Comparing electronic monitoring system with observer data for estimating non-target species and discards on French tropical tuna purse seine vessels

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Electronic monitoring system (EMS) was recently implemented on French tropical tuna purse seiners to complement the current Orthongel's observer program and to increase observer coverage both in the Indian and Atlantic Oceans. The main objective was to test the efficiency and the potential of the EM system compared to regular observer programs. In this perspective, 'mixed' trips involving both EMS and on-board observers were conducted on the Torre Giulia and Gevred CFTO vessels over 2015-2016. In this study, we analyzed non-target species and discard data from six mixed trips and compared EMS to observer estimations using generalized linear models (GLMs). Good matches between both methods were observed for tuna discards, including for skipjack and for the bigeye/yellowfin discard group. However divergences between estimations and methods were noted for non-target catch and the difference appeared to depend on the species. For species with high occurrence such as triggerfish and mackerel scad which are systematically discarded, EMS provided similar estimates as on-board observation. EMS could actually be more efficient than observers to describe the discarded volume of these species as it allows exhaustive counts on the discard belt. However, for larger species such as sharks and billfishes or for high commercial value species such as dolphinfish, EMS systematically underestimated occurrence and discards volume compared to observers. Indeed these species can be handled at different places on deck (individuals release directly at sea) or below deck (individuals kept for cooking or for wells) and EMS usually failed to document their retrieval due to camera distance or dead angles. We conclude that with some improvement on camera installation as well as with minimal crew collaboration, EMS on French tropical tuna purse seiners appears to be a promising tool for monitoring discards and non-target catch at an acceptable species identification resolution to supplement regional observer program.

Keywords: electronic monitoring system, observer, non-target species, discards, purse seine, tropical tuna, sharks, billfishes.

INTRODUCTION

Observer data are essential for the sustainable management of fisheries as it provides important information on fish stocks and the impacts of fishing pressure on the marine environment. Observer programs for tuna fisheries have been implemented for many years to help monitoring fishing operations worldwide and to control what is known as best practices. Each program involves industry and science collaboration and aims to collect a range of data to improve the assessment of tuna stocks, bycatch discards and compliance to Regional Fisheries Management Organization (RFMO) conservation measures.

In this study, we define the non-target catch as the portion of individuals that is caught unintentionally while targeting major commercial tuna. In the case of purse seine tropical tuna fisheries, this includes *bycatch* on minor tuna species or common associated species such as triggerfish or dolphinfish but also *incidental catches* of sensitive or iconic species such as sharks, cetaceans, rays or sea turtles (see Annex). Also, discard is defined here as the portion of target or non-target species that is not kept on board. The majority of bycatch species are discarded at sea (either dead or alive) but some individuals might be kept on board for cooking or for local market. On the other hand, all sensitive species should ideally be released alive and unharmed (Annex). Information and data on bycatch, incidental catch and discards are important for observer programs as it helps monitoring both target and non-target populations and protecting sensitive species.

Since the implementation of observer programs, most of these data were collected by human observers on board but in recent years, electronic monitoring system (EMS) on tuna fishing fleet has been tested as an alternative observing tool to complement and increase observer coverage (Hosken *et al.*, 2016, Larcombe *et al.*, 2016, Ruiz *et al.*, 2016a; Ruiz *et al.*, 2016b). EMS consists in image recording systems with hardware (cameras, sensor and GPS) and software to monitor and post-analyze the fishing activities of a vessel. One advantage of the EMS is to increase the monitoring on vessels where human observers are not be able to work for logistic and security reasons. Another advantage is to compensate for the potential high costs and complex organization involved in observer placement and debriefing. In general, tuna fishing companies found in this new technology a good opportunity to increase to 100 % the observer coverage of their fleets with the objective to obtain an “eco-label” certification.

Pilot studies on EMS have been conducted on purse seine tuna fisheries both in the Indian and Atlantic Oceans (Chavance *et al.*, 2013; Ruiz *et al.*, 2012; Ruiz *et al.*, 2014a; Ruiz *et al.*, 2014b; Monteagudo *et al.*, 2014) where data requirements for management purposes of tuna RFMO are increasing. Advantages and drawbacks of EMS were compared to the classical on-board observation. Preliminary results indicated that EMS can be more effective for some specific tasks, equivalent for some of them, and weaker for some other tasks currently conducted by humans. After some adjustments, it can be a valid tool to monitor the fishing effort, set type, total tuna catch by set, and bycatch (Ruiz *et al.*, 2014a). As a consequence, a large number of tropical purse seiners are now equipped with EMS. However as boat configuration and manufacturer installations are different, minimum standards are recommended for EMS and each vessel needs to be first certified by these minimum standards (Restrepo, 2014, Ruiz *et al.*, 2016b).

In this perspective, an electronic monitoring project was launched and implemented in 2014 by Orthongel within the OCUP (*Observateur Commun Unique et Permanent* - Common Unique Permanent Observer) program on French tropical purse seiners. The OCUP program aims at taking scientific observers on board tropical tuna purse seiner to cover 100 % of their activities both in the Indian and Atlantic Oceans. The program also includes the training and boarding of national scientific observers of the different countries granting to French purse seiners access to their EEZ. The new CAT OOE (*Contrat d'Avenir Thonier- Optimisation de l'Oeil Electronique* - Tuna Contract for the future – Electronic Eye Optimisation) project, funded by France Filière Pêche was created to complement the current OCUP program with an extended collaboration involving CFTO (Compagnie Française du Thon Océanique), Thalos, Oceanic Développement and IRD partners. The priority was to monitor purse seiners of the Indian Ocean where spatial and temporal at sea-observer coverage was insufficient due to piracy-related security risks on-board. To date, 42 % of all French tuna purse seiners are equipped with cameras. This mainly includes the fishing company CFTO, with eight vessels operating in the Indian Ocean and two vessels equipped with EMS in the Atlantic Ocean. All trip recordings are viewed and analyzed by 'on land' observers from Oceanic Développement. Since 2016, more than 57 EMS trips were analyzed, including 'mixed' trips where a human observer was also present on board.

A preliminary analysis from Oceanic Développement conducted on the *Torre Giulia* 141 "mixed" trip (Bonnieux & Relot-Stirnemann, 2016) indicated that the EMS installation was able to distinguish the type of sets (free school, floating object named FOB and null set) with 100 % reliability but was not always able to identify the type of FOB (log or fish aggregating device). The system also appeared to provide a relatively good estimation of the volume of discards for tuna and non-target species but the lack of image precision or quality seemed to induce a loss of information in terms of species identification, especially for look-alike individuals such as yellowfin (*Thunnus albacares,* YFT) and bigeye (*Thunnus obesus,* BET) juveniles (< 10 Kg) or bullet tuna (*Auxis rochei,* BLT) and frigate tuna (*Auxis thazard*, FRI). Similarly, external camera installations were able to record sensitive species (sharks, rays, turtles) 'best practices' on deck but not always to identify the species. As noted by previous EMS studies, in most cases, the taxonomic identification can only reach the family or the order level (Ruiz *et al.*, 2014, Monteagudo *et al.*, 2014). On the other hand, the discard camera was efficient to distinguish the species level from small sharks (*Carcharhinus falciformis,* FAL mostly) to dominant bycatch species such as dolphinfish (*Coryphaena hippurus* DOL), rainbow runner (*Elegatis bipinnulata* RRU), triggerfish (*Canthidermis maculata* CNT), wahoo (*Acanthocybium solandri* WAH), mackerel scad (*Decapterus macarellus* MSD), blue runner (*Caranx crysos* RUB) (Bonnieux & Relot-Stirnemann, 2016). These results were in general conform to conclusions from other pilot studies involving the *Torre Giulia* (Chavance *et al.*, 2013; Ruiz *et al.*, 2014).

The general objective of the CAT OOE project was to test the EMS installation, to validate the quality of electronic data compared to on-board observer data and finally to train national scientific observers of the OCUP program to analyze camera images (either to improve the data collected on board or to collect observer data when no observer is on board). In the continuity of Oceanic Développement work, this paper aims at testing the efficiency of the French electronic monitoring system based on the results of six selected 2015-2016 'mixed' trips (covered both by EMS and on board observers). Information on tuna discards and non-target species (retained and discarded) volume estimation via EMS were sometimes coarse or missing in previous EMS studies due to lack of data coming from different fishing strategies (large portion of bycatch species kept on board) and boat installations (absence of discard belt). As most French vessel configurations include a discard belt, a particular focus was established on tuna and non-target species discards estimation in this study. More generally this paper describes the methodology used in the CAT OOE project and characterizes the early performance of the EM system during this two year trial.

METHODS

Camera installation and data collection

EMS data used in this analysis were collected on 2 purse seine vessels: the *Torre Giulia* vessel operating in the Indian Ocean and the *Gevred* vessel operating in the Atlantic Ocean. Both vessels were able to board an observer and data were selected based on the quality of recordings for both EMS and on-board observations over the 2015 and 2016 period.

The *Torre Giulia* vessel was equipped by Thalos Company with 5 HD MOBOTIX digital cameras with 6 MP resolution (Figure 1). One camera with wide angle was installed in the crow's nest to cover the port side of the boat and to follow general fishing activity including setting, pursing, and brailing. Another camera placed on the desk was used to record brailing operations and discard activities on deck. Three other cameras with higher frequency (5 frames/second) were placed below the deck along the conveyor belt to follow the sorting operations and to determine the species composition. One of them was placed at the end of the discard belt to estimate the volume of discards. The *Gevred* vessel was equipped with the same standard configuration but with one more camera placed on the crow's nest to enlarge the vision on the starboard side, where large species are released at sea (Figure 1). One of the cameras placed below to deck was installed to get a wider view on the whole conveyor belt and the wells.

External cameras were equipped with GPS which enable to geolocalize each frame and to record vessel position (one position per minute). Crow's nest cameras were set to record continuously whereas desk and internal cameras are triggered by vessel speed. The system was checked remotely on a regular basis to ensure it was operational. Image data were stored digitally and full hard disks are transmitted to Oceanic Développement for analysis (Figure 2). Electronic recordings were reviewed using the *Oceanlive* software developed by Thalos. Fishing operations were selected using logbook indications and analyzed independently. Forms and tables were adapted to EMS observations but most of the collected data was the same as the information collected by on-board observers (Figure 2).

On-board observer data used in this study were derived from the OCUP monitoring program. Observers used standard methods defined by the EU and t-RFMOs and filled different forms and data sheets with information about tuna catch in weight, species composition, non-target catch in numbers and floatings objects. All data were validated and stored within *Observe 4.06* database developed by IRD (Cauquil *et al.*, 2009).

Species composition is very different between free-school and FOB sets (Amandè *et al*., 2010). As this study mainly focusses on non-target catch and discards, mixed trips were selected based on the abundance of FOB sets, which involved larger occurrence of bycatch. However both free school and FOB sets were taken into account in the analysis. Sets where pocket was released at sea, defined as null sets, were removed from the analysis as it is impossible for EMS to evaluate the discards in this dead angle. Sets with camera recording failure were also removed from the analysis. Discarded tuna as well as non-target species retained and discarded collected by EMS were compared to corresponding at sea observer data. Details about the number of sets by trip and by analysis are presented in table 1.

Statistical 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. Piñeiro *et al*. (2008) suggested that observed vs. predicted values should be plotted respectively on the y-axis and on the x-axis for these comparisons. In our study, generalized linear models (GLM) were used to compare at-sea observer data to the EMS data. The regression method was used as a simple description of the match between the two methods rather than a prediction model and was applied as following:

$$On - board\ observer \sim EMS\ +\ \varepsilon$$

In each GLM analysis, on-board observer records were considered as the 'dependent' variable (on the x-axis) and plotted against the EMS 'independent' variable (on the y-axis). Regression parameters including slope, y-intercept and standard deviation of the residuals were estimated and the predicted model was compared visually to the expected l:1 relationship, expressed as a slope of 1. Pseudo R^2 measures were computed based on GLM deviance and described as D squared (D^2) following Guisan & Zimmermann (2000) definition:

$$D^2\ =\ (Null\ deviance\ -\ residual\ deviance)\ /null\ deviance$$

where the null deviance is the deviance of the model with the intercept only, and the residual deviance is the deviance that remains unexplained by the model after EMS variable has been included.

For discarded tuna expressed in weight (kg), only positive sets (weight > 0) from both EMS and on-board observers were taken into account in the analysis (Table 1). As the discard data are continuous and positive and the variance increasing with the mean, we assume that the error is gamma distributed (McCullagh and Nedler, 1989). We examined the regression coefficients and whether the confidence intervals of estimated values encompassed 0 for the intercept and 1 for the slope. When these conditions were met (or approached), the hypothesis that both methods are equivalent could be validated (Piñeiro *et al.*, 2008).

We separated the analysis for the combination of all tuna species (including minor tuna) and for the most abundant major tuna species: skipjack (*Katsuwonus pelamis*, SKJ) and yellowfin/bigeye grouped together (YFT/BET) as young individuals were not differentiated via EMS. When the MAX (scombrids) category was present in the set, we chose to reattribute (or not) the MAX value to SKJ or YFT/BET group depending of the presence of other minor tuna and/or the dominance of one species over the other.

For the non-target catch analysis (which includes sensitive species but excludes minor tunas) we separated the total non-target species analysis from the discarded analysis, taking into account that the retained fraction of bycatch species (fate) might be difficult to observe with

EMS due to cameras dead angles. For each analysis that was based on the number of individuals (counts), we applied a GLM with identity link and Poisson error distribution (Mc Cullagh and Nedler, 1989). We removed sets with 0 observations only when bycatch was detected by none of the methods (Tableau 1). The GLM analysis was also examined for the shark and billfish groups of species and for the most abundant non-target species (CNT, RRU, MSD, WAH, FAL) found in this analysis.

GLM analyses were performed with *R* software (http://www.r-project.org/) using the stats and glm2 (Marschner, 2011) packages. Goodness of fit (D^2) for each model was assessed using the modEva package (Barbosa *et al.*, 2013).

RESULTS

Tuna discards

The preliminary examination of tuna discards GLM plots indicated that EMS and on-board observer methods seemed to be equally reliable to estimate total tuna discards as well as categories of major tuna species (Figure 3). In each case, model fits were quite high ($D^2 > 0.50$) and predicted GLM (solid line) for tuna discards closely approached the expected 1:1 relationship (dashed line) meaning that both methods estimations were almost equivalent. GLM statistics corroborated this idea and showed that in each case estimated slopes were close to 1 and that the confidence intervals of the slope encompassed the expected value in all cases (Table 2). The confidence intervals of the y-intercept were not enclosing the 0 value, however the lower boundary (2.5%) of y-intercept was estimated relatively close to 0.

The closest slope estimate (0.995) was found for the group YFT/BET. This results tends to indicate that when these two species were grouped in one category its volume estimation was equivalent for both methods. However the model fit was the lowest (D^2=0.506) which indicated that residual deviance remained significant. For SKJ species and total tuna species group, the slope was slightly above 1 but was influenced by one outlier with an estimated value superior to 5 mt (5000 kg) for SKJ and 6 mt for total tuna species. In this case the gap between methods was explained by the fact that during one set, EMS detected a large volume of small tuna fishes (mainly SKJ) put on deck and directly discarded at sea out of sight of the observer who was working below.

Note that the number of observations for tuna discards was not particularly high in any of the categories (N < 30 for YFT/BET group). A part of this result is coming from the fact that a large number of observations were missing for one or the other method. For instance, 20 observations of tuna discards were available from the EMS analysis of *Torre Giulia* trip 146 but none were registered by the on-board observer (Table 1).

In general, EMS estimates seemed to be reasonably close to on-board observations for tuna discards. It could be interesting to get a higher number of comparable observations for this analysis to further validate these findings.

Non-target catch

In general terms, GLM plots and results for non-target catch show that EMS and observers were not equally reliable for estimating the total non-target catch or the catch of large size species such as sharks or billfishes (Figure 4; Table 3). D^2 were heterogeneous ranging from 0.018 (billfish) to 0.583 (sharks). Statistics show that the estimated slope was above 1 for the total non-target catch (1.819) and below 1 for sharks (0.687) and none of the interval confidences encompassed the expected value. The billfish estimate was evaluated with a negative slope (-0.067) and the GLM failed to provide coherent regression because the number of observation/individuals was too low and the variance too high.

For the non-target catch analysis by species, we obtained different results depending on the species (Figure 5; Table 3). D^2 were moderate, ranging from 0.195 to 0.578, meaning that there was quite important amount of deviance that was not explained by the models. For the most abundant bony species (CNT, RRU) the slope of the relationship was above 1. For CNT, the slope was close to 1 (1.033) and the confidence intervals were narrow around this value meaning that both methods seemed to be equivalent for this particular species. However the fit of the model was moderate (D^2 =0.396). For RRU, the estimated slope was clearly above 1 (1.451) and seemed to be influenced by few outliers above 1000 (counts) from EMS. For the rest of the species, the slope was below 1, meaning that EMS estimated fewer individuals than on-board observer. This tendency was clear for species with commercial value such as DOL and WAH where the estimate was found below 0.40 (0.338 and 0.232 respectively) but was less pronounced for MSD, which reached 0.833. Finally, the GLM analysis on the most common shark species FAL confirmed the previous shark analysis by showing a good model fit (D^2= 0.578) but a slope around 0.604, meaning a global underestimation of this species by the EMS.

When looking in details at total discard observations on the GLM plot, one can see that EMS seemed to overestimate values in number compared to on-board observer counts. In particular few outliers (three values > 4000 individuals) originating from the EMS contributed to the positive slope and the lack of model fit (D^2=0.386). It was found that these values originated from the *Gevred* 5 trip. These estimates were based on a time sequence raised to the total sorting duration because the discard flow on this boat was too intense for the ‘on land’ observer to count. For the same *Gevred* trip, some on-board observer data have also appeared not to be raised as we found a large number of observations ranging around the same value, when EMS gave in parallel much higher estimates.

Zero value observations were found associated to non-zero observations for both EMS and on board observers, implying that one of the method may have been more efficient than the other to detect some individuals depending on the case. It is worth noting that zero observations from EMS were found for small non-target species but also for relatively large species such as sharks or billfishes. These results and most of other EMS underestimation cases may be explained by camera installation which may not be sufficiently efficient (dead angle, distance) to follow all the sorting operations on or below the deck. Another reason might also be a camera vision partly obstructed with drops or a bad light exposition which prevent species identification. For example, four null EMS observations for billfish were coming from Torre Giulia 146, where deck camera was registered to be dirty and overexposed for most of the trip. EMS might have failed to identify the billfishes (supposedly small individuals) released at sea due to camera lack of vision.

Non-target catch discards

The GLM analysis was repeated for the portion of non-target catch that was observed as discards and compared to previous non-target catch analyses (Table 4, Figure 6 and 7). In general, D^2 were slightly lower and the trend remained the same with a more pronounced slope (2.066) for the total non-target catch discards and a less pronounced slope (0.619) for the total sharks which was still underestimated by the EMS. Billfish regression remains weak and negative due to lower number of observations (N=11).

When divided by individual species, model fit (D^2) increased for most species except for DOL species. For bycatch species with low commercial value such as CNT or MSD, the trend remained the same and showed that all (or almost all) individuals were discarded. For species like DOL, WAH and RRU that may be kept on board for cooking or sold on local markets, the trends were different. RRU discards were still overestimated by EMS and the slope was more pronounced (1.722) than in non-target catch analysis. DOL discards remained underestimated with a lower slope reaching 0.346. However in the case of WAH discards, the GLM detected that both EMS and on-board observation methods appeared equivalent with an estimated slope of 0.958 and confidence intervals enclosing the expected value of 1. The model fit for this species also increase (D^2= 0.401).

Compared to non-target catch data, a large number of zero values coming from on-board observations were found in the discard analysis. Sometimes these values were recorded within the same trip, which may be related to the sampling method used by the on-board observer. For example on TG146 over 20 sets, DOL individuals were identified as discards in only 1 set for on-board observer compared to 13 sets with EMS. The same result was found for WAH with individuals viewed as discards in 1 set compared 8 sets with EMS. In these cases, it seems probable that EMS counts on discards belt were not recorded by the observer because he was not present at this time or was working on other tasks. On the other hand, zero values from EMS discards observations might still be explained by dead angles or obstructed vision on deck or along the conveyor belt. Following the same logic, the EMS underestimation of DOL or FAL discards showed that the current camera configuration on boat was not able to record all the handling operations for these species.

DISCUSSION

EMS as installed on French purse seine appeared to be a promising tool to monitor the type of fishing set, non-target catch volume and composition, discards and best practices on board. Overall, this study tends to validate the preliminary analysis performed by Oceanic Développement and other previous studies made on EMS for tropical tuna purse seiners.

Results on tuna discards showed that the EMS was able to reproduce on-board observer work and estimate equivalent volume of discards of all species of tunas combined and of the most common tuna species SKJ or group of tuna species (YFT/BET). Despite a smaller number of comparable data for these categories, there were good indications that EMS might be as efficient as on-board observer to perform this particular task. However it was noted that the species of discarded tuna was not always recognizable with EMS, as identification was dependent on the size of individuals, their condition factor, fish disposition on belt, fish distance from cameras and image quality (Bonnieux & Relot-Stirnemann, 2016). Therefore, EMS may be less precise than on-board observation in terms of species identification, especially when discard operations take place on the deck. EMS weight estimation may also be less precise than on-board estimation because the 'on land' observer has no direct access to the fish. It was proposed by Oceanic Développement to record tuna discards in number instead of weight as it is difficult for the 'on land' observer to estimate the mean weight, especially when species is not recognizable (Bonnieux & Relot-Stirnemann, 2016).

For non-target catch analyses, the number of observations was higher and the GLMs indicated significant divergences between EMS and on board observer method. Overall, the total non-target catch appeared to be overestimated by EMS. However the results were different when discriminated by individual species or group of species. Further analyses have shown that the overestimated trends were actually influenced by outliers coming from the most common bycatch species (mainly RRU and CNT) caught on the *Gevred* trip. On this vessel, the discard flow was higher and in some cases it was not possible for observers to count individuals in an exhaustive way. In this case, on-board and 'on land' observers may use different methods to raise their observations, which could contribute to overall differences. Consequently, a threshold could exist for high volumes of non-target catch where both methods diverge due to the raising methodology. When observations are raised, the exactitude of the estimation may vary according to the observer method and its validity may be questioned. However, it should be noted that in most cases 'on land' observers have used an exhaustive method to count individuals as electronic technology provides the opportunity to do so. EMS estimations of discards were therefore supposedly more precise and reliable than on-board estimations and the overall difference recorded on *Gevred* may be interpreted more as an underestimation from on-board observers than an overestimation from EMS.

Furthermore, it was shown that for most individual non-target catch and discards species analyses, the EMS tended to underestimate the number of individuals with significant differences. CNT and MSD species (which are usually systematically discarded) are the species where the methods difference was the lowest (GLM slopes closest to 1). Most of these non-target fishes were indeed put on the discard belt and were recorded by the discard camera at the end of the belt. For larger species such as sharks or billfish or for species with high commercial value (DOL, WAH), retrievals may happen at several places and may not be recorded by cameras. This factor was depicted in previous studies as one the most influential for the difference between EMS and observer estimates (Ruiz *et al.*, 2014a, Chavance *et al.*, 2013). For example, a large portion of small FAL individuals are transiting below deck and come within view of the discard conveyor camera. However some individuals were also handled above the deck. Usually, this happens for larger individuals but it may also occur for smaller ones. Cameras on deck are installed quite far from the discard operations and it is sometimes difficult for the 'on land' observer to register the individuals at the species level. Also the starboard side of the deck has dead angles and is not covered by cameras in the case of *Torre Giulia*. It can be difficult to follow the fate of some individuals. These factors may explain the EMS sharks underestimation and the difference between non-target catch and discards. Other factors such as backlight, overexposure and/or splashing water on external cameras could also play a role on sharks and billfishes EMS underestimation at deck level.

Species such as DOL or WAH are often kept on board for cooking or within wells for local market. A part of the retrieval may be recorded by the EMS because some individuals were taken directly at the beginning of the conveyor belt. However a large part of these retrieval operations are not recorded because the camera installation is not covering the totality of the activities performed in the lower deck. A difference was found between the DOL and WAH analyses in terms of registered discards. WAH bycatch appeared underestimated by EMS however its discards fate is well documented by both methods. In comparison, DOL bycatch and discards were both underestimated by EMS and higher model fit (D^2=0.513) was obtained for bycatch model. In this case, it seems possible that the volume and the fate of DOL was not yet well registered by EMS. The presence of dead angles both below and above deck may explain a large part of the EMS/on board differences for this species and for others. Retrieval operations at several points of the vessel appeared to represent a challenge both for EMS and on-board observers when it comes to estimate bycatch species with high commercial value. On the other hand, the ubiquity ability of the EMS to cover both the upper and lower decks simultaneously during a given fishing set may allow detecting individuals which were not detected otherwise by the on-board observer.

CONCLUSION

Our study shows that EMS as installed on French purse seine boat is able to provide useful data on tuna and non-target catch discards and validate many of the same observations that a regular observer program can deliver. Some differences between EMS and on-board observation were observed but part of them may be explained by differences in observer raising methodologies, especially when non-target catch volumes were high. EMS seems to have better potentials in estimating discards of low commercial species bycatch than non-target species as a whole. Good matches were obtained for tuna discards or bycatch species with small interest such as CNT and MSD. However systematic EMS underestimation for sensitive species such as sharks or high commercial value species such as billfishes, DOL and WAH species indicates that EMS installation might not be enough efficient to register all retrieval and discarding operations. This particular issue may be solved by adding more cameras to cover a larger portion of the activities. In particular, another camera could be installed on the upper deck to cover the star board side of the vessel and register the release of large individuals, such as sharks or billfishes.

Another limitation for EMS is the precision of taxonomic identification, especially for look-alike species or for individuals that are handled far from the camera. To compensate for this issue, more efforts could be done on camera configuration (resolution, frame rate) and camera cleaning to increase species identification both on deck and below deck. It was proposed to work with the crew to develop a standardized approach to handling catch that would improve the EMS ability to accurately document each event (Ruiz *et al.*, 2014a).

To conclude, we could say that EMS configuration within the CAT OOE project appears to deliver useful and complementary information on non-target catch and discards for observer programs that seems to be conform to the minimum standard proposed by Ruiz *et al.* (2016b). It is important to note that current EMS calibration may be optimal for the *Torre Giulia* and the *Gevred* vessels but may not be reproducible for all CFTO vessels. Indeed vessel configurations and processing of the catch can differ substantially, which makes it difficult for a single system to perform adequately in all circumstances (Restrepo *et al.*, 2014). To be useful, EMS installation must be customized aboard each vessel and must be coordinated with clear objectives, defined by the science and management needs. One advantage is that EMS installation is flexible and can be modulated with potential new objectives. For example, the CTOI 17/04 resolution on the retention of non-target species will likely to have an impact on observer methodology. In this case, goals could be redefined and EMS could be used in priority to monitor sensitive species release and best practices. Even if the system should remain as independent as possible from fishing operations, some tasks (camera cleaning, camera health statement, non-target catch handling transparency) still need to engage the collaboration of vessel owners and crew. From this perspective, EMS on French tropical purse seiner may become a valuable tool for improving future regional observer programs.

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Table 1. Number of available sets used for method comparison in each GLM analysis during the 6 sampled trips.

Vessel	N° Trip	Port	Tuna discards	Total non-target catch	Non-target catch discards
Torre Giulia	137	Victoria	8	8	8
Torre Giulia	141	Victoria	18	30	30
Torre Giulia	142	Victoria	2	17	11
Torre Giulia	146	Victoria	0	20	20
Torre Giulia	147	Victoria	10	23	20
Gevred	5	Abidjan	4	26	20
Total			42	124	109

Table 2. Summary statistics and estimated parameters outputs from the GLM regression between EMS and on-board observer data for tuna discards analysis

	N	D^2	Parameters	Estimates	Confidence intervals		p- value
					2,50%	**97,50%**	
Total tuna discards	42	0,781	*slope*	1,093	0,725	1,670	0,000
			intercept	8,506	3,385	17,836	0,07
SKJ discards	33	0,729	*slope*	1,116	0,675	1,918	0,002
			intercept	5,594	1,497	13,885	0,119
YFT/BET discards	23	0,506	*slope*	0,995	0,551	1,599	0,000
			intercept	3,076	0,031	9,080	0,087

Table 3. Summary statistics and estimated parameters outputs from the GLM regression between EMS and on-board observer data for non-target species analysis

	N	D^2	Parameters	Estimates	Confidence intervals		p- value
					2,50%	**97,50%**	
Total	124	0,386	*slope*	1,819	1,800	1,838	<2e-16
			intercept	34,791	32,206	37,463	<2e-16
Total sharks	105	0,583	*slope*	0,687	0,615	0,761	<2e-16
			intercept	1,832	1,437	2,274	1,61E-15
Total billfishes	36	0,018	*slope*	-0,067	-0,232	0,141	0,536
			intercept	0,731	0,397	1,173	0,001
CNT	100	0,396	*slope*	1,033	1,007	1,06	<2e-16
			intercept	54,126	51,500	56,795	<2e-16
RRU	96	0,335	*slope*	1,451	1,412	1,489	<2e-16
			intercept	25,033	23,565	26,554	<2e-16
MSD	66	0,425	*slope*	0,833	0,789	0,878	<2e-16
			intercept	15,505	14,351	16,717	<2e-16
DOL	93	0,513	*slope*	0,338	0,308	0,369	<2e-16
			intercept	4,138	3,554	4,765	<2e-16
WAH	69	0,195	*slope*	0,232	0,189	0,278	<2e-16
			intercept	3,933	3,407	4,506	<2e-16
FAL	96	0,578	*slope*	0,604	0,531	0,681	<2e-16
			intercept	1,914	1,528	2,347	<2e-16

Table 4. Summary statistics and estimated parameters outputs from the GLM regression between EMS and on-board observer data for non-target catch discards analysis

					Confidence intervals		
	N	**D^2**	**Parameters**	**Estimates**	**2,50%**	**97,50%**	**p- value**
Total discards	109	0,356	slope	2,066	2,042	2,09	<2e-16
			intercept	61,842	58,447	65,319	<2e-16
Total sharks	92	0,533	slope	0,619	0,545	0,697	<2e-16
			intercept	1,886	1,444	2,386	1,58E-12
Total billfishes	11	0,121	slope	-0,429	-1,828	0,623	4,57E-01
			intercept	1	0,294	2,323	4,50E-02
CNT	99	0,406	slope	1,094	1,065	1,122	<2e-16
			intercept	54,011	51,339	56,731	<2e-16
RRU	91	0,376	slope	1,722	1,677	1,769	<2e-16
			intercept	26,776	25,326	28,276	<2e-16
MSD	66	0,426	slope	0,833	0,789	0,878	<2e-16
			intercept	15,505	14,351	16,717	<2e-16
DOL	77	0,203	slope	0,346	0,289	0,407	<2e-16
			intercept	6,593	5,940	7,287	<2e-16
WAH	41	0,401	slope	0,958	0,75	1,197	1,3E-12
			intercept	3,038	2,510	3,635	<2e-16
FAL	88	0,572	slope	0,551	0,475	0,630	<2e-16
			intercept	1,749	1,346	2,209	4,94E-13

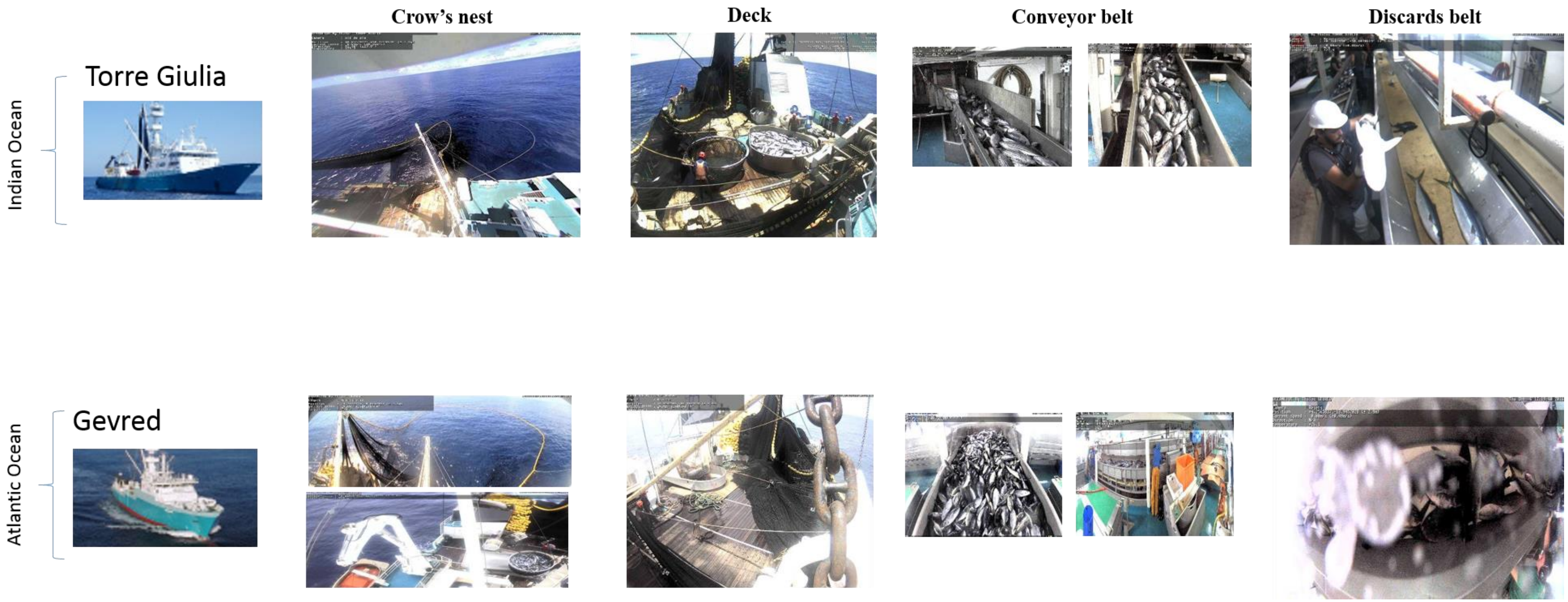

Figure 1. Details of EMS installation on *Torre Giulia* and *Gevred* CFTO vessels and global view from each camera.

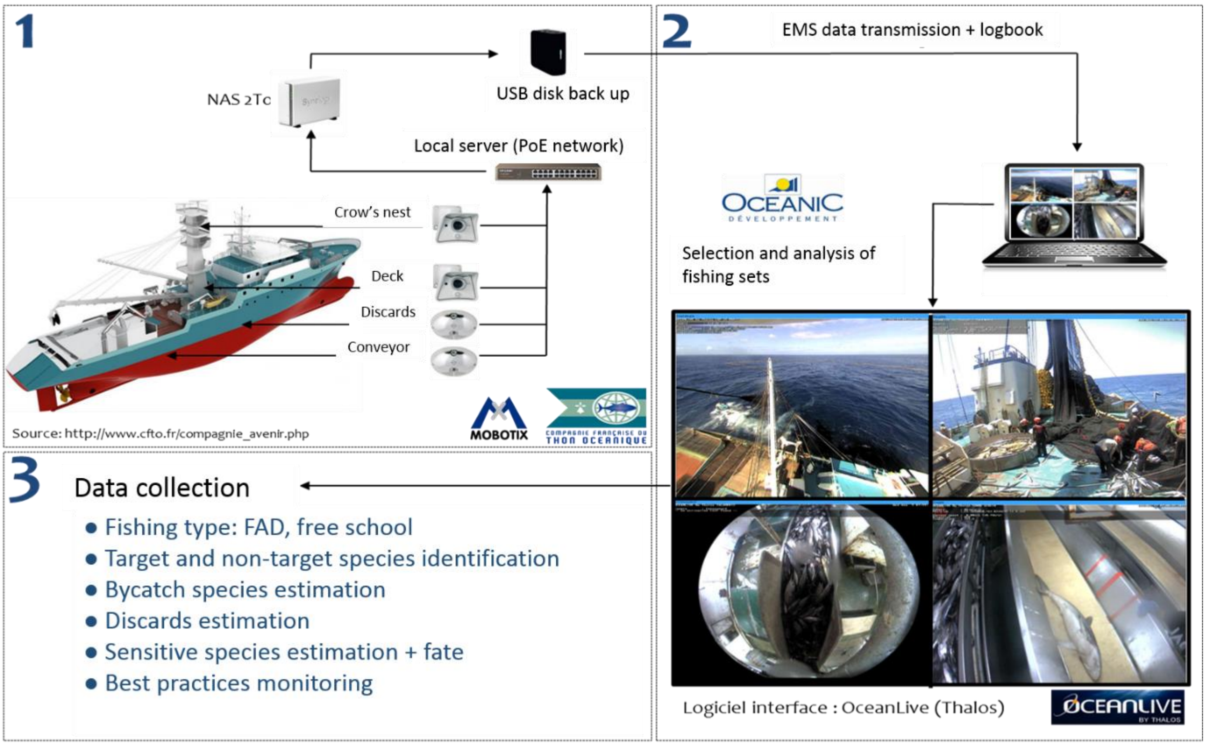

Figure 2. Schematic representation of the EMS installation and the process of data collection

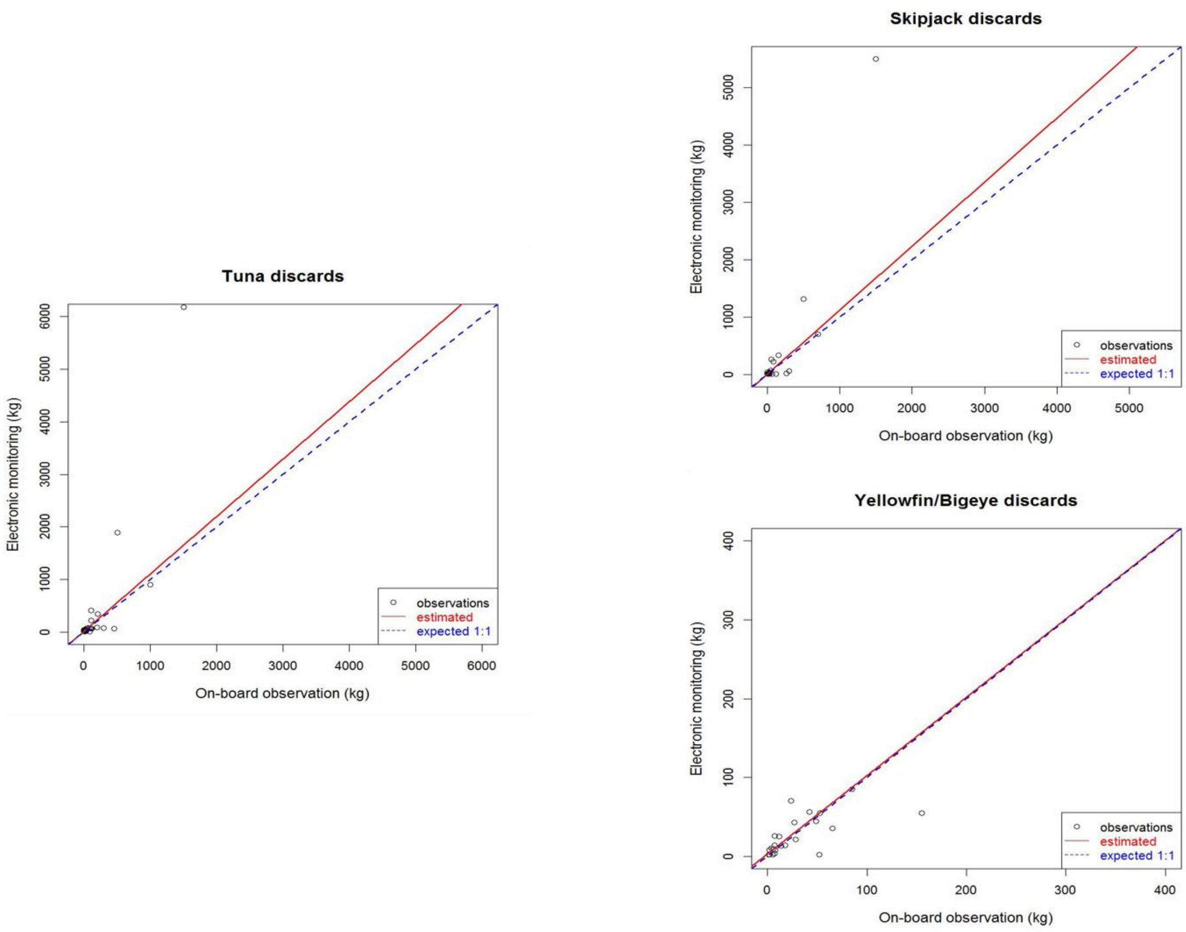

Figure 3. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EMS and on-board observers records of tuna discards. GLM analysis was performed for total tuna discards (N=42) and for skipjack (N=33) and yellowfin/bigeye (N=23) tuna discards.

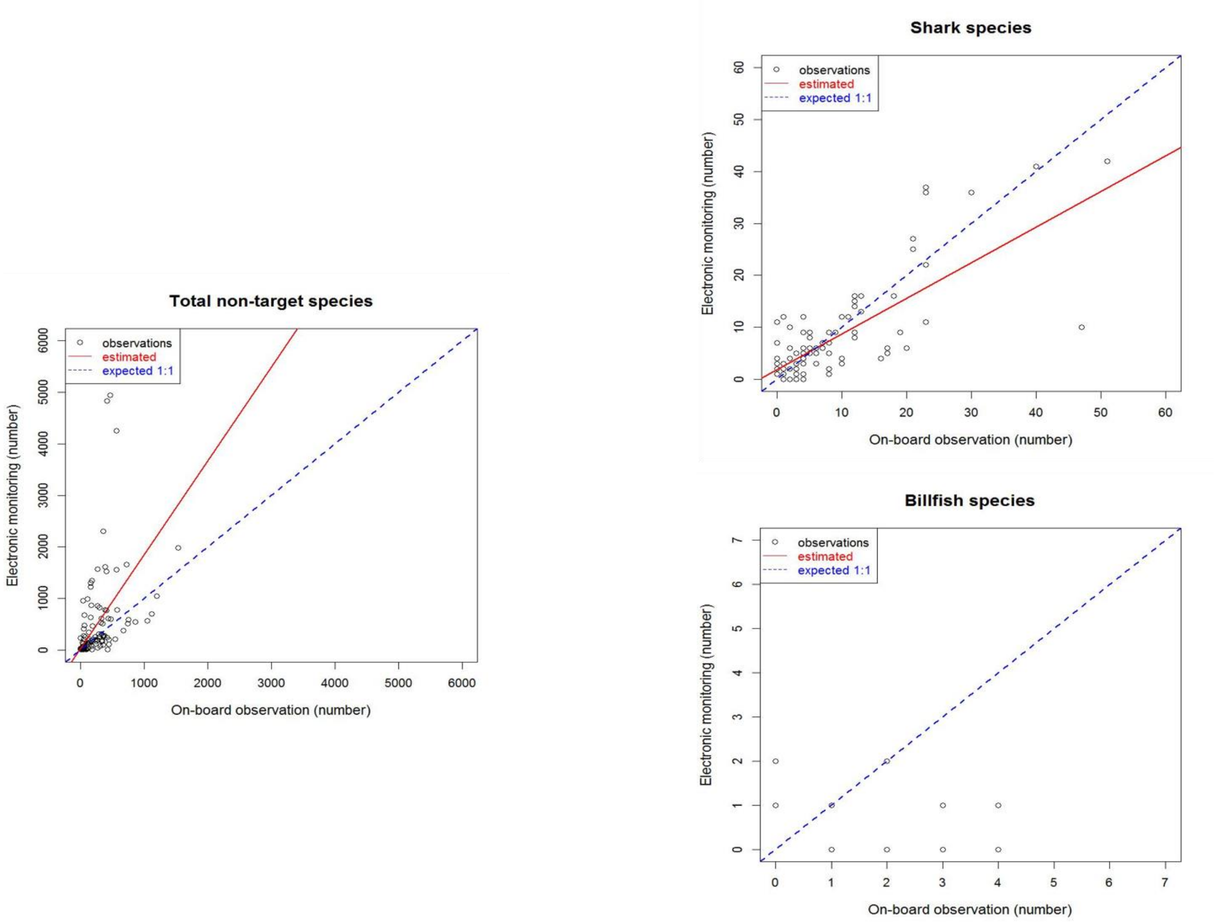

Figure 4. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EMS and on-board observers records of non-target catch. GLM analysis was performed for total non-target species (N=124) and for sharks (N=105) and billfishes (N=36) species.

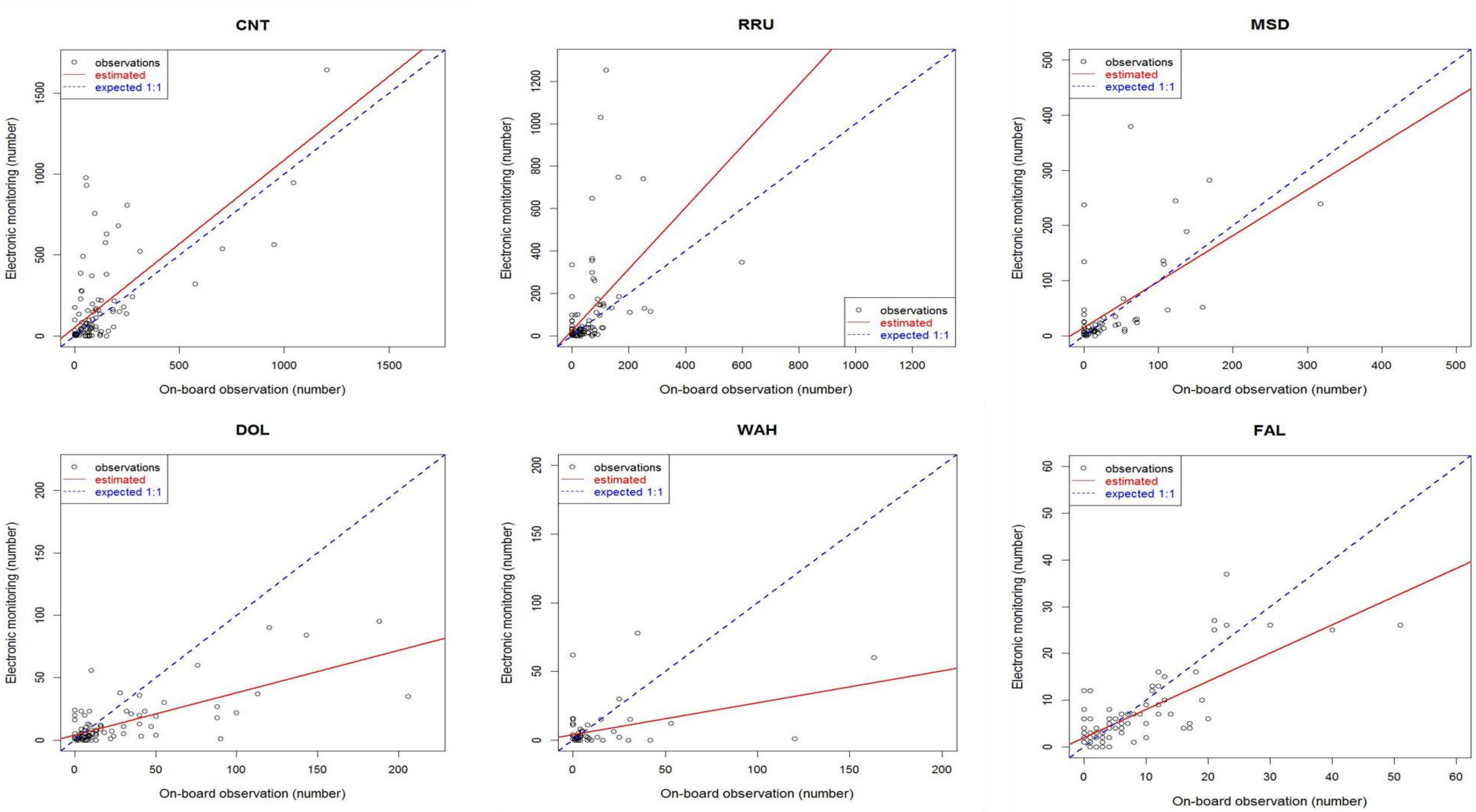

Figure 5. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EMS and on-board observers records of non-target catch. GLM analysis was performed for individual non-target species *Canthidermis maculate* CNT (N=100), *Elegatis bipinnulata* RRU (N=96), *Decapterus macarellus* MSD (N=66), *Coryphaena hippurus* DOL (N=93), *Acanthocybium solandri* WAH (N=69) and *Carcharhinus falciformis* FAL (N=96).

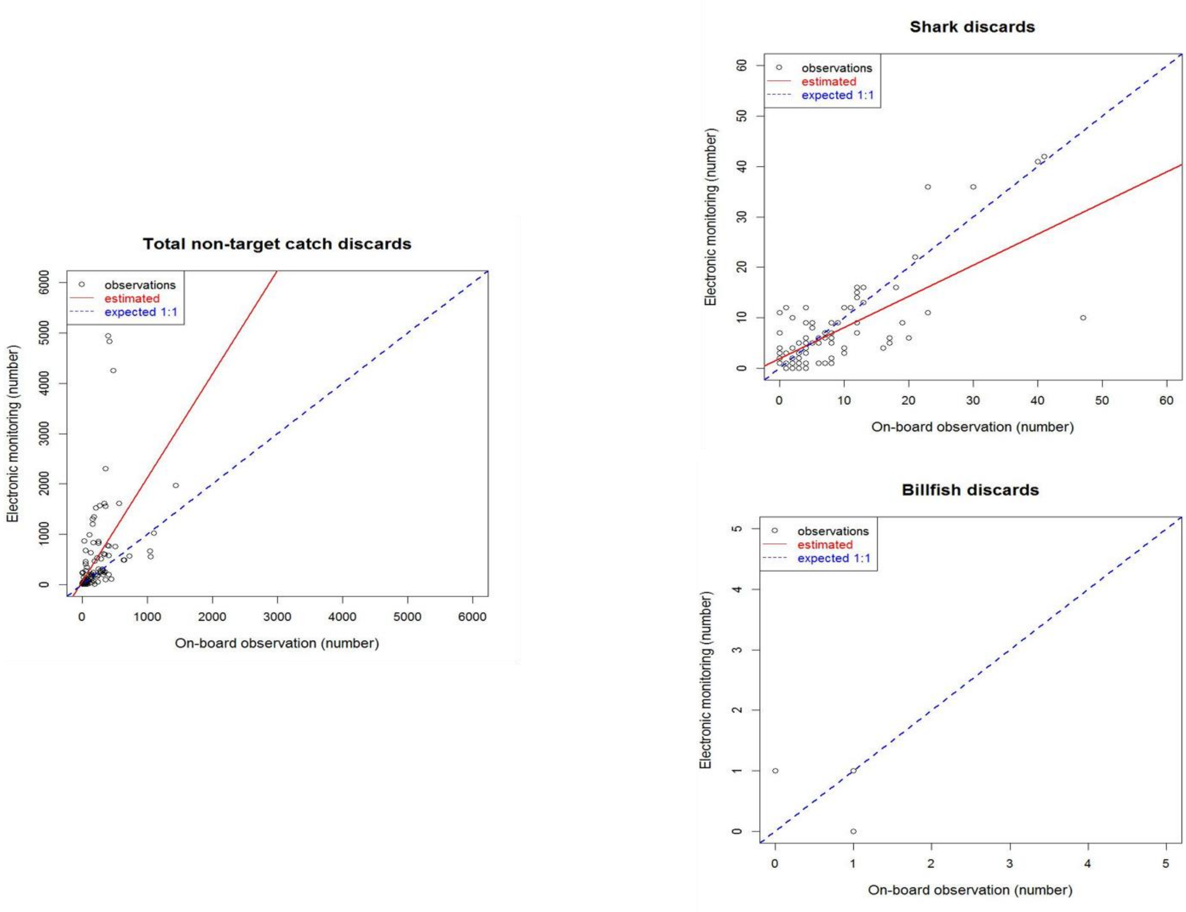

Figure 6. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EMS and on-board observers records of non-target catch discards. GLM analysis was performed for total non-target catch discards (N=109) and for sharks (N=92) and billfishes discards (N=11).

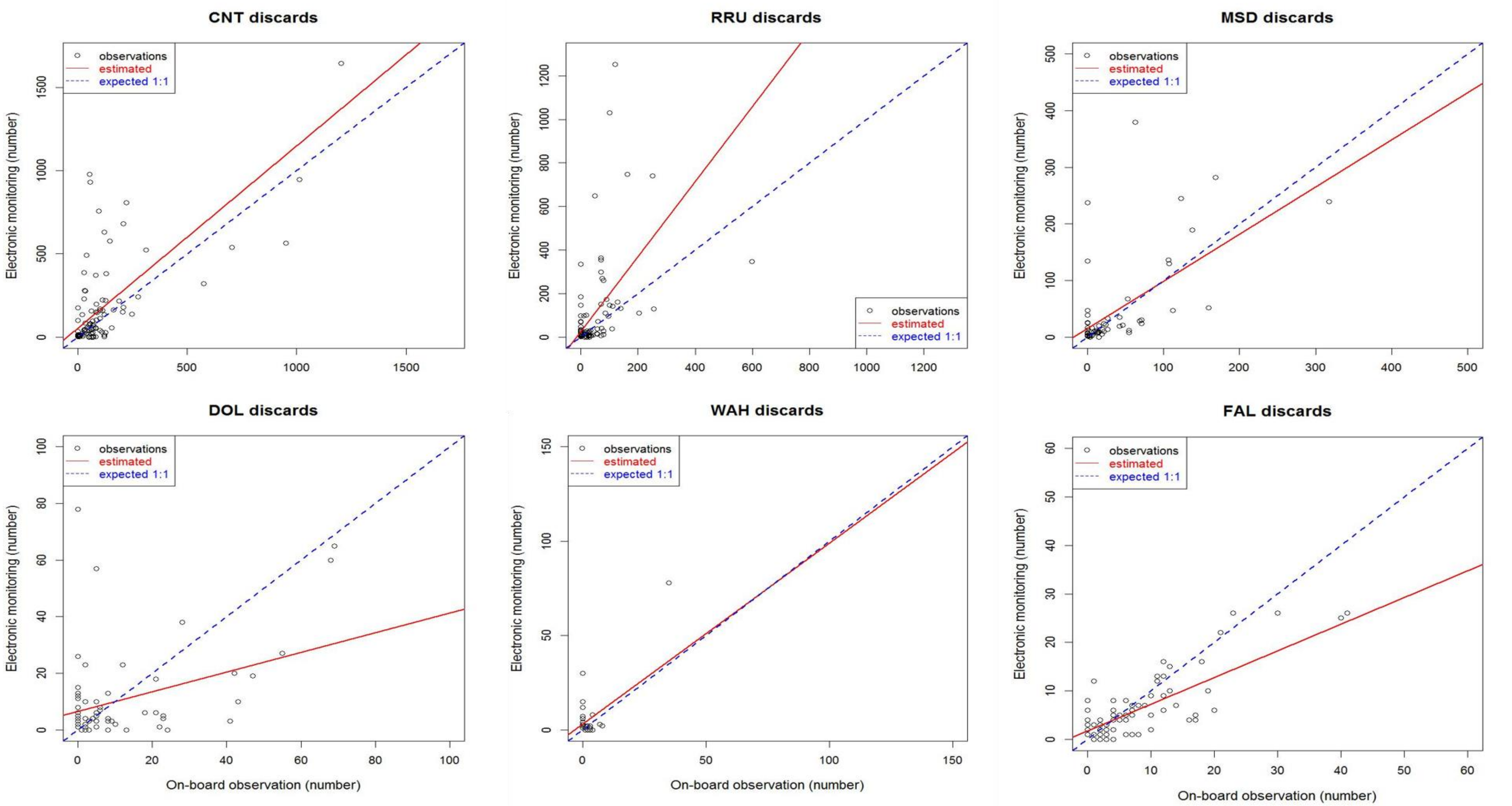

Figure 7. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between EMS and on-board observers records of non-target catch discards. GLM analysis was performed for individual non-target species *Canthidermis maculate* CNT (N=99), *Elegatis bipinnulata* RRU (N=91), *Decapterus macarellus* MSD (N=66), *Coryphaena hippurus* DOL (N=77), *Acanthocybium solandri* WAH (N=41) and *Carcharhinus falciformis* FAL (N=88).

Annex. General description of purse seine catch categories and their associated fate defined in OCUP observer program.