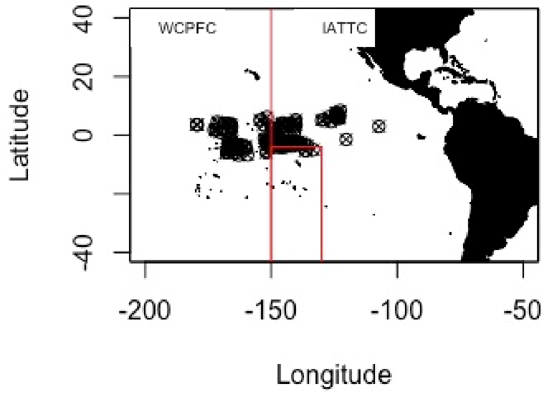

Figure 2.- Map of fishing locations.

Table 2.- Number of total, valid and skunk fishing sets by fishing mode in all the 7 trips investigated and by observation sampling source. FAD = FAD sets, Free = Free school fishing sets, DOL= Dolphin associated sets. * For logbook, only information on valid sets was available.

	Valid sets			**Sunk Sets**			**Total Sets**		
Observation	**FAD**	**Free**	**Total**	**FAD**	**Free**	**Total**	**FAD**	**Free**	**Total**
Observer	148	0	148	7	0	7	155	0	155
EMS	149	0	149	3	3	6	152	3	155
Logbook	148	0	148	0	0	0	148	0	148

Geographical positions of the fishing sets from EM, observers and logbook were compared with the purpose of assessing the level of correspondence between the three information sources. The fishing set locations from EM, observer and logbook are identical for all identified sets (Figure 2). The position of the set is recorded by EM, observer and logbooks when the skiff is release to the water. . The absolute values of the latitude and longitude differences indicated that a large correspondence between fishing sets positions (latitude and longitude) among information sources. The results showed that most of the pairs of coordinates differed in < 0.01 decimal degrees (~1km) (Table 3, Figure 3). Maximum discrepancies between location of fishing sets was 0.025° between EM and Observers (latitude) and 0.05° between EM and Observer/logbook (longitude). Differences between observers and logbooks were negligible indicating that observers collect information on fishing set location from Logbooks.

Table 3.- Differences in absolute values of latitude and longitude among different information sources.

EM-Observer	**EM-Logbook**	**Observer-Logbook**

	Latitude	Longitud	Latitude	Longitud	Latitude	Longitud
Percentile 1%	0.000100	0.000094	0.000033	0.000033	0.000000	0.000000
Percentile 25%	0.003500	0.002990	0.003000	0.002650	0.000000	0.000006
Median	0.008200	0.007300	0.006800	0.005900	0.003330	0.003330
Percentile 75%	0.013200	0.010300	0.011000	0.009320	0.003330	0.003340
Percentile 99%	0.025600	0.021100	0.019100	0.018500	0.003330	0.003340
Maximum	0.025600	0.038398	0.019067	0.046633	0.020000	0.053328

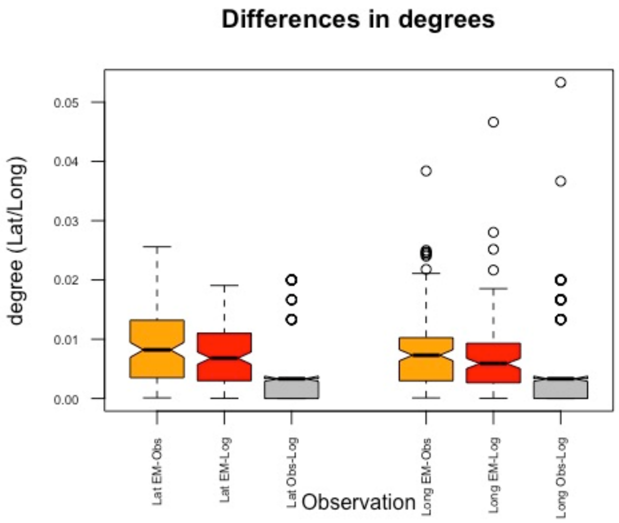

Figure 3.- Boxplot for the absolute difference of latitude/longitude between observation sources.

Comparison of tuna catches between observation sources

Overall, total retained tuna catch considering all trips together was very close between EM, Observers and Sales, providing a good correspondence of total retained catches among them (Table 4). For EM the total retained catch for all trips was 6 % less than sales information. Observer estimates of retained total tuna catch was almost exactly the same as the logbooks, indicating that observers use catch information given to them by the vessel captain. By trip, the correspondence of EM estimates with sales varied from +4% to -12% while the range for observers/logbooks was between +4 % and -8 % (Table 4).

Table 4.- Tuna catch estimates (mt) by trip from EM, Observer, Logsheet and Cannery sales.

Trip	EM	Obs.	Log.	Sales
1	1400	1480	1480	1502
2	1414	1485	1485	1493
3	1342	1353	1354	1300
4	1364	1428	1428	1422
5	1283	1348	1344	1459
6	1340	1480	1480	1436

Trip	EM	Obs.	Log.	Sales
1	-7%	-1%	-1%	1502
2	-5%	-1%	-1%	1493
3	3%	4%	4%	1300
4	-4%	0%	0%	1422
5	-12%	-8%	-8%	1459
6	-7%	3%	3%	1436

7	1334	1460	1460	1481
Total	9476	10034	10031	10092

7	-10%	-1%	-1%	1481
Total	-6%	-1%	-1%	10092

The total retained catch by species was variable among trips (Table 5). Generally, EM and observers estimated lower amounts of bigeye and skipjack and larger amounts of yellowfin than sales information; which were considered more reliable (IOTC, 2013; Lewis, 2017) . However, the differences from EM are larger than those for observers/logbooks.

Table 5.- Tuna catch estimates (mt) by species and trip from EM, Observer, Logsheet and Cannery sales. The percentages are calculated as the difference between the estimations source (EM/Observers) and sales (Observer source-Sales/Sales).

	EM						Observer						Sales		
Trip	BET		SKJ		YFT		BET		SKJ		YFT		BET	SKJ	YFT
1	381	-35%	623	-27%	397	456%	705	21%	719	-15%	56	-22%	582	848	71
4	729	-7%	527	-8%	107	69%	799	1%	554	-3%	75	18%	788	571	63
5	58	-73%	996	-15%	228	224%	144	-33%	1074	-9%	130	84%	214	1175	70
6	490	25%	777	-18%	74	-19%	367	-6%	990	4%	123	34%	391	953	92
7	725	6%	494	-34%	116	138%	550	-20%	846	13%	64	32%	687	746	48
Total	2382	-10%	3416	-20%	922	167%	2565	-4%	4183	-3%	448	30%	2661	4293	345

The GLM to compare EM total retained catch and observer/logbook estimations showed a high correspondence between the different source of information analysis (Figure 4 and Table 6). Observer data and logbook data followed a relationship very close to the 1:1 relationship indicating that both basically use the same information. Therefore, only EM and observer data were compared in subsequent analyses. In all relationships, the 95% confidence intervals of the intercept were close to 0 or encompassed. Similarly, in all relationships, the 95% confidence intervals were close to 1 or comprised 1. GLM model fits explained a large amount of deviance of the model (D2 > 95% in all models analyzed). Although the differences were small, there was a significant difference in correspondence between EM and observers by RFMO, with equivalence slightly increasing in WPO (Figure 4).

Table 6.- Summary statistics and estimated parameter outputs from the GLM regression between EM analyst and observer/logbook catch estimates (N=number of sets observed, D^2=deviance explained by the model).

Comparison	**N**	**D^2**	**Parameters**	**Estimates**	**CI 2.5%**	**CI 97.5%**	**P-value**
EM~OBS	148	95.6%	Intercept	0.607	0.382	0.832	3.6e-6***
			Slope	0.965	0.932	0.998	< 2e-16***
OBS~LOG	147	100.0%	Intercept	-0.003	-0.016	0.010	0.642
			Slope	1.001	1.000	1.001	<2e-16***
EM~LOG	147	95.5%	Intercept	1.531	0.838	2.224	2.38e-4***
			Slope	0.930	0.892	0.968	<2e-16***
EM~OBS	143	96.2%	Intercept	3.061	1.827	4.295	2.55e-5***

by RFMO	Observer	0.890	0.832	0.947	<2e-16***
	RFMO	-2.567	-3.813	-1.321	7.7e-4***
	Observer*RFMO	0.061	-0.011	0.133	0.0963

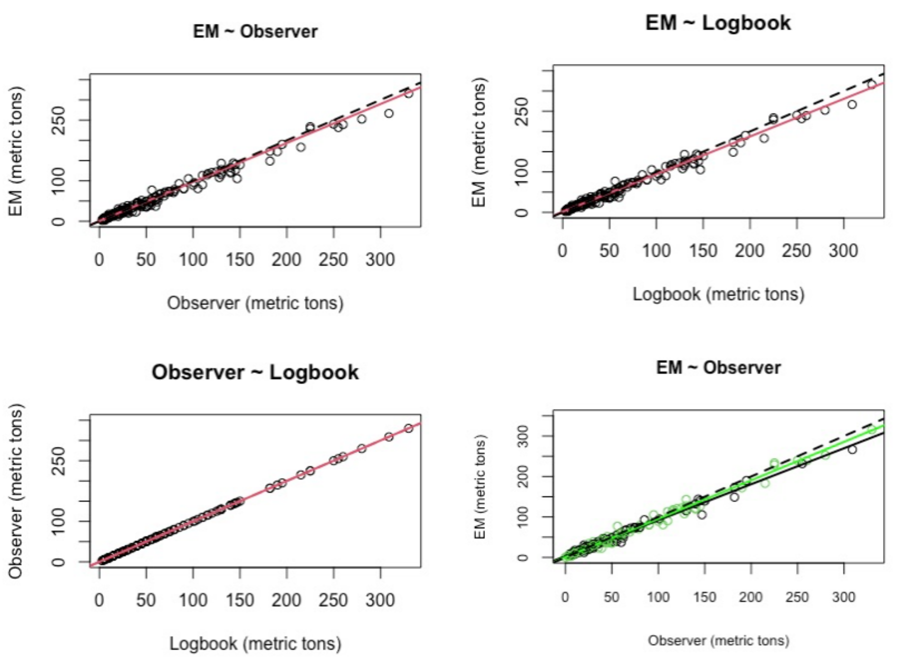

Figure 4.-_ Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and other information sources (observer and logbooks) (a, b) and between observers and logbook (c). Estimated regression for EPO (solid black) and WPO (solid green line) in d.

By species, the correspondence between EM and observer retained catch was worse than the total retained catch comparisons. However, for the main species in volume within a set, skipjack and bigeye, the species specific GLM to compare EM total retained catch estimated and observer estimations by species showed a reasonable correspondence (Figure 5 and Table 7). Except for yellowfin, in all relationships the 95% confidence intervals of the slope contained or were close to 1. GLM model fits explained 48.9%, 65.8% and 74.7% of deviance of the model for bigeye, bigeye and yellowfin together, and skipjack respectively. Relative to observer estimates, EM tended to underestimate the retained catch of skipjack and bigeye in comparison to observer estimate, the underestimation being less pronounced for bigeye, while yellowfin retained catch was overestimated when compared with observer estimates.

Table 7.- Summary statistics and estimated parameter outputs from the GLM regression between EM analyst and observer retained catch estimates by species (N=number of sets observed, D^2=deviance explained by the model).

EM-OBS	N	D2	Parameters	Estimates	CI 2.5%	CI 97.5%	P-value
SKJ	146	74.7%	Intercept	3.2229	1.9293	4.5164	2.28e-06***
			Slope	0.7294	0.6533	0.8055	< 2e-16***
BET	80	48.9%	Intercept	4.2335	1.5456	6.9214	0.00241**
			Slope	1.0070	0.6630	1.3510	1.17e-7***

YFT	114	11.6%	Intercept	4.0513	0.8210	7.2815	0.01443*
			Slope	1.4609	0.5287	2.3931	0.00241**
YFT+BET	139	65.8%	Intercept	1.900500	0.641178	3.159814	0.00337**
			Slope	1.1058	0.880573	1.331053	< 2e-16***

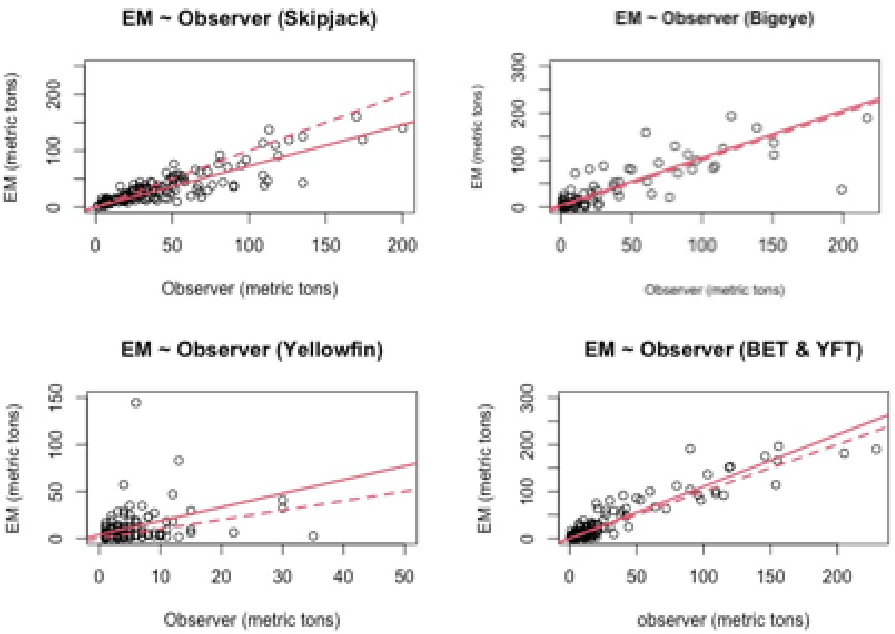

Figure 5.- Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and observer retained catch estimation by species.

Discards

Discarded tuna quantities were low during the sampled trips. There were 7 out of 148 valid sets where discarded tuna weight was larger than one mt according to any data source. From these, in 3 sets discarded tuna weight was larger than 10 tones, all of which were the last fishing set of a given trip. Discarded tuna catch was limited to some gilled in the seine net and damaged small-size fish or last fishing sets when well capacity had been filled. During the seven trips, EM recorded discards in 46 out of 148 sets while observers recorded discards in half of those sets (24 out of 148). The amount of bigeye and yellowfin tuna discarded observed by EM and observers in all trips altogether were very similar (16 vs 15 mt for BET and 2.4 vs 2 mt for YFT for EM and observers respectively), however, it was more variable within trips. For SKJ, observers estimated 11 mt less than EM (17% less than EM) (Table 8).

Table 8.- Estimated discards (mt) by observer system for each species. N: the number of fishing sets where discards were recorded, BET: bigeye, SKJ: skipjack, and YFT: yellowfin.

	EM					Observer				
Trip	**N**	**BET**	**SKJ**	**YFT**	**Total**	**N**	**BET**	**SKJ**	**YFT**	**Total**
1	10	0.2	4.7	0.5	5.4	6	4	17	0	21
2	8	5.5	18	1.1	24	4	2	7	0	9
3	9	3.4	30	0.6	34	4	5	14	0	19
4	7	1.3	2.3		3.6	2	1	2	0	3

5	3		0.6		0.6	3	1	4	2	7
6	3	4.5	8.5	0.2	13	2	1	7	0	8
7	6	1.1	2.6		3.7	3	1	4	0	5
Total	**46**	**16**	**66**	**2.4**	**85**	**24**	**15**	**55**	**2**	**72**

Comparison of by-catches between observation systems

For billfishes, large and small bony fishes bycatch (see appendix 1), EM recorded fewer individuals than observers did. For billfishes for example, while observers recorded 43 individuals, EM observed 30 (Table 9, Figure 6). Both observation systems recorded the same number of rays, 5 in total, however, the species recorded by both observations systems were different (Appendix 1). On the other hand, EM recorded one turtle bycatch, which was released alive, while observers recorded none. For sharks, the number observed by EM (1630) was 14% larger than the number recorded by the human observers (1436). However, most sharks were not identified to the species level by EM and, therefore, observers recorded more silky sharks (1428 individuals) than the EM did (327) (Appendix Table 21). In general, a good correspondence of total bycatch numbers was obtained for sharks, rays and billfishes (Table 9).

Table 9.- Bycatch in number by species group recorded by EM and observers.

Bycatch Group	EM	Observer
Billfishes	30	43
Large Fish	4094	5131
Rays	5	5
Sharks	1630	1436
Small Fish	227	6770
Turtles	1	0
Total	**5987**	**13385**

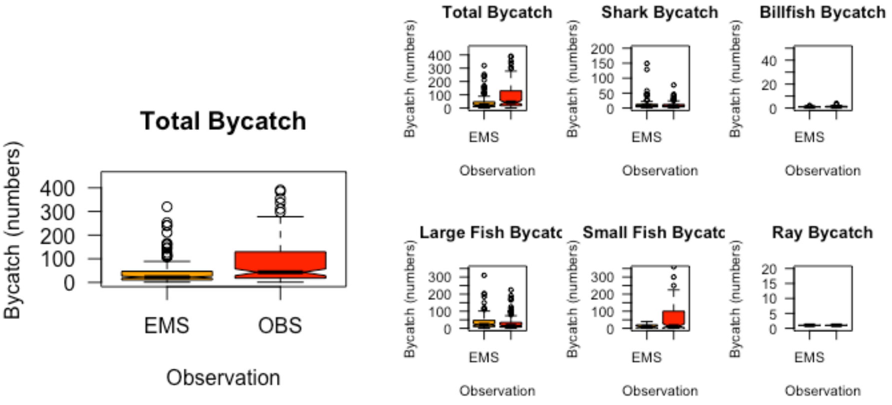

Figure 6.- Boxplot of total bycatch in numbers reported by EM and observers.

The most common species of sharks, billfishes and bony fishes were recorded by both monitoring systems. The main species identified by both methods were: Silky shark (*Carcharhinus falciformis*), Dolphinfish (*Coryphaena hippurus*), Wahoo

(*Acanthocybium solandri*), Rainbow runner (*Elagatis bipinnulata*), Blue marlin (*Makaira nigricans*), triggerfish (*Canthidermis maculata*), and Pelagic stingray (*Pteroplatytrygon violacea*). Oceanic white-tip shark (*Carcharhinus longimanus*), black marlin (*Istiompax indica*) and other small fishes were only recorded by observers but not EM. In many cases, for both monitoring systems, the taxonomic identification only reached the family level or, in the case of unidentified sharks/mantas, the order level (See Appendix 1). Observers identified more individuals and species at the species level for less numerous and rare bycaught species.

Wilcoxon non-parametric tests showed that the estimates of total bycatch, shark bycatch and billfish bycatch are significantly different between EM and Observers ($p< 0.05$). GLM was only performed for sharks, billfishes, large bony fishes and small bony fishes since the number of observations were very small for other groups or for applying to single species.

For bycatch species, with the exception of sharks, EM reported fewer bycatch items than were reported by observers (Figure 7 and Table 10). For those species groups, the estimated slope was far from 1 and the confidence intervals of the slopes were below the expected value of 1.0. The correspondence between EM and observer was large for sharks as the GLM showed that the 95 % confidence interval of the slope contained 1 (Figure 7 and Table 10). For sharks, the GLM fit explained 41.7% of the model deviance.

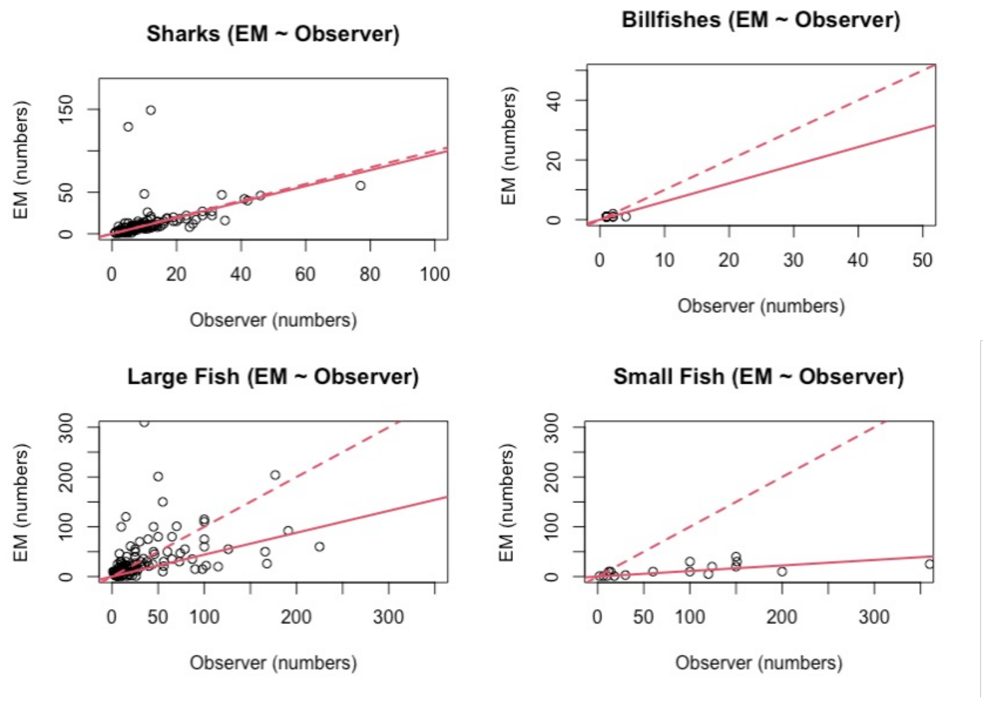

Figure 7.- Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and observer bycatch estimation by species groups.

Table 10.- Summary statistics of GLM relationship between EM and observer data of the different bycatch groups.

EM-OBS	**N**	**D2**	**Parameters**	**Estimates**	**CI 2.5%**	**CI 97.5%**	***P*-value**
Sharks	131	41.7%	Slope	0.959	0.762	1.156	<2e-16 ***

Billfishes	19	77.5%	Slope	0.609	0.446	0.771	3.11e-07 ***
Large Fishes	111	39.2%	Slope	0.441	0.337	0.544	1.63e-13 ***
Small Fishes	17	67.7%	Slope	0.111	0.071	0.152	2.73e-05 ***

Size frequency of silky shark (assuming that unidentified individuals from EM correspond to silky sharks) recorded by EM and observers are shown in Figure 8. Mann-Whitney-Wilcoxon test showed that the medians of the size frequency distribution are coming from identical populations (*p*= 0.6371). Statistical comparison of length frequencies recorded by observers and EM using the two-sample Kolmogorov & Smirnov test also showed that the length frequencies are not statistically different (Ds=0.149, *p*=0.71).

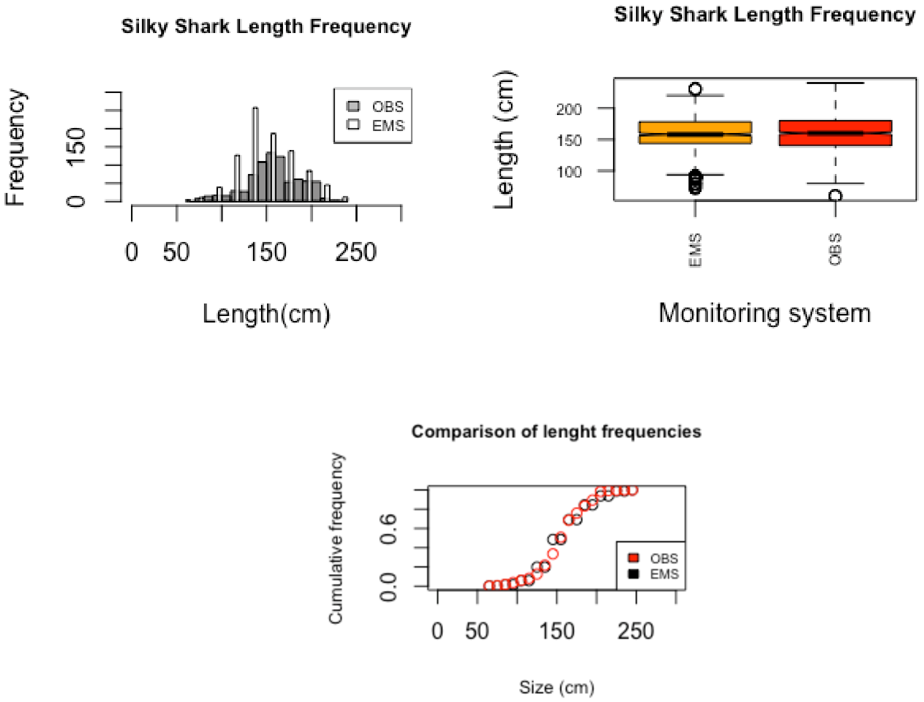

Figure 8.- Comparison of silky shark (a) length frequencies, (b) boxplot, and (c) cumulative length frequencies for Kolmogorov-Smirnov test between EM and observers.

Discussion

EM technological advances have largely improved recently and, hence, integrated monitoring systems are being considered in RFMOs in general, and tuna RFMOs, in particular, as a monitoring tool to complement and/or augment or replace human observers (Emery et al. 2019b; Emery et al. 2018; Helmond et al. 2019). EM is capable of collecting fishery-dependent information such as fishing set type, FAD activities, fishing set position and time, total and retained catch as well as catch by species, discards, bycatch and size frequencies of the catch and bycatch (McElderry, 2008; van Helmond et al., 2019). EM will allow to collect an enormous quantity of information that could be used either as a census of all fishing activity or to monitor a percentage of fishing activities (Mangi et al., 2015). Moreover, EM could be used in conjunction with strong Monitoring, control and surveillance (MCS) system to verify that fisheries are complying with management rules (Emery et al., 2019c; van Helmond et al., 2019).

Although some discrepancies in relation to the type of sets between free school and FAD sets were observed in skunk sets, overall EM has proven a valid tool to estimate the type of fishing set. In the tuna purse seine fishery, the identification of the type of sets is very important to estimate correctly the fishing effort and catch per unit effort (CPUE) used in the assessment. Not only for the CPUE but also for the determination of bycatch level as the bycatch is different among purse seine fishing sets (free school, FAD and dolphin sets) (Hall & Roman, 2013). Moreover, the determination of the type of set is crucial for the Marine Stewardship Council (MSC) certified fisheries both in FAD and free school as currently different type of sets could be included in a particular MSC Unit of Assessment, until the new MSC definition of the Unit of Assessment enters into force[8]. For example, PNA MSC purse seine fishery is certified for free school sets and, therefore, the identification of the type of set in a fishing trip is fundamental. In this sense, it could be concluded that the placement of the cameras is correct to identify the types of fishing sets. FAD activities (e.g. such as deployment, maintenance, visits, repairs, retrievals) were also recorded by EM but have not been analyzed in this study. Before fully implementing EM it would be advisable to also analyze the correspondence between EM and observers in relation to FAD activities which has been demonstrated to be reliable in support vessel (Legorburu et al., 2018) and in a pilot for purse seiners (Itano, Heberer, & Owens, 2019).

In this study, retained total catch of tunas by set was estimated by EM as reliable as that by observers/logbook. However, although generally similar, some differences in total catch was observed when comparing total retained catch estimate by EM and sales to the canneries. Thus, EM system following minimum standards in purse seine could be a valid monitoring system to accurately estimate retained tuna catch, provided that some improvements are included by the EM analysist when counting/weighting the brails. For EM to be implemented widely, a good correspondence between observers, logbooks but specially landings (or sales) of tuna catches by species is needed. It is a requirement of EM to record accurately retained catches for EM to be implemented widely as a complement, or replacement, of observers or other monitoring system (port landing, etc…) (Emery et al., 2019c). In this study, EM has not shown to be as reliable to estimate catch by species as it did for total tuna catch. The comparison of total retained catch by species between EM system and sales showed that the estimations were different. But this was also for the case of observers. When comparing the information by set, EM estimation of the main species, such as skipjack and bigeye and the combination of bigeye/yellowfin, was proven to be less accurate but statistically similar to the estimates made by observers. Surprisingly, EM estimates of YFT were very different from those estimations by observers, being EM YFT estimates larger than observer estimates. In previous works, bigeye has proven to be more difficult to estimate by EM (Itano et al., 2019; Ruiz et al., 2015) but in this case yellowfin estimates among monitoring systems were very different. The activity of these vessels took place in the central Pacific Ocean where relatively more bigeye is caught in FADs sets while the EM analyst could be more familiarized to analyze FAD sets from other regions where yellowfin is more predominant than bigeye. This could explain the discrepancies

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[8] https://www.msc.org/docs/default-source/default-document-library/for-business/program-documents/fisheries-program-documents/msc-fisheries-certification-process-2-2-summary-of-changes.pdf

between this study and other similar studies comparing EM and observer estimated catch in purse seiners (Briand et al., 2018; Ruiz et al., 2015). However, when considering both bigeye and yellowfin together, the relationship and correspondence between EM and observers improved. The difficulty associated with identifying the species could be due to the large volume that enters the conveyor belt very rapidly (each brail contains ~ 8 mt for Aurora B and 9 mt for Rosita C of tuna that are rapidly processed). When passing through the conveyor belt, the cameras are unable to capture clear images of individual tunas, the species as they are moving together with various layers mixed, making the posterior identification of species by EM analyst difficult. The EM system process used to estimate the catch by species used a grid of known dimensions to measure/identify the fish in the grid to the species level and then extrapolate the species composition to the total catch recorded for that particular set. An improvement to the species composition estimates could be obtained when developing a system where the fish pass in one single layer on the conveyor belt or the cameras are better placed to count and measure more fish by set, or even by brail, which would allow more accurate estimations. Our results in relation to the similarity of total tuna retained catch between EM and observers and the lower capability of EM to estimate correctly the retained catch by species have been also observed in other tuna fishery EM studies (Emery et al., 2019c; Júpiter, 2017; McElderry, 2008; Ruiz et al., 2015).

For bycatch species, EM allows to identify main bycatch species as observers do; however, the capability of EM to estimate same number of bycatch items in comparison to observers varies greatly by species group. For large individuals, such as sharks, billfishes and, to a lower extent, large bony fishes; EM identified a similar overall number of individuals when considering all trips together. For billfishes, there were some differences between EM and observers which could be related to the camera configuration as the final configuration did not capture images of the area where some of the billfishes could be manipulated by the crew (i.e. rail over the chain while the net is coming up with entangled fish). EM was not tailored to estimating small fishes for which observer estimates were much higher. This could be related to the fact that the EM camera configuration was not tailored to detect and identify small bycatch and/or analysts focused on main bycatch species of concern by purse seiners while bycatch estimation for smaller, more productive, fish species was not deemed a priority task. Depending on the objective of the observer program as well as resources, EM can be set up differently, and the EM analyst could also focus/estimate different variables (Emery et al. 2018; Helmond et al. 2019; McElderry 2008). Another reason for this lack of agreement in the bycatch estimates of small fishes and large bony fishes, is how the purse seiner operates. Large volumes of the catch including tunas, other small/large bony fishes and even small sharks, are loaded directly to the conveyor belt and, making it difficult to estimate the bycatch by the EM analyst both in the upper and in the lower deck. As the fish are passing through the conveyor with fishes to top each other in several layers, the EM analyst could not identify all of them. This is particularly important for small fishes that could be hiding among larger tuna specimens when passing through the conveyor belt to the wells where they are retained together with tunas. In this case, the handling process makes the identification of some bycatch groups to the species level difficult and, thus, it would be necessary to adjust the bycatch handling tools and practice as well as the location/performance of the cameras in order to increase the species identification of the bycatch species (AFMA, 2015; Júpiter, 2017; Michelin, Elliott, Bucher, Zimring, & Sweeney, 2018; Plet-Hansen et al., 2017; van Helmond et al., 2019). For example, some purse seiners use hoppers on the upper deck. Hoppers are used as an intermediate step between the brail and the conveyor belt. Fishers release part of the brail in the hopper to handle bycatch in the upper deck, and to control the flow of tunas going to the lower deck (Murua et al., 2020). The use of hoppers would improve the capture of bycatch species images by the EM cameras and the subsequent identification of species by the EM analysts. Thus, if EM system should be tailored to crew/vessel catch handling methods and if EM analyts devote more time to also appraise the amount of smaller finfishes, the EM monitoring capability to accurately identify the bycatch to species level could be increased.

For sharks, which are the main bycatch issue in the FAD purse seine fishery (ISSF 2019), the congruence between EM and observer was high. And contrary to other studies, where shark estimations by observers was greater than EM (Ames 2005; Emery et al. 2019a; Larcombe et al. 2016; Ruiz et al. 2015), in our case, the EM system allowed estimating a larger number of sharks. Although both EM and observer collected data are estimates, considering that the count of sharks were done using images, it could be concluded in this case that the estimation from EM is more accurate than from observers to whom shark could have passed unnoticed. While the EM is capturing images in the upper and lower decks, the observer can only count sharks in the where they are located (e.g. upper deck or lower deck); which could explain the differences between the estimations. And this was also the case for turtles as EM identified one turtle interaction while observer identified none; similar to other cases where EM estimated more turtle bycatch (Bartholomew et al., 2018b). However, when looking at the species level, this congruence diminished as 80 % of the shark by EM were recorded to family or group level. This is another challenge for EM technology as precise taxonomic identification is fundamental for assessing the impact of fishing activity in the ecosystem (Todorovic, Juan-jordá, Arrizabalaga, & Murua, 2019). Nevertheless, this is something that could be improved by adjusting the location/quality of the cameras to better capture the images of shark bycatch and by improving bycatch handling practices and tools to separate from the catch (e.g. hopper) and, particularly, with improved skills in species identification by EM analyst. Considering that this study was conducted in 2017, at which time EMS was starting, it can be expected that EM analyst have gathered more experience and currently the species identification is more accurate. It should be taken into account that over 90% of shark bycatch in purse seine is comprised by silky sharks while the second in importance is oceanic white tip sharks (Amandè et al., 2010). In our case, EM did not identify any oceanic whitetip shark while observers identified 6. For other shark species, observers identified all sharks, except 1 from 1436 individuals, up to the species level. Observer practices in IATTC have also evolved over time to improve species identification which was not as good as currently in the beginning of the observer program (Lezama-Ochoa et al., 2019, 2017). This will be the “normal” evolution of EM as increasing knowledge by EM analyst will, in turn, improve the data collected. As soon as more EM trips, and images, are available artificial intelligence to automatically analyze images could increase the accuracy of species identification, allowing the analysis of more samples with less cost and in a timelier manner, overall reducing the cost of the analysis. The next phase of EM development should be focused and prioritized on artificial intelligence project so as to develop a robust and accurate system of EM monitoring (French, Fisher, Mackiewicz, & Needle, 2015; Luo, Li, Wang, Li, & Sun, 2016).

In summary, despite some limitations of EM system, EM in purse seiners has the ability to collect fishery dependent data on fishing set type and location of the fishing sets as well as consistent estimates of total target retained catch and to a lesser extent catch by species for major species, such as skipjack and combination of bigeye/yellowfin, and shark bycatches. As such, EM systems can be used to complement, increase and reinforce human observer programs, logbooks, port sampling and any other monitoring system. However, further developments of both the EM camera system placement/quality of the images, catch handling protocol by the crew/vessels as well as EM analyst sampling protocols and experience with species identification would be needed to improve the accuracy of data collected by EM. Data collected by EM would only be useful if it is collected in a consistent way, following developed minimum standards. Both, human observers and EMS are complementary each with their own weaknesses and strengths. EM is valuable for science where it is difficult to place an observer onboard, or to increase the coverage achieved by human observers, however, currently is limited for a purely scientific monitoring program which includes the collection of other type of data (e.g. biological samples). For compliance, EM has the advantage of inviolability of the data, the possibility to review images as many times as desired and the lower cost. Nevertheless, the human observer program would be still needed to allow, from time to time, the validation of and comparison with the EM system but, more importantly, for the collection of other type of data (e.g. biological samples) that EM is unable to collect.

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Appendix 1.- Bycatch in number by species (FAO code) and species group.

Group of species/species	Electronic Monitoring	Observers	TOTAL
BILLFISH	**30**	**43**	**73**
BIL	**13**		**13**
Marlins,sailfishes,etc. nei	13		13
BLM		**5**	**5**
Black marlin		5	5
BUM	**17**	**25**	**42**
Blue marlin	17	25	42
MRNI		**11**	**11**
Marlin, nei		11	11
SSP		**1**	**1**
Shortbill spearfish		1	1
SWO		**1**	**1**
Swordfish		1	1
LARGE FISH	**4094**	**5131**	**9225**
BAF		**1**	**1**
Flat needlefish		1	1
BAZ	**1**		**1**
Barracudas, etc. nei	1		1
CXS		**3**	**3**
Bigeye trevally		3	3
DOL		**3007**	**3007**
Common dolphinfish		3007	3007
DOX	**1845**		**1845**
Dolphinfishes nei	1845		1845
GBA	**9**	**29**	**38**
Great barracuda	9	29	38
LOB	**1**	**4**	**5**
Tripletail	1	4	5
MOX	**1**		**1**
Ocean sunfish	1		1
MRW	**1**		**1**
Sharptail mola	1		1
NGT		**1**	**1**
Island trevally		1	1
RRU	**1009**	**771**	**1780**
Rainbow runner	1009	771	1780
RUB	**51**		**51**
Blue runner	51		51
UDD		**9**	**9**
Whitetongue jack		9	9
WAH	**1175**	**1294**	**2469**
Wahoo	1175	1294	2469

YTL	**1**	**12**	**13**
Longfin yellowtail	1	12	13
RAY	**5**	**5**	**10**
MAN		**1**	**1**
Manta rays		1	1
PLS	**3**	**1**	**4**
Pelagic stingray	3	1	4
RMJ	**1**		**1**
Spinetail mobula	1		1
RMV	**1**	**2**	**3**
Manta ray, nei		2	2
Mobula nei	1		1
STT		**1**	**1**
Stingray, nei		1	1
SHARK	**1630**	**1436**	**3066**
FAL	**327**	**1428**	**1755**
Silky shark	327	1428	1755
OCS		**6**	**6**
Oceanic whitetip shark		6	6
RSK	**1302**	**1**	**1303**
Requiem sharks nei	1302		1302
Requiem sharks, nei		1	1
SKH	**1**		**1**
Various sharks nei	1		1
SPZ		**1**	**1**
Smooth hammerhead shark		1	1
SMALL FISH	**227**	**6770**	**6997**
ALM		**6**	**6**
Unicorn filefish		6	6
ALN		**864**	**864**
Scrawled filefish		864	864
CNT	**227**	**5635**	**5862**
Ocean triggerfish		5635	5635
Rough triggerfish	227		227
ECO		**61**	**61**
Bluestriped chub		61	61
KIN		**1**	**1**
Blue-bronze sea chub		1	1
KYE		**2**	**2**
Cortez sea chub		2	2
KYP		**9**	**9**
Drummer		9	9
MSD		**179**	**179**
Mackerel scad		179	179
NAU		**1**	**1**
Pilotfish		1	1

PSC		**8**	**8**
Freckled driftfish		8	8
REO		**1**	**1**
Shark sucker		1	1
TRI		**3**	**3**
Triggerfishes, durgons, nei		3	3
TURTLE	**1**		**1**
TTX	**1**		**1**
Marine turtles nei	1		1
Total general	**5987**	**13385**	**19372**