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Comparing Electronic Monitoring and human observer collected fishery data in the tropical tuna purse seine operating in the Western and Central 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 two sets of different observer data collected on 6 trips of tuna purse seiners in the Eastern and Western 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 both observer programs and 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 both observers' programs. EM tended to underestimate the retained catch of skipjack in comparison to both observers estimates and slightly overestimate bigeye and yellowfin, the overestimation being less pronounced for bigeye than for yellowfin. For bycatch species, EM is able to identify main bycatch species as observers do. However, the capability of EM to estimate the same number of bycatch items in comparison to IATTC and WCPFC observers varies greatly by species group. For sharks, which are the main bycatch issue in the FAD purse seine fishery, the overall congruence between EM and observers was high. EM and IATTC observer identified a similar overall number of individual sharks, however, WCPFC observers estimated lower number of shark individuals than the other two monitoring systems when considering all trips together.

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 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

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with non-target species (FAO, 1997) and for assessing the effectiveness of management measures. 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 to identify the sex of fishes and 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 Fisheries 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.

For areas where observer coverage is low, 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., 2018; 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). Relevant to the Western and Central Pacific Area, the WCPFC through its Project 60 (Better purse seine catch composition estimates) has approved the investigation of video-based sampling for improving the estimation of species and size compositions in the tropical tuna purse seine fishery (Peatman, Williams, & Nicol, 2020).

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, and two different human observers programs 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 as well as to compare the information collected by different human observer programs.

Material and Methods

EM records, observer data, and logbook data were simultaneously collected during six trips, with a total of 113 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
Aurora B.	5	October-November	19		2	21
Aurora B.	6	November-December	9	1	6	16
			73	1	39	113

Electronic Monitoring System

The Satlink SeaTube EM (with central processing unit, digital video cameras, and type approved VMS receiver) was used. A six-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 imagery from all six 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˚).

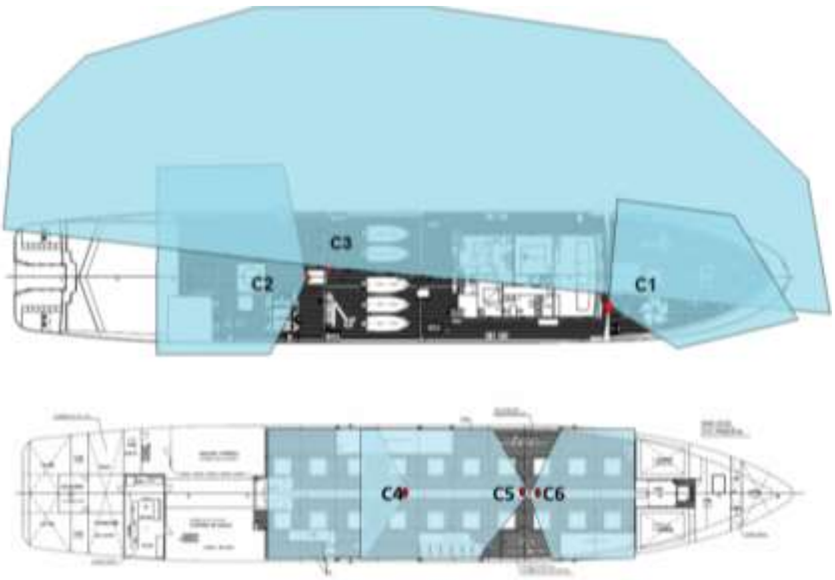

Figure 1.- Cameras onboard Rosita C and Aurora B.

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

When these vessels operate in both tuna RFMOs in the same trip, they have two observers onboard: (i) one observer to cover IATTC sets following standards and requirements of the IATTC - Agreement on the International Dolphin Conservation Program (AIDCP) and (ii) a second observer to cover WCPFC sets following standards of WCPFC Regional Observer Program. However, as both programs are cross-endorsed by both RFMOs, each observer also collected information on fishing activities in the other RFMOs. Thus, simultaneous observer data collection was gathered via two observer programs in the eastern and western and central Pacific Ocean.

Both observers are following similar standards and forms to collect general and purse seine fishery specific fishing activities to document vessel characteristics, crew details, daily activities, fishing set date-time and location, type of fishing set, retained catch and discards (both target and bycatch species), length frequency measurements of bycatch species, and details of all FADs activities (e.g. deployment, encounters, repairs, sets upon, etc.).

However, the standards and methods use to estimate catch information by species is different. The IATTC – Agreement on the International Dolphin Conservation Program (AIDCP) observer, under the Spanish National Observer Program, collected data using IATTC standards and forms, in both regions of the Pacific was used for the analysis. The total catch is estimated using the total brail capacity and the number of brails (as well as information of the well completeness provided by the Captain) and, then, the observer using visual estimates as well as experience from skipper and crew estimate the species composition of the catch based on the amounts of skipjack, yellowfin and bigeye observed during the net hauling, sacking and brailing.

The WCPFC ROP observers also estimate the total catch (mt) using the total brail capacity and the number of brails which represents the total weight of the catch. An estimate weight of observed bycatch is then subtracted to appraise the total catch of target tuna catch. Observers record species specific catches for the set based on visual estimates, as for the IATTC, which are also separated between retained and discards. WCPFC ROP observers also sample catches using the grab sample protocol, which requires observers to randomly select five fish from each brail which are then identified to a species level and their lengths recorded. Grab samples are used to generate species size compositions for aggregate purse seine catch data, and size compositions, which are used in stock assessments and other routine analyses. However, grab sample-based estimates of species compositions have been shown to be imprecise at a set and trip level, given the low numbers of samples relative to the catch. As such, the observer's visual estimates are considered to provide a more accurate species composition of the catch at the set level, and are used as the basis of comparisons in this study.

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

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 both observers' 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 different observer estimates rather than as a predictive model (Freedman, 1997). GLM model formulation was:

$$EM \sim OBS\ estimate * OBS\ program\ (IATTC\ or\ WCPFC) + \varepsilon$$

And, if there are differences between observers and EM,

OBS IATTC ~ OBS WCPFC + ε

Where *EM* and *OBS estimate* are the estimates of catch (in metric tons, mt) and bycatch (in numbers) in each fishing set by Electronic Monitoring and Observers, respectively, *OBS program* is the Regional Observer Program estimating the catch and bycatch, 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 Observer program, a main effect of observer program and the interaction between observer estimate and observer program 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

Six 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 one fishing set made in the Cook Islands EEZ (Figure 2). In total, 113 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 three out of 113 fishing sets (65%) were performed in WCPFC area, 39 (35%) in IATTC area and one fishing set in the overlap area between IATTC and WCPFC. EM identified 108 valid sets, while IATTC observer and the logbook recorded 107 valid sets and the WCPFC observer106 valid sets. All valid sets were identified as FAD sets by EM system, IATTC observer, and the logbook, however, WCPFC observer classified two valid sets as free school sets. EM identified one valid FAD set with up to 0.5 metric tons of yellowfin while observers and logbooks considered it null which explained the difference between monitoring systems. More differences were observed in the identification of the skunk sets, with IATTC observer recording all of them (six sets) as FADs, while both WCPFC observer and EM classified three out of the total as free school skunk sets and the rest as FAD skunk sets (two in the case of EM and four by WCPFC observer).

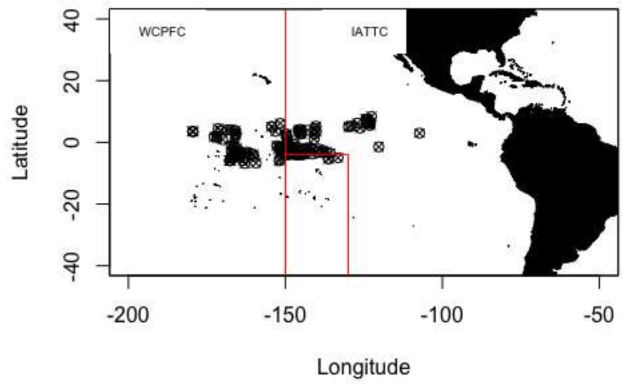

Figure 2.- Map of fishing sets locations.

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

	Valid sets			**Skunk Sets**			**Total Sets**		
Observation	**FAD**	**Free**	**Total**	**FAD**	**Free**	**Total**	**FAD**	**Free**	**Total**
EM	108	0	108	2	3	5	110	3	113
IATTC Obs	107	0	107	6	0	6	113	0	113
WCPFC Obs	104	2	106	4	3	7	108	5	113
Logbook*	107	0	107	0	0	0	107	0	107

Geographical positions of the fishing sets from EM, IATTC/WCPFC observers and logbook were compared with the purpose of assessing the level of correspondence between the four information sources. The fishing set locations from EM, observers and logbook are identical for all identified sets (Figure 2). The position of the set is recorded by EM, observers and logbooks when the skiff is released into the water. The absolute values of the latitude and longitude differences indicated that a large correspondence between fishing set 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˚ (approximately 200 meters) between EM and IATTC observer for latitude and 0.16˚ (approximately 1.7 kilometers) between EM and WCPFC observer for longitude (1st set of one trip but excluding this set the maximum difference was for WCPFC observer and EM 0.04˚). 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-IATTC Obs.		**EM- WCPFC Obs.**		**EM-Logbook**		**Observer-Logbook**	
	Latitud	Longitud	Latitud	Longitud	Latitud	Longitud	Latitud	Longitud
Percentile 1%	0.00021	0.00015	0.00002	0.00010	0.00011	0.00004	0.00000	0.00000
Percentile 25%	0.00330	0.00310	0.00143	0.00213	0.00310	0.00253	0.00000	0.00001
Median	0.00760	0.00679	0.00300	0.00430	0.00753	0.00667	0.00333	0.00333
Percentile 75%	0.01250	0.01006	0.00448	0.00715	0.01182	0.00963	0.00333	0.00334
Percentile 99%	0.01747	0.01617	0.00843	0.01130	0.01526	0.01805	0.01900	0.01900
Maximum	0.02290	0.02500	0.01770	0.16608	0.01907	0.04663	0.02000	0.05333

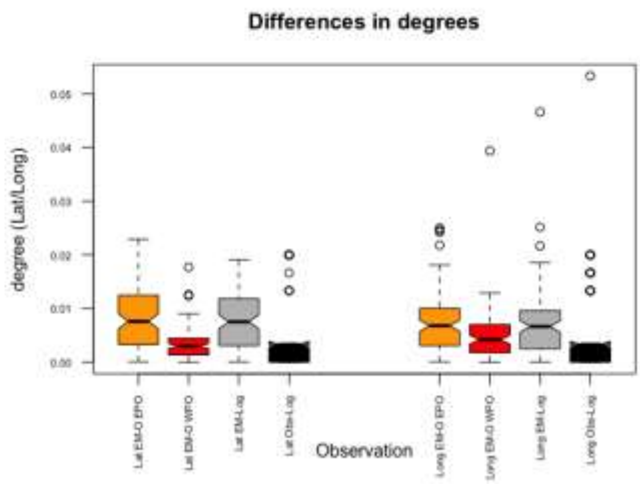

Figure 3.- Boxplot for the absolute difference of latitude/longitude between observation sources.

<u>Comparison of tuna catches between observation sources</u>

Overall, total retained tuna catch considering all trips together was very close between EM, both 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 5 % less than sales information. IATTC observer estimates of retained total tuna catch was almost exactly the same as the logbook, indicating that observers may use catch information given to them by the vessel captain. By trip, the correspondence of EM estimates with sales varied from +3% to -10% while the range for observers/logbooks was between -1 % and +4 % (except for one trip where the WCPFC observer discrepancies with sales was +10%) (Table 4). In general, EM estimates by trip are lower than those estimates from observers/logbooks and sales.

Table 4.- Tuna catch estimates (mt) by 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).

Trip	**EM**	**IATTC Obs**	**WCPFC Obs**	**Log**	**Sales**
1	1400	1480	1489	1480	1502
2	1414	1485	1475	1485	1493
3	1342	1353	1351	1354	1300
4	1364	1428	1429	1428	1422
5	1340	1480	1581	1480	1436
6	1334	1460	1465	1460	1481
Total	**8194**	**8686**	**8790**	**8687**	**8633**

Trip	**EM**	**IATTC Obs**	**WCPFC Obs**	**Log**	**Sales**
1	-7%	-1%	-1%	-1%	1502
2	-5%	-1%	-1%	-1%	1493
3	3%	4%	4%	4%	1300
4	-4%	0%	0%	0%	1422
6	-7%	3%	10%	3%	1436
7	-10%	-1%	-1%	-1%	1481
Total	**-5%**	**1%**	**2%**	**1%**	**8633**

The total retained catch by species was variable among trips with not a clear pattern between monitoring systems (EM or observers) but showing larges discrepancies with sales information, which were considered more reliable (IOTC, 2013; Lewis, 2017) (Table 5). The differences of total retained catch by species from EM are greater than those for observers. Considering all trips, EM estimated lower amounts of bigeye and skipjack than sales information, while IATTC observers estimated similar amounts than sales for both species and WCPFC observers estimated similar amounts for skipjack but lower than sales for bigeye (comparable to EM estimates). The three monitoring systems estimated much larger amounts of yellowfin catches than sales information.

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

	EM						IATTC Observer						WCPFC Observer						Sales		
Trip	BET		SKJ		YFT		BET		SKJ		YFT		BET		SKJ		YFT		BET	SKJ	YFT
1	381	-35%	623	-27%	397	456%	705	21%	719	-15%	56	-22%	707	21%	722	-15%	60	-16%	582	848	71
4	729	-7%	527	-8%	107	69%	799	1%	554	-3%	75	18%	707	-10%	603	6%	120	89%	788	571	63
5	490	25%	777	-18%	74	-19%	367	-6%	990	4%	123	34%	375	-4%	1020	7%	186	102%	391	953	92
6	725	6%	494	-34%	116	138%	550	-20%	846	13%	64	32%	560	-18%	807	8%	98	102%	687	746	48
Total	2324	-5%	2420	-22%	694	152%	2421	-1%	3109	0%	318	16%	2348	-4%	3153	1%	463	69%	2447	3118	275

The GLM to compare EM total retained catch and observer estimations showed a high correspondence between EM and the different sources of information (Figure 4 and Table 6). The comparison between EM and both observer datasets showed that for both observers the 95% confidence intervals of the intercept encompassed 0 and that 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). The congruence between EM and observers was not significantly different between regional observers (Table 6). Both observer data and logbook data followed a relationship very close to the 1:1 relationship indicating that both basically use the same information.

Table 6.- Summary statistics and estimated parameter outputs from the GLM regression between EM/Logbook and observers by Regional Observer Program (IATTC/WCPFC) 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	108	95.2%	Intercept	0.76031	-0.00844	1.52907	0.0525
			Slope	0.95115	0.90752	0.99478	<2e-16***
			WCPFC obs	-0.48508	-0.05743	-1.47159	0.3952
			Observer*RFMO	-0.00419	-0.06586	0.05748	0.8935
Logbook-OBS	108	99.2%	Intercept	-0.00080	-0.29447	0.29288	0.996
			Slope	1.00012	0.98111	1.01914	<2e-16***
			WCPFC obs	0.04726	0.25802	-0.27508	0.839
			Observer*RFMO	-0.00933	-0.03645	0.01780	0.499
EM-Logbook	108	95.0%	Intercept	0.76130	-0.01783	1.54040	0.0554
			Slope	0.95100	0.90682	0.99524	<2e-16***

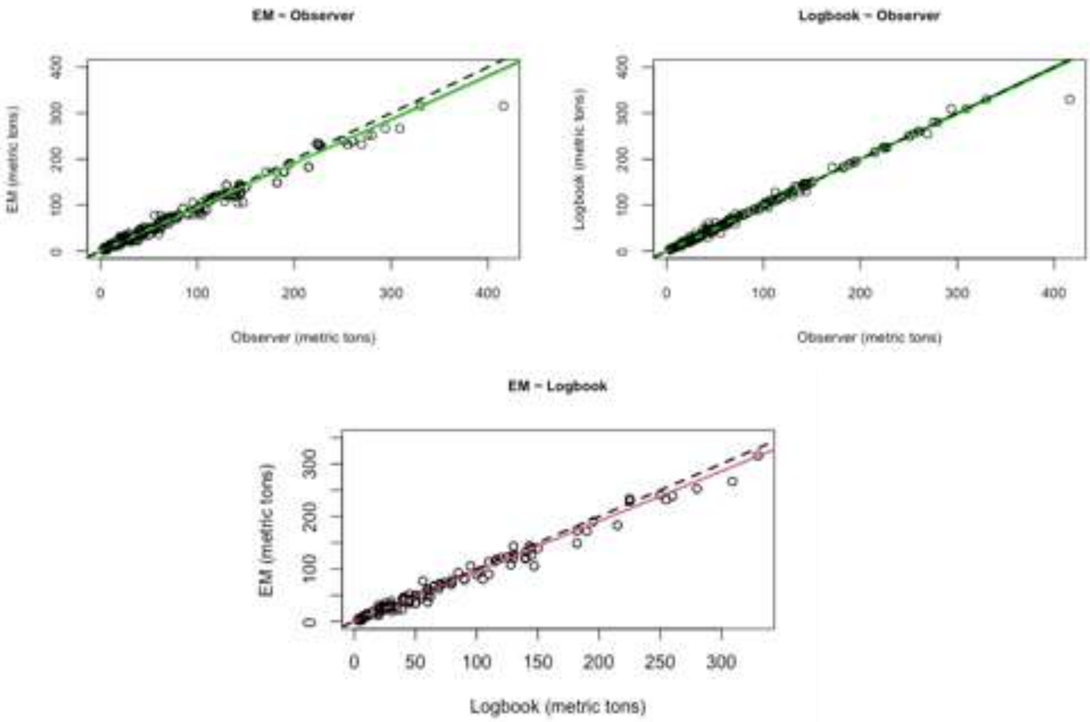

Figure 4.- Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and observer information by observer program (a), between logbook and observer information by observer program (b) and between EM and logbook (c). Estimated regression for IATTC observer (solid black) and WCPFC observer (solid green line).

By species, the correspondence between EM and observers retained catch was worse than the total retained catch comparisons. In this comparison, there was no significant difference in congruence between regional observers. 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 for bigeye but not for skipjack (Figure 5 and Table 7). For bigeye, the 95% confidence intervals of the slope of the GLM relationship contained 1, while it was not the case for skipjack. For yellowfin, the relationship between EM and observer was weak and GLM model fit explained 12.9% of deviance. In contrast, for yellowfin and bigeye together the relationship between EM and both observer datasets indicated that the 95% confidence intervals of the slope comprised 1. The GLM model fits explained 51.0%, 73.3% and 66.0% of deviance of the model for bigeye, skipjack and bigeye plus yellowfin, respectively. Relative to observer estimates, EM tended to underestimate the retained catch of skipjack in comparison to observer estimates and overestimated bigeye and yellowfin, the overestimation being less pronounced for bigeye than for yellowfin.

Table 7.- Summary statistics and estimated parameter outputs from the GLM regression between EM and observers by Regional Observer Program (IATTC/WCPFC) species 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 (Bigeye)	108	51.0%	Intercept	6.02780	2.72995	9.32570	0.0004***
			Slope	0.96050	0.64930	1.27178	9.96e-09***
			WCPFC obs	-3.43160	-2.96422	-8.64627	0.1012
			Observer*RFMO	0.22260	-0.23427	0.67942	0.3370
EM-OBS (Skipjack)	108	73.3%	Intercept	2.27763	0.71658	3.83868	0.0044**
			Slope	0.73841	0.65161	0.82520	<2e-16***
			WCPFC obs	-0.36842	-0.84876	-3.72426	0.7501
			Observer*RFMO	-0.00888	-0.13218	0.11442	0.8872
EM-OBS (Yellowfin)	108	12.9%	Intercept	4.21703	0.12543	8.30864	0.0434*
			Slope	1.65182	0.50207	2.80156	0.0051**
			WCPFC obs	-1.50164	-1.55412	-6.84436	0.5488
			Observer*RFMO	0.01779	-1.42869	1.46427	0.9806
EM-OBS (Bigeye + Yellowfin)	108	66.0%	Intercept	2.67708	0.91369	4.44047	0.0031**
			Slope	1.15748	0.90565	1.40932	<2e-16***
			WCPFC obs	-1.45276	-1.18361	-4.02950	0.1655
			Observer*RFMO	0.07052	-0.26992	0.41096	0.6834

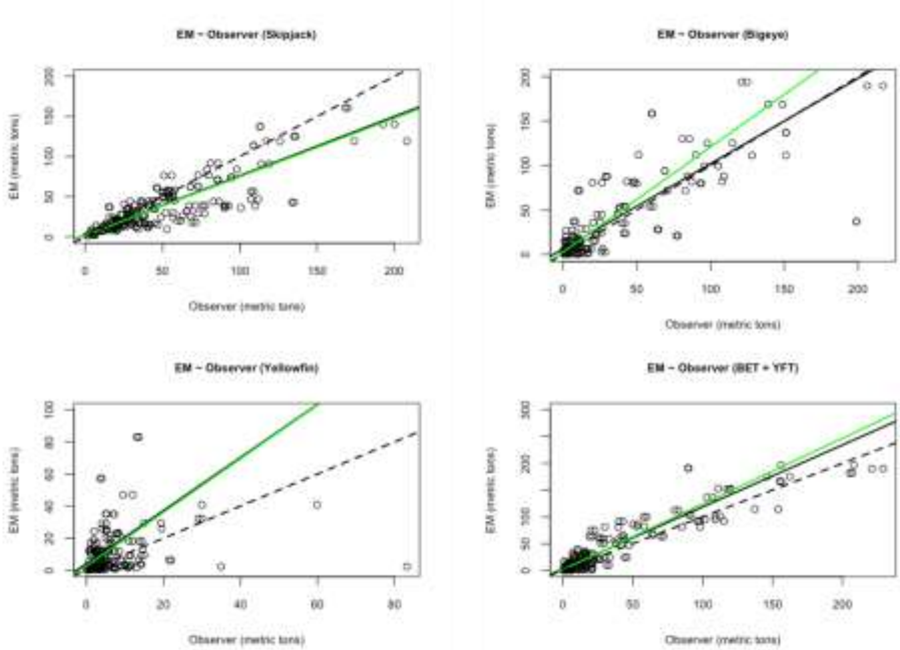

Figure 5.- Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and observer retained catch estimation by species. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and observer information by observer program. Estimated regression for IATTC observer (solid black) and WCPFC observer (solid green line).

The GLM to compare IATTC observer retained catch estimation against WCPFC observer estimations showed a high correspondence between the different source of observer information for total retained catch, bigeye and skipjack but not for yellowfin; which could be explained by the lower amount of yellowfin caught in most of the sets (Table 8).

Table 8.- Summary statistics and estimated parameter outputs from the GLM regression between IATTC observer and WCPFC observer total retained catch estimates and retained catch by species (N=number of sets observed, D^2=deviance explained by the model).

IATTTC - WCPFC	N	D^2	Parameters	Estimates	CI 2.5%	CI 97.5%	P-value
SKJ	106	98.4%	Intercept	0.0474	-0.4512	0.5460	0.8510
			Slope	0.9907	0.9631	1.0183	< 2e-16***
BET	98	91.1%	Intercept	0.5456	0.2462	0.8450	0.0004***
			Slope	0.9722	0.8729	1.0714	< 2e-16***
YFT	106	96.4%	Intercept	-0.8800	-1.2430	-0.5171	5.17e-06***
			Slope	1.0231	0.9875	1.0587	< 2e-16***
YFT+BET	88	68.1%	Intercept	0.771240	0.3038	1.2387	0.0015 **
			Slope	0.71484	0.5762	0.8535	< 2e-16***

Discards

Discarded tuna quantities were low during the sampled trips. Discarded tuna weight was estimated larger than one mt in nine out of 113 valid sets by EM and 15 out of 113 valid by IATTC and WCPFC observers. From these, in three sets, discarded tuna weights were estimated larger than 10 tones by EM and in two sets by IATTC/WCPO observers, all of which were the last fishing set of a given trip. Discarded tuna catch was limited to some damaged fish gilled in the seine net and small-size fish and/or last fishing sets when well capacity had been filled. During the six trips, EM recorded discards in 46 out of 148 sets while observers recorded discards in half of those sets (24 out of 148). The number of sets with discards recorded by WCPFC observer (76) compared to EM (43) and IATTC Observers (21) which could be due to WCPFC observer recording discards < 100 - 200 kilograms in many of the valid sets. Considering discards quantities larger than 200 kilograms, WCPFC observer recorded 24 sets with discards which is a similar amount to that estimated by the IATTC observer. The amount of bigeye tuna discarded observed by EM and both observers in all trips altogether were very similar (16 by EM versus 14 and 15 mt for BET by IATTC and WCPFC observers, respectively). However, it was more variable within trips. For SKJ, observers estimated 11 mt less than EM (17% less than EM) (Table 9).

Table 9.- 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.

DISCARDS	EM					IATTC Observer					WCPFC Observer				
Trip	**N**	**BET**	**SKJ**	**YFT**	**Total**	**N**	**BET**	**SKJ**	**YFT**	**Total**	**N**	**BET**	**SKJ**	**YFT**	**Total**
1	10	0.2	4.7	0.5	5.4	6	4.0	17.0	0.0	21.0	6	4.0	17.0	0.0	21.0
2	8	5.5	17.5	1.1	24.1	4	2.0	7.0	0.0	9.0	20	1.8	6.4	1.4	9.6
3	9	3.4	30.1	0.6	34.1	4	5.0	14.0	0.0	19.0	10	5.3	14.2	0.2	19.8
4	7	1.3	2.3		3.6	2	1.0	2.0	0.0	3.0	5	1.0	2.9	0.0	4.8
5	3	4.5	8.5	0.2	13.2	2	1.0	7.0	0.0	8.0	19	1.5	6.9	1.3	9.7
6	6	1.1	2.6		3.7	3	1.0	4.0	0.0	5.0	16	1.4	4.6	0.2	6.2
Total	**43**	**16.0**	**65.7**	**2.4**	**84.1**	**21**	**14.0**	**51.0**	**0.0**	**65.0**	**76**	**15.0**	**52.1**	**3.1**	**71.1**

Comparison of by-catches between observation systems

For billfishes, large and small bony fishes bycatch (see appendix 1), in general EM recorded fewer individuals than IATTC observer did, however, the estimations were similar for large fishes and billfishes between WCPFC observer and EM. For billfishes for example, while IATTC observer recorded 36 and WCPFC observer 25 individuals, EM observed 19 (Table 10 and figure 6). EM and both observers recorded one pelagic stingray in the same set, and EM and WCPFC observer recorded one manta ray while IATTC observer recorded two manta rays. The pelagic stingray and the manta observed by the three monitoring systems was recorded on the same sets (Appendix 1). For sharks, the number observed by EM (1140) was similar than the number estimated by IATTC observer (1212), with a difference of only 72 individuals. However, WCPFC observer recorded 737 sharks, around 35-40 % less than EM and IATTC observer. However, most sharks were not identified to the species level by EM and, therefore, observers recorded more silky sharks (1204 and 736 individuals recorded by IATTC and WCPFC observers, respectively) than the EM did (127) (Appendix 1). In general, a good correspondence of total bycatch numbers was obtained for rays and billfishes, while for sharks it was good between EM and IATTC observer but not for the WCPFC observer (Table 10).

Wilcoxon non-parametric tests showed that the estimates of total, shark and large fish bycatch between EM and WCPFC observer were not significantly different (p>0.05) while both observer systems were significantly different with IATTC observer (p< 0.05). The amount of bycatch of small fish was significantly different between EM and IATTC observer but not significantly different between EM and WCPFC observer and IATTC and WCPFC observers.

Table 10.- Bycatch in number by species group recorded by EM and observers from IATTC and WCPFC ROPs.

Bycatch Group	**EM**	**Obs. IATTC**	**Obs. WCPFC**
Billfishes	19	36	25
Large Fish	1700	3257	1620
Rays	2	3	2
Sharks	1140	1212	737
Small Fish	87	1468	312
Total	**2948**	**5976**	**2696**

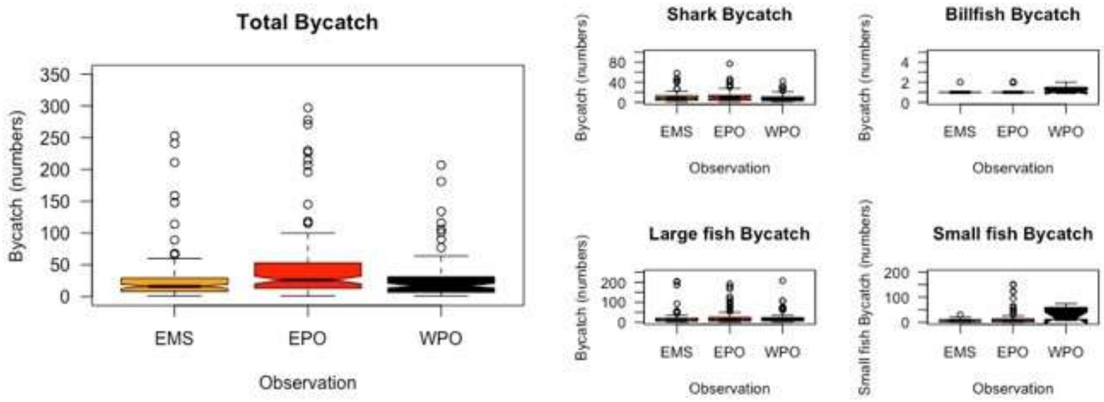

Figure 6.- Boxplot of total bycatch in numbers reported by EM and observers.

The most common species of sharks, billfishes and bony fishes were recorded by EM and both observers. The main species identified by all monitoring systems 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*), scalloped hammerhead (*Sphyrna lewini*), black marlin (*Istiompax indica*) and other small fishes were only recorded by observers but not EM. In many cases, for all 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.

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 both observers (Figure 7 and Table 11). For those group of species, 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 both observers was large for sharks as the GLM showed that the 95 % confidence interval of the slope contained 1 (Figure 7 and Table 11).

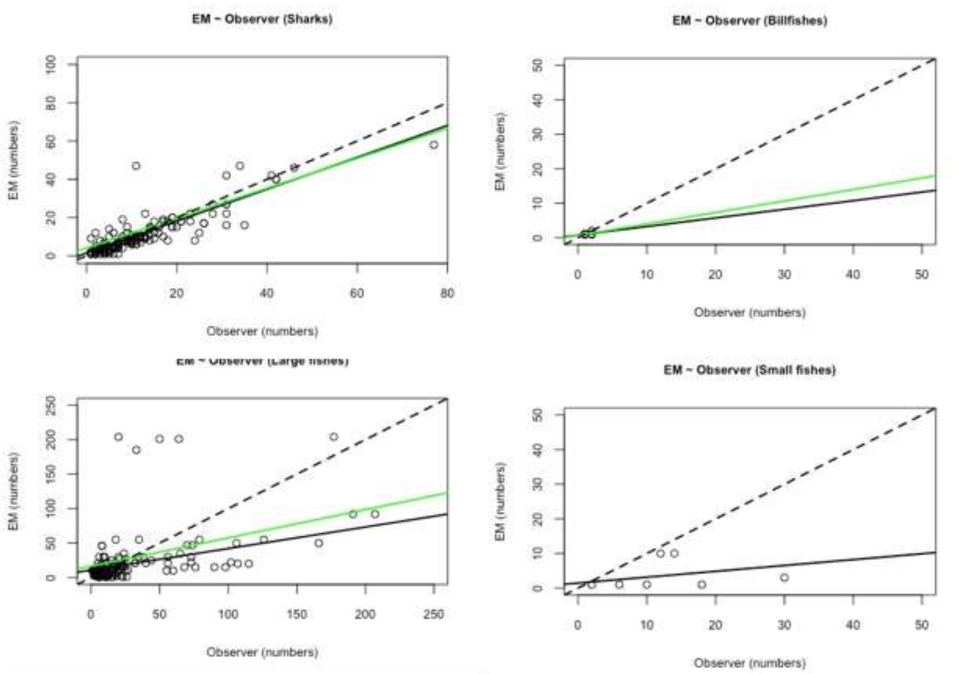

Figure 7.- Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EM and observer bycatch estimation by species groups.

Table 11.- Summary statistics of GLM relationship between EM and observer data of the different bycatch groups. Summary statistics and estimated parameter outputs from the GLM regression between EM and observers by Regional Observer Program (IATTC/WCPFC) of the different bycatch groups (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**
Sharks	134	22.1%	Intercept	1.4577	-3.3095	6.2250	0.5470
			Slope	0.8333	0.5577	1.1089	<1e-8***
			WCPFC obs	2.6005	2.7454	-5.7635	0.4680
			Observer*RFMO	-0.0513	-0.5641	0.4615	0.8440
Billfishes	34	24.6%	Intercept	0.7500	0.4191	1.0809	<6.97e-5***
			Slope	0.2500	-0.0063	0.5063	0.0555
			WCPFC obs	-0.0833	-0.7242	-0.6092	0.7334
			Observer*RFMO	0.0833	-0.3050	0.4717	0.6640

Large Fish	129	29.0%	Intercept	10.8763	1.6417	20.1109	0.0214*
			Slope	0.3123	0.2161	0.4084	<2.52e-9***
			WCPFC obs	5.7197	-1.8311	-19.7274	0.4492
			Observer*RFMO	0.0970	-0.1894	0.3834	0.5039
Small Fish	13	89.7%	Intercept	1.4597	-2.4007	5.3202	0.4086
			Slope	0.1696	0.1110	0.2281	0.000156***
			WCPFC obs	15.9927	2.1308	-4.9093	0.005914**
			Observer*RFMO	NA	NA	NA	NA

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 from EM and IATTC observer are coming from identical populations (p= 0.7996) but from different populations for EM/IATTC observer comparing with WCPFC observer. 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 between EM and IATTC observer (Ds=0.149, p=0.68) but they are statistically different between EM and WCPFC observer (Ds=0.587, $p<0.05$) and IATTC and WCPFC observer (Ds=0.568, $p<0.05$). The difference on silky shark size frequencies between EM-IATTC observer and WCPFC observer could be due to the low number of silky shark measurements collected by WCPFC observer during these trips.

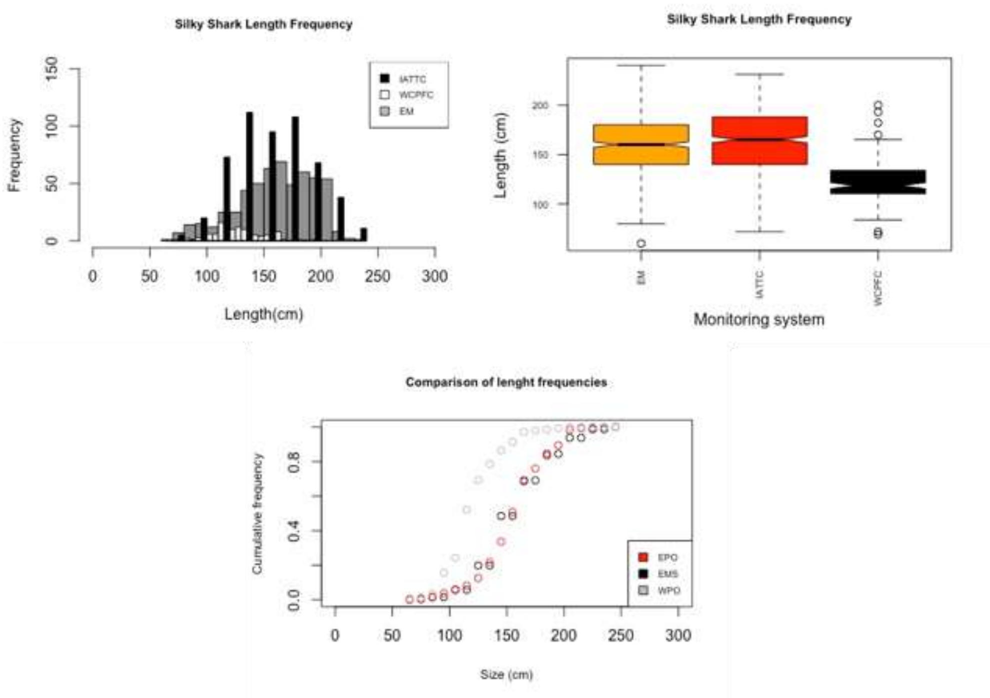

Figure 8.- Comparison of silky shark (a) length frequencies, (b) boxplot, and (c) cumulative length frequencies for Kolmogorov-Smirnov test between EM and observers (IATTC and WCPFC observer programs).

Discussion

EM technological advances have 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 could potentially be used 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 a 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 and that the WCPFC observer recorded two free-school sets as free when other monitoring systems recorded none, 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 set 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). 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 reliably as that by both 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 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 both 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 both observers. EM tended to underestimate the retained catch of skipjack in comparison to both observers estimate and slightly overestimate bigeye and yellowfin, the overestimation being less pronounced for bigeye than for yellowfin. Surprisingly, EM estimates of YFT catch were much higher than those by observers. 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 FAD 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 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. However, a system to move the fish through the conveyor belt in a single layer could greatly delay the loading of the catch to the wells and, thus, alternative ways, such as operating in this manner a few times during the set, should be investigated. 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 the same number of bycatch items in comparison to IATTC and WCPFC observers varies greatly by species group. For sharks, EM identified a similar overall number of individuals than IATTC observer. However, WCPFC observer estimated lower number of shark individuals than the other two monitoring systems when considering all trips together. For billfishes and, to a lower extent, large bony fishes, EM identified a similar overall number of individuals than WCPFC but IATTC observer estimated larger numbers than other monitoring systems did. 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, particularly by IATTC observer. 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 analysts devote more time to also appraise the amount of 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 both observers 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 similar number of sharks than the IATTC observer and greater than the WCPFC observer. Although both EM and observer collected data are estimates, considering that the count of sharks were done using images, it could be the case that 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 simultaneously, the observers can only count sharks in the place where they are located (e.g. upper deck or lower deck); which could explain the differences between the estimations. However, when looking at the species level, this congruence diminished as 80 % of the shark by EM were recorded to the 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 analysts. Considering that this study was conducted in 2017, at which time EM was a relatively new system on purse seine vessels, it can be expected that EM analysts 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 and WCPFC observer did not identify any oceanic whitetip shark while IATTC observers identified six specimens and both observers identified one hammerhead shark specimen while EM did not. Observer practices 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. In the future, EM development should also be focused on artificial intelligence projects so as to develop a robust and accurate system of EM monitoring, for example, for species identification (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 similar 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 than observers. In general, both regional observer monitoring systems collect similar information on total retained catch, catch by species and discards while some differences could be observed in bycatch numbers (e.g. sharks). 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. In the WCPO, the Data Collection Committee[7] is the appropriate body for undertaking this type of work (which has already been developed for longline EM). Both, human observers and EM 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 potentially lower costs. 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. sex of fish and biological samples) that EM is unable to collect and that are essential data in scientific assessments.

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

Group of species/species	Electronic Monitoring	IATTC Observer	WCPFC Observer
BILLFISH	**19**	**36**	**25**
BIL	**7**		
Marlins,sailfishes,etc. nei	7		
BLM		**5**	**2**
Black marlin		5	2
BUM	**12**	**25**	**21**
Blue marlin	12	25	21
MLS			**1**
Striped marlin			1
MRNI		**4**	
Marlin, nei		4	
SSP		**1**	**1**
Shortbill spearfish		1	1
SWO		**1**	
Swordfish		1	
LARGE FISH	**1700**	**3257**	**1620**
AMB			**1**
Greater amberjack			1
BAF		**1**	
Flat needlefish		1	
BAZ	**1**		
Barracudas, etc. nei	1		
CXS		**3**	
Bigeye trevally		3	
DOL		**1638**	**719**
Common dolphinfish		1638	719
DOX	**610**		
Dolphinfishes nei	610		
GBA	**7**	**29**	**9**
Great barracuda	7	29	9
LOB		**4**	
Tripletail		4	
MAS			**4**
Pacific chub mackerel			4
MOX	**1**		
Ocean sunfish	1		
MRW			**1**
Sharptail mola			1
NGT		**1**	
Island trevally		1	
RRU	**789**	**771**	**423**

Rainbow runner	789	771	423
RUB	**11**		
Blue runner	11		
UDD		**9**	
Whitetongue jack		9	
WAH	**280**	**789**	**460**
Wahoo	280	789	460
WHA			**3**
Hapuku wreckfish			3
YTL	**1**	**12**	
Longfin yellowtail	1	12	
RAY	**2**	**3**	**2**
MAN		**1**	
Manta rays		1	
PLS	**1**	**1**	**1**
Pelagic stingray	1	1	1
RMB			**1**
Giant manta			1
RMJ	**1**		
Spinetail mobula	1		
RMV		**1**	
Manta ray, nei		1	
SHARK	**1140**	**1212**	**737**
FAL	**127**	**1204**	**736**
Silky shark	127	1204	736
OCS		**6**	
Oceanic whitetip shark		6	
RSK	**1012**	**1**	
Requiem sharks nei	1012		
Requiem sharks, nei		1	
SKH	**1**		
Various sharks nei	1		
SPL			**1**
Scalloped hammerhead			1
SPZ		**1**	
Smooth hammerhead shark		1	
SMALL FISH	**87**	**1468**	**312**
ALM		**6**	
Unicorn filefish		6	
ALN		**9**	
Scrawled filefish		9	
CNT	**87**	**1188**	**147**
Ocean triggerfish		1188	147
Rough triggerfish	87		
ECO		**61**	
Bluestriped chub		61	

KIN		**1**	
Blue-bronze sea chub		1	
KYE		**2**	
Cortez sea chub		2	
KYP		**9**	
Drummer		9	
MSD		**179**	**40**
Mackerel scad		179	40
NAU		**1**	
Pilotfish		1	
PSC		**8**	
Freckled driftfish		8	
REO		**1**	
Shark sucker		1	
TRI		**3**	**125**
Triggerfishes, durgons nei		3	125
#N/D			**51**
UNS			**51**
UNSPECIFIED			51
Total general	**2948**	**5976**	**2747**