ELECTRONIC EYE: ELECTRONIC MONITORING TRIAL ON A TROPICAL TUNA PURSE SEINER IN THE ATLANTIC OCEAN

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SUMMARY

Electronic Eye (EE) is an electronic monitoring systems based on the automatic photo taking and developed by Marine Instruments S.A. This system was developed with the aim of being an alternative, or a complement to human observers. The overall objective of this study was to test the use of EE on a tropical tuna purse seiner in the Atlantic Ocean, and determine the feasibility of the EE to reliably document fishing effort, set-type, catch, and bycatch on the tuna purse seine fishery. To achieve these objectives, EE and an observer were deployed simultaneously on a complete fishing trip. Based on this research, EE is a valid tool for monitoring number of sets, set-type and total tuna catch within the tropical tuna purse seine fishery; however some future adjustments are still needed for the monitoring of the bycatch. Thus, the EE system could be a complement to observers or even a real alternative, according to the final goals of a monitoring program.

RÉSUMÉ

L'œil électronique (EE) est un système de suivi électronique fondé sur la prise automatique de photographies et mis au point par Marine Instruments S.A. Ce système a été développé dans le but de servir d'alternative ou d'être le complément des observateurs humains. L'objectif global de cette étude était de tester l'utilisation de l'œil électronique sur un senneur ciblant les thonidés tropicaux dans l'océan Atlantique et déterminer si l'œil électronique pouvait documenter de façon fiable l'effort de pêche, le type d'opération, la prise et les prises accessoires de la pêcherie de thonidés par les senneurs. Afin d'atteindre ces objectifs, l'œil électronique et un observateur ont été déployés simultanément sur une sortie de pêche complète. Sur la base de cette recherche, l'œil électronique s'est avéré un outil valide pour surveiller le nombre d'opérations, le type d'opération et la prise de thons totale au sein de la pêcherie de senneurs tropicaux ; toutefois, il est nécessaire d'y apporter quelques ajustements à l'avenir pour le suivi des prises accessoires. C'est pourquoi le système d'œil électronique pourrait être un complément aux observateurs ou même une véritable alternative, en fonction des objectifs finaux du programme de suivi.

RESUMEN

El Ojo Electrónico (EE) es un sistema electrónico de seguimiento basado en la toma automática de fotos y desarrollado por Marine Instruments S.A.. Este sistema fue desarrollado con el objetivo de ser una alternativa o un complemento a los observadores humanos. El objetivo global de este estudio era probar el uso del EE en un cerquero tropical en el Atlántico y determinar la viabilidad del EE para documentar con fiabilidad el esfuerzo pesquero, el tipo de lance, la captura y la captura fortuita en la pesquería de cerco de túnidos. Para lograr estos objetivos, el EE y un observador se embarcaron simultáneamente en una marea completa. Basándose en esta investigación, el EE es una herramienta válida para hacer un seguimiento del número de lances, del tipo de lance y de la captura total de túnidos en la pesquería de cerco tropical, sin embargo son necesarios algunos ajustes futuros para el seguimiento de la captura fortuita. Por lo tanto, el sistema EE podría ser un complemento a los observadores o incluso una alternativa real, conforme a los objetivos finales de un programa de seguimiento.

KEYWORDS

Electronic Eye, Data collection, Purse seining, Total catch, By-catch, Atlantic Ocean

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1. Introduction

1.1 Background

Fisheries electronic monitoring systems generally consist of several cameras with several sensors that record key aspects of a fishery, such as vessel location, vessel speed, set location, catch, fishing methods or protected species interactions. These technologies could provide traditional and new information at fine spatial scales and with near real time availability in support of multiple objectives, from scientific research to compliance monitoring. These systems have been fully integrated as a fishery monitoring tool in some places such as the west coast of Canada. Additionally, they are gaining popularity in many other places as an alternative or compliment to human observer programs; mainly in places were several difficulties arise when placing observers onboard. These difficulties are usually related to the high costs and space limitations onboard. In some cases, like in the western Indian Ocean, problems such as piracy make it extremely difficult or dangerous to place human observers onboard.

In 2012 ISSF (International Seafood Sustainability Foundation) carried out for the first time an evaluation test of an electronic monitoring system on the high-seas in the tropical tuna purse seine fishery. This trial showed that this kind of technology has great potential for the monitoring of the tuna purse seine fishery (Ruiz *et al*., 2014). Since then, there have been new systems developed by various commercial vendors that intend to provide electronic monitoring for purse seiners.

The company Marine Instruments S.A. developed the system Electronic Eye (EE), an electronic monitoring equipment design for tropical tuna purse seine vessels which is based on automatic high definition photo cameras.

The purpose of this study was to test the use of the system EE on a tropical tuna purse seine vessel operating in the Atlantic Ocean. The main objectives of this study was to compare the data collected using EE to the data collected by observers to determine if EE system can be used to reliably collect unbiased data on commercial purse seine vessels. This main objective was divided into three specific objectives:

a) Evaluate the reliability and functionality of EM to monitor fishing operations including set locations and set-type.
b) Evaluate the reliability and functionality of EM to estimate total tuna catches by set, both for the retained and for the discarded components.
c) Evaluate the reliability and functionality of EM to estimate bycatch such as sharks, billfishes and turtles.

2. Materials and methods

2.1 Data collection

The study was carried out during April and June 2014, to examine the ability of EE to collect unbiased and precise catch and bycatch data in the tuna purse seine fishery. EE and an observer were deployed simultaneously on a complete fishing trip on a purse seine fishing vessel operating in the Atlantic Oceans. A vessel owned by Pesquería Vasco Montañesa, S.A. (PEVASA) was selected to take part in the study. The boat is a 75.6 m tuna purse seiner based in Abidjan, Ivory Coast.

The Electronic Eye (**Figure 1**) has a camera that takes high definition pictures (Full-HD) with a 2 megapixels resolution. The maximum shutter speed is 1 image per second. The time between pictures can be configured and different triggers can be used for the photo shooting, like the vessel speed or movement sensors. Installation of the device is simple requiring only a power supply. Electronic Eye is a tamper proof device. The images cannot be modified and are encrypted and associated with the vessel track (GPS position, date and time). The system has four security levels with different access codes, thus only authorized users can access the data. All de data are stored in internal hard drives, which have more than 6 month self-sufficiency in usual fishing conditions. In addition to the data stored on the hard drive, real time information is also sent hourly to a land station; this information contains; vessel position, number of taken photos and system status (possible cuts on the power supply).

During the monitored trip photos were taken continuously during the complete day. However, the speed of the boat was use to reduce time between photos during fishing operations. Pictures were recorded in a routine way each 5 minutes during searching and transit activities, but each 5 second during fishing operations (below 4 knots).

Eight independent EEs were installed in four different placements (**Figure 2**). One system per position would be enough, but extra systems were installed to prevent interruptions in the picture sequences in case any equipment was damaged: EE 1 on the crow's nest portside (**Figure 3**): This system allowed viewing the roller on the port side and the area where the sack is emptied during brailing. The opening angle of the camera was wide enough, and allowed viewing the speedboat taking the FAD out from the net before rings were up.

- EE 2 on the crow's nest starboard (**Figure 4**): This system allowed viewing the starboard of the fishing deck, where release of the large size bycatches occurs.

- EE 3 on the top deck (**Figure 5**). This system was installed in the control console. It allows a complete view of the brailing. It was used to estimate the total catch by set based on the fullness of each brail and known brail total capacity. A complete brail was accounted as 8-10 tonnes depending on the average size of the catch. This camera also permitted the detection of large size bycatch species if they were removed from the brail on the main deck.

- EE 4 on the bow (**Figure 6**): This system allows detecting discarded tunas when the bow crane was used to discard fish directly from the below deck.

Fishing activity occurs in the same way during each set; the set begins when the net boat enters the water and begins to pull the net to encircle the school. All fishing activity occurs on the port side of the vessel where the net is set, pursed, sacked and then the fish are brailed aboard. While fish are being sorted the crew removes some of the large bodied bycatches such as billfishes, sharks, and turtles from the brailer. Large bodied bycatch species, including sharks and turtles, are discarded on the starboard side after being measured and handled by the observer. The bulk of the fish are then transferred through the hatch to the below deck area. Once in the below deck area, fish are sorted on the conveyor and placed into storage holds. If discards occur, fish is discarded in the bow, directly from the below deck and using a crane.

The data collected using the EE systems were reviewed, by an experienced observer, in the lab using the Beluga software. Beluga is a software package that integrates and displays EE GPS and imagery data for review.

For comparison with EE data, observers for this study used the standard methods used in the EU observer program. During the trips, observer filled in five different data sheets (Delgado de Molina, 1997) with information about tuna species, bycatch species and Fish Aggregating Devices (FADs). Even if observer data are also based in estimates, these data was assumed to be the baseline data for the purposes of this study. However, it is necessary to mention that since the accuracy of observer estimates are not known, relative differences between the two methods can be due to imprecision with both.

Observers collected route data every hour, and all the fishing operations are sampled throughout the trips. Within each set, the priority of sampling for the observer was (1) estimating discarded tunas and measuring a subsample, (2) measuring sharks, billfishes and turtles, (3) estimating the number or weight of smaller bycatch species, measuring a subsample. Retained tuna catch information was recorded directly from the fishing logbook, and logbook information is based on an estimate made by the crew.

2.2 EE and observer data comparison

Classification of set type

Differences in set-type classification made by the observer and by the EEs were analyzed first. This is a crucial element of the tropical tuna purse seine fishery monitoring program and helps to define the fishing effort of the fleet. The set classification made by the observer, free-school set (FSC) or fishing aggregating device set (FAD), was considered as the correct one and the degree of sets correctly classified during the EE data review process was calculated. An exact binomial test (Concover, 1971) was used to calculate the probability of success during the set classification. EEs classification was based on imagery review. Reviewer checked if the speedboat took out from the net any FAD during the fishing operation. Additionally vessel track and catch composition were also used to estimate set type.

For FAD sets, the imagery commonly showed a FAD being towed by the speedboat during within camera view. On the other hand, during free-school sets, the imagery show both the skiff and the speedboat moving in circles until the rings were up to avoid fish escaping while the net is not completely closed. Then, classification of set type was mainly based on images, however the speed and the track of the vessels can be also helpful during the review; during the documented FAD sets, the vessel tended to approach the fishing area with constant speed, then slow down, then return to full speed immediately before the shooting operation. Alternatively, during free-school sets, the EE data showed that the speed prior to setting was more variable while the vessel followed the school and did not drop as low as during FAD sets.

Analysis of tuna catch

Total tuna catch per set was compared between EE and observer estimates using a GLM (Generalized Linear Model) regression model. Skunk (failed) sets were omitted and only sets with more than 0.1 metric tons of catch were included in the analysis. A common approach to evaluate models is to regress predicted vs. observed values (or vice versa) and compare slope and intercept parameters against the 1:1 line. As Piñeiro *et al*. (2008) proved, for these comparisons, observed (in the y-axis) vs. predicted (in the x-axis) regressions should be used. Then we applied the model assuming that the EE record was the independent variable and estimates made by observer the dependent variable with which statistical error is associated. As the catch data are continuous and positive, and their variance increased with the mean, the error was considered to be gamma distributed. The EE and the observer data were expected to follow a 1:1 relationship, expressed as a slope of 1 in a regression model. Thus, we utilized an identity link and examined whether the 95% confidence intervals of the estimated intercept encompassed 0 and the confidence intervals of the estimated slope embraced 1. In that situation, the hypothesis that EE catch estimates were as reliable as observer recordings was not rejected.

Discarded tuna were inexistent during the monitored trip, thus no analytical comparison was done.

By-catch estimation

For bycatch, a GLM with the same model structure and procedures as in the tuna catch was also used to compare the total number of captured individuals estimated by both monitoring methods. The difference between the two cases was the applied error distribution. In the case of bycatch the measured variable was counts, as both observer and EE reviewer estimated the number of sharks and billfishes instead of their biomass. A GLM with Poisson error distribution and link =identity was therefore used. Sets where bycatch was detected by neither sampling methods were omitted from the regression analysis because they were considered to be structural zeros. Model fits were performed using the statistical software R including the packages stats and glm2 (Marschner, 2011).

3. Results

3.1 Classification of sets

Both EE and observer identified same number of fishing sets, including for each of the sets; date, time (shooting, rings up, end of the set), and set location. Furthermore, both methods allowed identification of set-type for all these fishing events; 42 of the 43 monitored sets were correctly identified using EE. Exact binomial test shows a probability of success of 97.67 % (p-value < 2.2e-16) and 95 % confidence interval between 87.7% and 99.9% of success. Of those 43 sets, the observer records shows that 22 were FSC, and 21 were FAD sets. The EE reviewer identified one set during the first trip as a FAD set, while the observer classified it as a free school set. This set was classified as FSC by the reviewer in a first moment, based on the track and images. The track shows the typical approach to a FSC set, and the EE reviewer did not identify any FAD on the images. However, on the images the reviewer identified some species normally associated with FADs, and then he decided to classify it as FAD set.

3.2 Tuna catch estimation

Retained tuna

Total retained tuna catch for the complete trip estimated both by EE and observer was very similar. The observer estimated 863 tones, while 856 tones were estimated by the EE. This is, less than %1 difference. Furthermore, GLM results corroborated that there were good indications that EE and observer data were equally reliable methods for estimating total catch per set (**Figure 7, Table 2**). The solid line in the figure shows the fitted linear regression and the dashed line indicates the expected 1:1 relationship. The 95% confidence intervals of the intercept encompass 0, and 1 is enclosed by the 95% confidence intervals of the slope.

Discarded tuna

Discarded tuna quantities were none existent during the trip that was monitored. Discarded tuna catch was limited to some gilled and damaged small size fish. However both the observer and the EE considered these discards as negligible.

3.3 By-catch estimation

The observer registered 233 sharks and 50 billfishes in the bycatch, while the EE data only contained records of 107 sharks and 17 billfishes (**Table 1**). GLM results show that EE and observer were not equally reliable methods for estimating bycatch. EE estimates were significantly lower than the observer estimates both for total sharks and for total billfishes. **Figure 8** shows the comparison of the estimated numbers of the bycatch estimates per set from EE and observer for the total shark and total billfishes. The summary of the statistical GLM fits for the different species is shown in **Table 3**. In general, the EE tended to underestimate consistently the catch of the different species.

In the case of total sharks, the estimated slope coefficients had narrow limits, but they were clearly above the expected value of 1.0. Silky shark (*Carcharhinus falciformis*) and scalloped hammerhead (*Sphyrna lewini*) were the most caught species, as recorded by the observer. Same species were detected by the EE. Nevertheless, with the EE method, the taxonomic identification only reached the species level for 65% of the individuals. The taxonomic identification of the remaining 35% of the individuals only reached family level. Additionally, 2 oceanic whitetip sharks (*Carcharhinus longimanus*) were recorded by the observer, which were never detected by the EE cameras (**Table 1**).

Billfishes provided a weaker regression because of the low number of observations. Furthermore, the estimated slope coefficients were also clearly different to the expected value of 1.0. The observer recorded 33 Atlantic sailfishes (*Istiophorus albicans*) and 17 Atlantic blue marlins (*Makaira nigricans*). EE reviewer also detected 11 of these blue marlins, but only 5 sailfishes were identified (**Table 1**).

In the case of turtles, only two individuals were caught (and released alive) and identified by the observer within the fishing trips; one hawksbill sea turtle (*Eretmochelys imbricate*) and one olive ridley sea turtle (*Lepidochelys olivacea*). Only one of these turtles was recorded using EE prior to its release, however, it was impossible to identify the species.

On the other hand, one devil ray (*Mobula spp.*) was also detected by the EE cameras, which was never recorded by the observer.

4. Discussion

4.1 Set type classification

Classification of set type, FSC vs FAD, is used for stratification in most tropical tuna purse seine fishery statistics. It is important to be able to discriminate between the two, as the type of set is a major factor determining the catch and bycatch composition (Hall, 2013). It is therefore crucial to be able to discriminate between the two types of sets. The approach used in this research to identify set types from photos appears to be effective. It is however important to note that the usefulness of this method could be limited to vessels with similar fishing behaviour.

When the cameras captured the moment in which the speedboat pushed the FAD outside the seine, there was no doubt that it was a FAD set (**Figure 3**). However, even without realizing this particular moment during the fishing operation, there are other indications that can help us discriminating between FSC and FAD. The speed of the boat and how the vessel approaches the school or the species composition in the catch, give us clues about the type of set. If conclusions based on the EE photos and based on the other indicators do not match, the reviewer may re-look at the pictures more closely and make a final decision. This was the case of the unique set where there was discrepancy between the observer and EE. Neither the observer nor the EE reviewer showed the FAD, however the reviewer decides to classify the set as FAD set based on the species composition. The reviewer identified some rainbow runners and trigger fishes on the deck, and then the reviewer assumed that there was a log or natural drifting object.

This result is consistent with other studies carried out with electronic video monitoring systems in the same fleet and ocean (Ruiz *et al*., 2012). Contrastingly, results during similar pilot projects in the Pacific and Indian Oceans failed to achieve such high performance in classifying the set type (Chavance *et al*., 2013; Ruiz *et al*., 2014). However, the difficulties encountered both in the Indian and Pacific Oceans seen to be related mainly with the alignment between camera views and fishing practices, and not with the feasibility of the electronic monitoring systems.

4.2 Tuna catch estimation

It is a general requirement in any fishery that catch should be accurately recorded (or within a determinate percentage of the true value), as measured in the landings. But in addition to landings, an independent estimate of the catch per set is very valuable when analyzing fisheries data; moreover, if we consider that this is a fishery in which fishing trips last up to 60 days and where fishing areas vary greatly within a trip, information by set is even more valuable. In general terms, as results show, observer and EE system estimates of total retained catch per set were not significantly different, thus total retained tuna catch can be accurately estimated using EE. Given the combination of the camera views, and a known brail volume or weight, it is feasible to accurately estimate the total catch per set.

On the other hand, there were not discarded tunas during the monitored trip. Thus it was impossible to perform any analysis to verify if EE could accurately estimate the discarded fraction of tunas. Anyway, all points on the main deck where discarding practices usually occur were covered by camera views; port side of the fishing deck where the damaged and gilled fish is discarded, bow view where bigger quantities are discarded directly from the below deck with a net, and starboard side of the fishing deck where big individuals are usually discarded (**Figures 3, 4, 5**). Thus it seems obvious to believe that at least it would be feasible to control the existence of tuna discards if any exists. In this sense, and given the relevance that discard bans are acquiring both in EU and in the tuna RFMOs, it is necessary to continue exploring the potential of the equipment for this purpose.

4.3 Bycatch estimation

The result of this study shows that the bycatch estimates made by the EE are consistently underestimated relative to the observer data. Two main reasons have been identified as responsible for this discrepancy. In first place, even if some large size bycatch individuals were removed from the brailer by crew members directly on the main deck, and discarded later from the starboard side, some other individuals (smallest ones presumably) were directly, and mixed with the bulk of the fish, transferred through the hatch to the below-deck area. The lack of cameras in this area makes it impossible for the EE reviewer to detect those individuals if they are retained and placed into storage wells. For that reason, differences between human and electronic methods are lower for the blue marlin than for sailfish. Most of the sailfishes where less than 2 meters length (lower jaw-fork length), as corroborated by the observer data, and went directly through the hatch to the below deck area. On the other hand, blue marlins, which had larger sizes, were in most of the cases first sorted from the brailer on the main deck, and then cut and transferred to the storage wells. Thus, it was easier for the reviewer to identify them with cameras on the control console an on the maintop portside (EE1 and EE3).

The difficulty encountered with the smallest shark is similar to that of sailfishes. Smaller sharks went straight down, to the below deck, and mixed with the bulk of the catch. These individuals are then discarded or released, so they should be detected with the starboard camera view (EE2). However, if this task is left to the end of the set, once the boat gets back its cruising speed (> 4 knots), the time between photos was back each 5 minutes. Then, many of these individuals were not detected by the EE reviewer.

One benefit of EE is that it allows the simultaneous analysis both of the main fishing deck and below deck. The devil ray detected by the EE could be a clear example of this situation. This by-catch was undetected by the observer, probably because he was on sampling on the below deck area.

Another challenge for the technology is the grade of taxonomic identification of the catch. The quality of images allowed identifying a large number of sharks and billfishes to species level, achieving slightly higher level of identification than previous experiences based on analog cameras (Ruiz *et al.*, 2012). However, there is still room for improvement. Current image quality (1920 x 1080 pixels) seems sufficient for an adequate taxonomic identification; however the period between shots (5 seconds) reduces the chances of getting good pictures where the distinctive characters of different species are visible. For instance, in the case of the turtles counting the plates could be crucial to identify the species, and then one photo will be needed at least, where the turtle is in the right position without any barrier between it and the camera hindering vision. Obviously, larger period between photos reduces the chances of getting the right picture.

5. Conclusion and recommendations

The main objective of this study was to determine the feasibility of the EE developed by Marine Instruments S.A. to reliably collect unbiased data on commercial purse seine vessels. Analyses in this study showed that EE can be used to determine; the number of sets (including date, time and position), set type, and total tuna catch as reliably as observers can. The main deck operations were generally well covered by camera angles, and EE image reviewer was able to make basic determinations of set type and target catch volume. As well, large bycatch species could also be assessed if they were handled on the fishing deck. But if the catch was brailed aboard and transferred directly to the below deck, that fraction of the catch fell outside the scope of the EE. Thus, in order to be fully comparable with the observer bycatch data, some improvements and adjustments are still needed.

During this experience, some possible improvements have been already identified:

i) Reducing the time between photos below 5 seconds, and keeping this shorter periodicity between photos for some time once the set is completed (regardless the vessel speed), the chance of detecting discarded species will substantially increase. Furthermore, the chance of getting adequate photos for detailed taxonomic identification will also increase. The current EE system already allows setting these changes, but then, the number of photos will increase, and the system should have sufficient capacity to store all that data.

ii) On the other hand, installation of new EE equipment on the bellow deck area will be necessary in order to correctly monitor the bulk that directly pass from the brail to that area (to the conveyor belt installed in the below deck). There are currently several EE cameras installed in this area; however these images have not been used for this study. Further work will be needed to determine the usefulness of these systems.

There are clearly still some limitations for the EE in comparison with human observers, limitations that must be overcome in the future. However, this does not mean that this system is not useful at present. According to the final goals of a monitoring program, the EE system could be a complement to observers or even a real alternative. For scientific monitoring purposes, EE will be valuable complement to the port sampling to gather target species catch statistics when these data are not, or are poorly, collected. For bycatch investigation, the use of EE could be a complementary tool to observers during the data collection process. EE is a useful alternative that could significantly increase the sampling coverage, even if the EE data were limited to effort, location, set-type and total tuna catch. However, there are many cases where full monitoring coverage is demanded for control and enforcement reasons. For example, the case of the ICCAT two-month prohibition on FAD fishing in an area off western Africa (ICCAT Rec. 11-01), the case in which an observer is demanded to fish in a determinate EEZ, the case of the possible control of the upcoming discard ban for EU vessels. In cases such as these, EE could function as a useful tool for monitoring the fishery.

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Table 1. Shark and billfish bycatch estimates (numbers) by set, made by observers and using EE. *Makaira nigricans* (BUM), *Istiophorus albicans* (SAI), unidentified billfish (BILL), *Carcharhinus falciformis* (FAL), *Sphyrna lewini* (SPL), *Carcharhinidae* (RSK), *Sphyrnidae* (SPY) and *Carcharhinus longimanus* (OCS).

	BILLFISH							SHARKS								
	ELECTRONIC EYE				OBSERVER			ELECTRONIC EYE					OBSERVER			
set	**BUM**	**SAI**	**BILL**	**TOTAL**	**BUM**	**SAI**	**TOTAL**	**FAL**	**SPL**	**RSK**	**SPY**	**TOTAL**	**FAL**	**SPL**	**OCS**	**TOTAL**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	1	1	0	1	3	0	0	0	3	4	0	0	4
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
6	0	0	0	0	0	7	7	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	7	7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	4	0	0	4	4	0	4	7	24	0	25	56	15	77	0	92
10	0	1	0	1	0	4	4	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
12	0	2	0	2	0	6	6	0	0	0	0	0	0	0	0	0
13	2	0	0	2	3	0	3	2	0	0	0	2	61	0	0	61
14	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
16	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
21	0	1	0	1	2	1	3	0	0	1	0	1	1	0	1	2
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1
27	0	0	0	0	0	0	0	1	0	0	0	1	3	0	0	3
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0
30	0	0	1	1	1	1	2	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	13	0	0	0	13	16	0	0	16
36	1	0	0	1	1	0	1	9	0	0	0	9	22	0	0	22
37	0	0	0	0	0	0	0	1	0	1	0	2	2	0	0	2
38	1	0	0	1	1	0	1	2	0	7	0	9	9	0	0	9
39	0	0	0	0	0	0	0	4	0	6	0	10	17	0	0	17
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
43	1	0	0	1	2	0	2	0	0	0	0	0	0	0	0	0
TOTAL	**11**	**5**	**1**	**17**	**17**	**33**	**50**	**43**	**24**	**15**	**25**	**107**	**154**	**77**	**2**	**233**

Table 2. Summary output of the GLM of the relationship between EM estimates and observer records in the determination of the total tuna catch. The GLM model assumed an identity link and gamma error.

	Coefficient estimate	*Confidence intervals*		*p-value*
		2.5%	*97.5%*	
Intercept	1.76	-0.13	4.02	0.125
Observer tuna catch	0.86	0.66	1.1	**1.15e-08 *****

Table 3. Summary statistics of the slopes of the GLM relationship between EM and observer data of the large size bycatch species, total sharks and totals billfishes.

	Estimate	*Confidence intervals*		*p-value*
		2.5%	**97.5%**	
Total Shark	1.69	1.403	2.008	**< 2e-16 *****
Total billfish	0.124	-0.506	0.91	0.766
Makaira nigricans	0,60	-0.07	1.4	0.158

Figure 1. Electronic Eye: The system comprises a full HD photo camera.

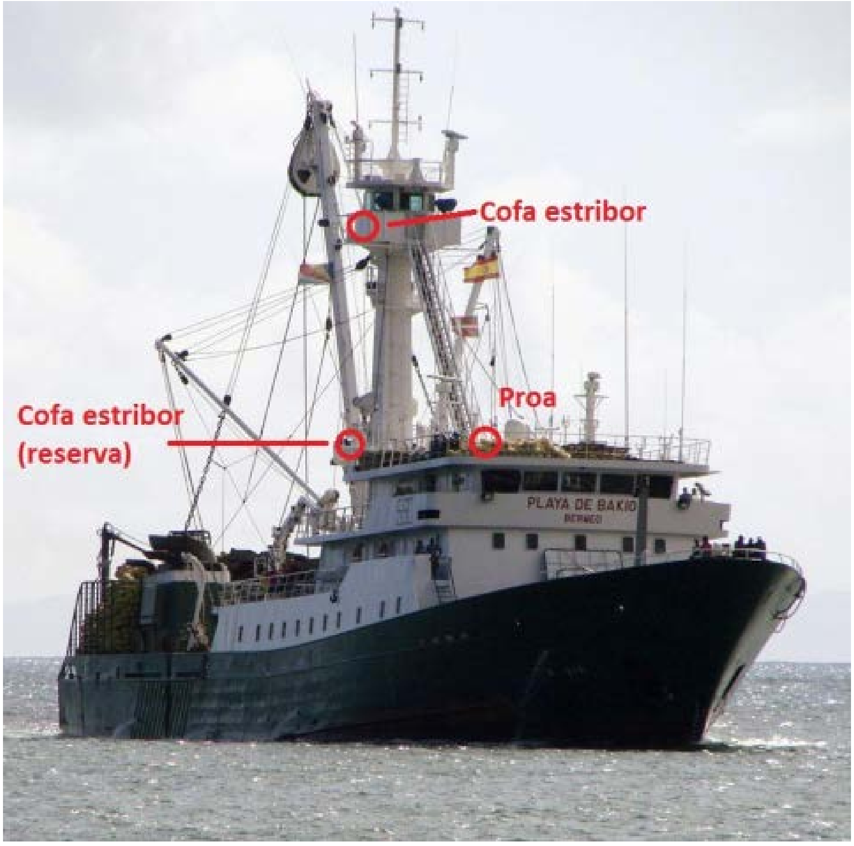

Figure 2. Camera placements (EE2 & EE4).

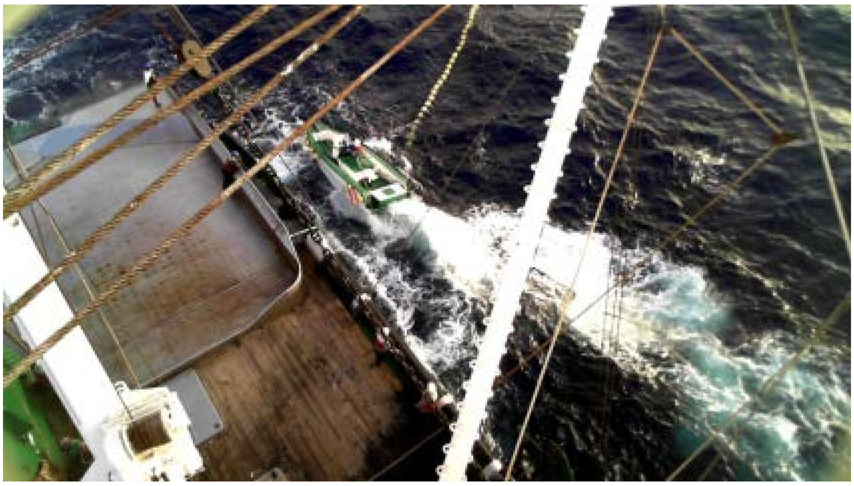

Figure 3. View of the EE 1 on the maintop portside, where it is visible the speedboat taking the FAD out from the net.

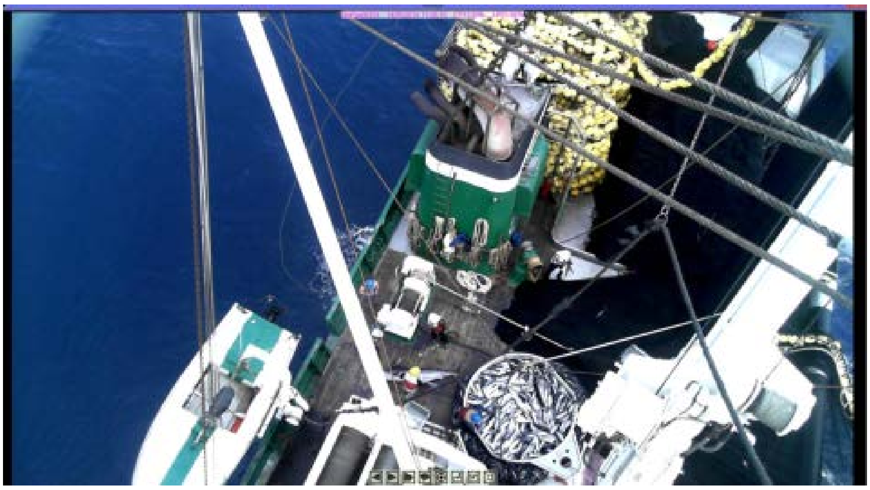

Figure 4. View of the EE 2 on the maintop starboard. This system allowed viewing the starboard of the fishing deck, where release of the large size bycatches occurs.

Figure 5. View of the EE 3 on the main deck. This system was installed in the control console. It allows a complete view of the brailing.

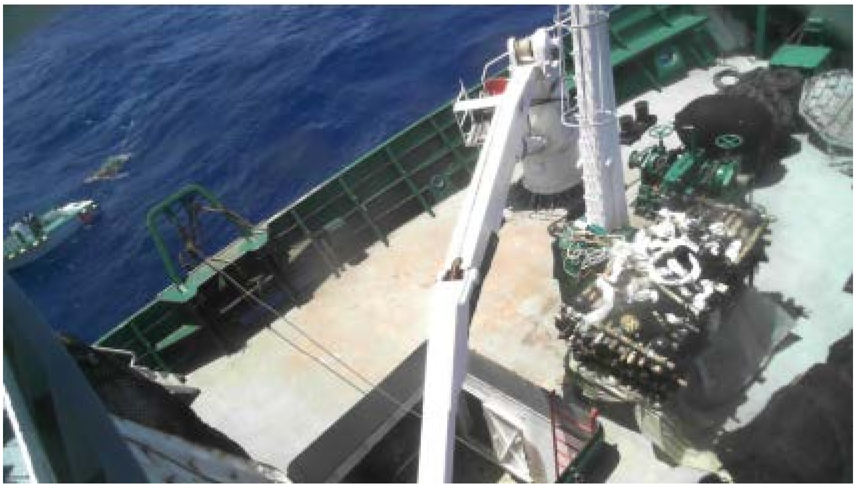

Figure 6. View of the EE 4 on the bow.

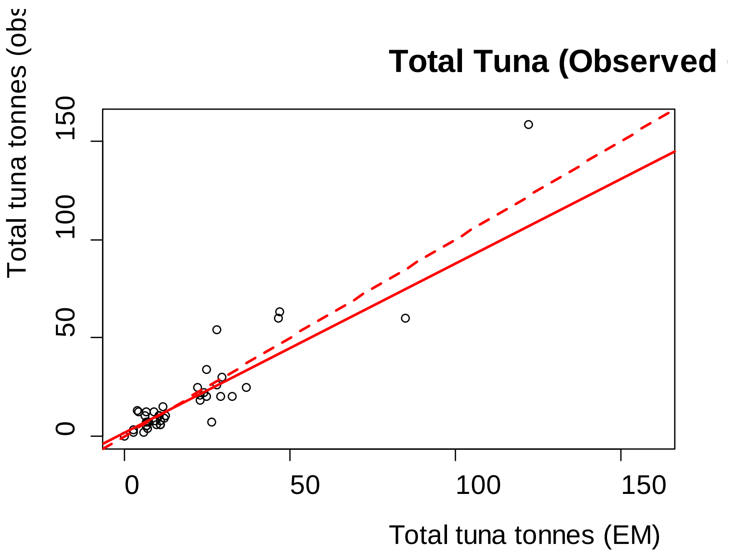

Figure7. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of total tuna catch in all valid fishing sets. The GLM estimates are given in **Table 3**.

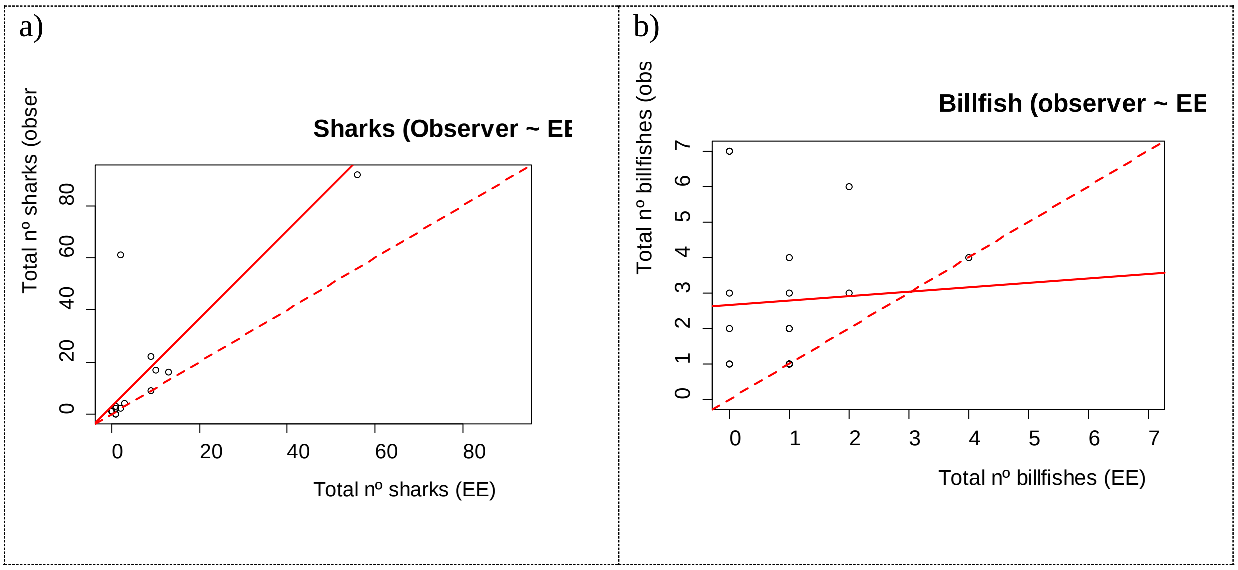

Figure 8. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of bycatch of the large size species: Total sharks (a) and total billfish (b).