Use of electronic monitoring systems to optimize observer sampling protocols onboard French purse seiners of the Indian Ocean

K. Briand [1,2,*], P. S. Sabarros[1,2], A. Maufroy[3], A.-L. Vernet[4], A. Yon[4], A. Relot-Stirnemann[4], A. Bonnieux[5], M. Goujon[3], P. Bach[1,2]

[1] MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, Sète, France
[2] IRD, Ob7, Sète, France
[3] ORTHONGEL, Concarneau, France
[4] Oceanic Développement, Rennes, France
[5] CFTO, Concarneau, France
*corresponding author, email: karine.briand@ird.fr

ABSTRACT

Observer programs on tuna purse seine vessels are essential to collect information on bycatch and discards in order to monitor the impact of fisheries on populations and ecosystems. On-board observers estimate discards following a sampling protocol and sometimes extrapolation methods (based on the number of brailers or time) when counting exhaustively is not possible. However, these methods may be biased because brailers have different filling rates, which in turns results in a heterogeneous flow of discarded individuals during the sorting process, and may lead to biased estimates. Electronic Monitoring Systems (EMS) have been implemented since 2013 on French purse seiners to complement on-board observer programs on vessels that cannot embark observers. On-board cameras allow monitoring sorting operations continuously and monitoring the discard flow in time and space (upper vs lower deck). In this study, we used EMS « counts per minute » of discards from 5 vessels operating in the Indian Ocean to describe the general trends in sorting flow on the upper and lower decks. We analysed 50 FOB (Floating Objects) fishing sets with various sorting time and simulated different observer strategies (using bootstrap without resampling) on the total number of discarded individuals in order to optimize (i) the total sampling duration and (ii) the duration of sampling sequences. This analysis is detailed at the species level on the lower deck where the number of individuals and the level of identification were higher. We finally propose an optimized sampling strategy for evaluating discards that reduces both sampling time and estimation bias, and that can be applicable to both electronic and on-board observations.

KEYWORDS

Sampling strategy | Electronic monitoring system | Observer program | Tropical tuna | Purse seine fishery | Non-target species | Discards

1. INTRODUCTION

The development of fisheries during the 20th century has led to increase the monitoring and regulation of fishing activities to preserve marine resources (Botsford et al., 1997; Gilman et al., 2017). In addition to quotas and other (output or input) control rules (e.g. Conservation and Management Measures), at-sea fishery observation programs have been implemented to collect independent information on fishing practices with the purpose of sustainable management (Davies, 2002). On-board observation usually involves trained biological scientists who collect specific data on fishing operations, catches and interactions of the vessel and its fishing gear with the environment. These data are used to assess fish populations, monitor the impact of fisheries on ecosystems and inform management decisions (Gilman et al., 2018).

In the case of tropical tuna purse seine fisheries, part of observer tasks consists in estimating tuna discards (in order to complement landings that are available on logbooks, fish damaged or unfit for human consumption) as well as bycatch and discards of non-target species and incidental interactions with sensitive species (ISSF, 2016). Though this proportion is lower than in other tropical tuna fisheries, bycatch represents a significant part of tropical tuna purse seine fisheries of the world which has increased with the use of Fishing Aggregating Devices (FADs, Hall and Marlon, 2013; Justel-Rubio and Restrepo, 2017). The main bycatch species consists of minor tunas, sharks, rays, bony fishes and billfishes. Non-tuna species represent an overall bycatch rate of 0.92%, with variations depending on the region (Justel-Rubio and Restrepo, 2017). While some species are retained for local market or fishing crew consumption, discards still represent 1 to 5 % of the total catch (Hall and Marlon, 2013).

Since the 1980's, scientific observer programs have been progressively implemented on-board tropical tuna purse seiners in the Atlantic and Indian oceans to quantify the volume of bycatch and discards (Amandé et al., 2011; Chavance et al., 2013). In addition to the minimum observer coverage of fishing activities required by Regional Observer Schemes (ROS) of tuna Regional Fisheries Management Organizations (t-RFMOs) and the European Union (EU), purse seine fleets have implemented voluntary programs to reach an exhaustive coverage of their fishing activities. Among others, these programs contribute to compliance with fishing agreement obligations and monitoring of responsible fishing schemes of fishing companies (e.g. best practices for releasing sensitive species such as sharks, rays and turtles; Poisson et al., 2012; ISSF, 2016). In particular, the producer organization ORTHONGEL representing French and Italian purse seiners has implemented the OCUP (*Common Unique and Permanent Observer*) program with the objective of reaching 100% of observer coverage in the Atlantic and Indian oceans (Goujon et al., 2018), by using on-board observation and electronic monitoring systems (EMS) when on-board observation is not possible.

During the last decades, EMS has been progressively implemented and tested in various tuna fisheries as an alternative tool to supplement on-board observation and increase coverage, especially for vessels that cannot embark observers (Emery et al., 2018; Emery et al., 2019; Gilman et al., 2019; Hosken et al., 2016; Restrepo et al., 2014; Ruiz et al., 2014). In particular, the French EMS pilot project named CAT OOE (*Contrat d'Avenir Thonier- Optimisation de* *l'Oeil Electronique* - Tuna Contract for the future – Electronic Eye Optimisation) was launched in 2013 on French and Italian tropical tuna purse seiners to compensate for insufficient spatial and temporal observer coverage at sea due, notably, to the presence onboard of piracy protection teams in the Indian Ocean, that does not allow boarding an observer on the smallest vessels. The primary objective of the project was to verify EMS abilities as an observation tool, in order to increase coverage to 100%. In total, 8 freezer purse seiners operating in Indian Ocean were equipped with a video acquisition system (cameras, sensors, GPS, computer hardware interface, hard drive, etc.) installed on the upper and lower decks and adapted to each vessel configuration.

Preliminary analyses of the data collected on board French and Italian tuna purse seiners have indicated that in most cases, EMS allowed to monitor discards and bycatch at an acceptable species identification resolution, especially in the lower deck, where discard cameras are closer to sorting operations (Briand et al., 2018b, 2020). Furthermore, results indicated that EMS can provide comparable estimates of discarded individuals to on-board observations, especially for species and group of species which are systematically discarded (Briand et al., 2018a). It was also noted that when the flow of discards is important, EMS could be more efficient than on-board observers at estimating the total number of individuals per species since it allows exhaustive counts on the discard belt using multiple reviews (Briand et al., 2018a; Ruiz et al., 2017). In comparison, for large fishing sets, observers may observe a fraction of sorting operations and extrapolate (based on time or the number of observed brailers) to estimate the total number of individuals as once described in the French IRD observer manual (IRD-Ob7, 2016).

Knowing that reviewing EMS records can be time consuming and tedious and that extrapolation methods used by on-board observers require constant improvement, a preliminary study was conducted to optimise the reviewing protocol of EMS records and the sampling/extrapolation protocol of on-board observers. Exhaustive "counts per minute" of bycatch and discards were collected using EMS and used to (i) evaluate the possibility of reducing the time of analysing EMS records by reviewing only samples of such records and (ii) verifying the validity of current on-board sampling/extrapolation methods compared to exhaustive counts (Briand et al., 2018b). Results indicated a high temporal heterogeneity of the discard flow on the discard belt, due to unequally filled brailers during the sorting process (Briand et al., 2020) and fish arriving in batches on the discard belt after each unloading of the brailer (Briand et al., 2018a). In the case of EMS, such results indicate that exhaustive counts should be preferred to counts of discarded individuals on samples of EMS records. In the case of on-board observation, such results indicate that that the current sampling/extrapolation strategies are not appropriate. Typically, on-board observers extrapolate from counting the discards from one brailer to the total number of brailers within the fishing set, or (ii) sample fish on the discard belt for a definite period of time and then extrapolate to the total sorting time. Even though on-board observers are instructed to be pragmatic and use the best available method, preliminary analysis of EMS counts per minute obtained on five French purse seiners of the Indian Ocean indicate that these methods may lead to biased estimates of discards due to the different sources of heterogeneity in the discard flow (Briand et al., 2020). Results from this preliminary analysis (N=48 fishing sets) also suggest that, when exhaustive counts are not possible (too large flow of discards), on-board observers should use an extrapolation method based on sorting duration rather than on the number of brailers. When exhaustive counts of discards are not possible, a total of 15 to 20 minutes sampling (depending of the species composition) by random sequences of 2-4 minutes was recommended to avoid bias (Briand et al., 2018b). Based on these first results, it was suggested to maintain the exhaustive reviewing of EMS records and to readjust on-board observer sampling protocols (Sabarros, 2020). However, at the end of this first study, further analysis and additional data collection were needed to obtain robust conclusions.

The present study aims at pursuing such initial work by analysing the sorting flow from additional purse seiners to validate our initial results at a larger scale for the French purse seine fleet operating in the Indian Ocean. In the present study, information on discard sorting operations were collected over 50 fishing sets from five purse seiners between 2018 and 2019. We describe the flow of discards both on the upper and lower decks using "counts per minute" detailed at the species level (when possible). These data are used to test a range of sampling methods in order to obtain better estimates of total discards in numbers for each fishing set and for each species. As for the previous study, the primary objective here is to optimize the total sampling time while maintaining robust estimates of discards (number of individuals) per species and reducing the variance of these estimates. We use bootstrap sampling techniques to (i) identify the optimal total sampling duration, and (ii) test the use of random sampling sequences from 1 to 4 minutes. Analyses are carried out for the total number of discarded individuals and separately for each of the most common bycatch species found in Indian Ocean and in the fishing sets analysed here, i.e., rough triggerfish (*Canthidermis maculata*), rainbow runner (*Elegatis bipinnulata*), mackerel scad (*Decapterus macarellus*), silky shark (*Carcharhinus falciformis*), wahoo (*Acanthocybium solandri*) and dolphinfish (*Coryphaena hippurus*; Hall and Marlon, 2013; Briand et al., 2020). Note that discards such as tunas (usually damaged and unsellable) are described in our results but are not taken into account in our testing sampling strategies as most of the individuals (especially for species that may be difficult to discriminate such as minor tunas and/or YFT and BET) are only categorized at the group level (TUN-Thunnini, TUS-Thunnus spp) with our current EMS configuration. For the same reasons, the species analysis is mainly carried out for the lower deck where individuals could be easily identified at species level when reviewing EMS records.

2. MATERIAL AND METHODS

2.1. Camera installation on-board purse seiners

The French purse seine vessels from our study are equipped by *Thalos* (https://www.thalos.fr/fr/solutions/superviser/oceanlive.html) with at least five HD MOBOTIX digital cameras with 6 MP resolution (see **Figure 1**). Cameras are placed at different strategic positions on the upper deck (crow's nest, desk) and below deck (conveyor and discard belts) to monitor fishing and sorting operations. Cameras of the upper deck are equipped with GPS which enables geolocalising each frame and recording vessel position (one position per minute).

One camera is installed in the crow's nest to cover the port side of the vessel and to monitor the general fishing activity including setting, pursing, and brailing. Another camera with wide angle is placed on the desk and is used to record brailing operations and discard activities on the upper deck. Finally, two or three other cameras with higher frequency (5 frames/second) are placed in the lower deck area along the conveyor and discard belts to monitor sorting operations. In particular, one camera is placed at the end of the discard belt in order to identify and count all discarded individuals returning to the sea. The crow's nest camera is set to record continuously whereas desk and lower deck cameras are triggered by vessel speed to record fishing operations only. Image data are stored digitally on hard disks and transmitted to *Oceanic Développement* for analysis.

Note that these EMS installations are customized for each purse seiner and there is no standard EMS configuration between vessels since the configuration of vessels can be different. Therefore, cameras are not always recording the same type of images on board. For example, some lower deck cameras focus directly on the discard belt whereas others record individuals falling in a discard chute. These differences are a challenge for EMS observers in terms of species identification and can create differences in observation quality (Briand et al., 2020). In our study, we chose to test several vessels with different sisterships (same vessel configuration) to take into account these differences.

2.2. EMS "counts per minute" data

Electronic observers at *Oceanic Développement* receive EMS recordings on hard drives at the end of each fishing trip. EMS data are analysed using the *OceanLive* software developed by *Thalos* (**Figure 1**). Most of the collected data is similar to the information routinely collected by on-board observers. However, unlike on-board observations, full recording of fishing operations and in-depth viewing of the records by cameras placed at different vessel locations can allow exhaustive counting of discarded individuals both on the upper and lower deck.

Since the present study mainly focuses on non-target species, we chose to consider only fishing sets on Floating Objects (FOB) that typically involve larger amounts of bycatch compared to free-swimming tuna school fishing sets (Amandé et al., 2011; Hall and Marlon, 2013).

Records from fishing sets made in 2018-2019 were broken down into sequences of one minute and discards were counted exhaustively for each one-minute sequence. EMS forms were specially adapted to these data collection. Sorting operations were reviewed entirely on the upper and lower decks using the desk and discards cameras. The sorting time was defined as the interval between the time when the first brailer opens ($\mathbf{T_0}$) and the time when the last fish $\mathbf{T_{LF}}$ is sorted. $\mathbf{T_0}$ was used as a common departure point for time sorting operations both on the upper and the lower decks.

Counts per minute of each species on the upper and lower decks were collected separately by EMS observers. Species identification was done at the higher resolution level. Note that on the upper deck, individuals disentangled from the net or sorted before $\mathbf{T_0}$ were also counted in our analysis and taken into account in the total number of discarded individuals. However, the overall flow of discards was only described between $\mathbf{T_0}$ and a maximum time defined at 60 minutes (no individual sorted after 60 minutes in our dataset). Details about the number of fishing sets per fishing trip and per type of analysis are presented in **Table 1**. The total number of individuals per fishing set and per species represents the “observed” value that will constitute the reference value when testing various sampling strategies.

2.3. Testing sampling strategies

We simulated custom sampling strategies that an on-board or an EMS observer could use to estimate the total number of individuals per species. Two variables of the sampling strategy were considered: (i) the total sampling duration and (ii) the duration of sampling sequences. These simulations were made by resampling the actual “counts per minute” data for each set. In each simulation, the number of discarded individuals (total and per species) per fishing set was calculated by extrapolation based on time. From this metric, we calculated the bias to the reference value (difference between the estimated and reference value; the bias can be positive or negative), the absolute bias and the coefficient of variation (CV) to assess the validity of the sampling strategies. Expecting that the bias and CV will decrease when increasing the sampling time, we identified the inflexion point where the bias and CV were sufficiently low to consider the extrapolations as robust.

(Eq. 1) *Bias = N estimated – N reference*

(Eq. 2) *Absolute bias = | N estimated – N reference |*

(Eq. 3) *CV = Standard deviation / Mean of N estimated*

2.3.1. Total sampling duration

A first strategy, consisting of counting discarded individuals during isolated sequences of one minutes was tested. For both the lower and upper decks, we sampled random minutes (without replacement) from one minute to the total duration of the fishing set using bootstrap (Efron and Tibshirani, 1993) and then extrapolated to the total number of discarded individuals. This operation was repeated 100 times for each fishing set. The mean and confidence intervals of the absolute bias from bootstrapped samples as well as CV of the extrapolations were then calculated. The objective was to identify an optimal sampling duration for which both the mean bias and CV of discard estimates would strongly decrease to become reasonably acceptable.

2.2.2. Sampling sequences

We tested an additional strategy consisting in repeating sampling sequences of a given duration throughout sorting operations. For each fishing set, we tested sampling sequences of 2, 3 and 4 consecutive minutes randomly chosen over the total duration of each fishing set, that were repeated from 1 sequence to the total number of possible sequences within each fishing set. This operation was repeated 100 times within a bootstrap procedure so as to provide means and confidence intervals. We then represented the mean of the absolute bias, and CV from bootstrapped series, as a function of the total cumulated sampling time found for each sampling sequence length.

3. RESULTS

3.1. Overall discard flow

The discard flow (number of discarded individuals throughout time) of the most common species and groups of species appeared different on the upper deck and the lower deck (all fishing sets combined). The analysis of both counts per minute and cumulative counts per minute from 0 to 60 minutes indicated that the general discard flow (all species combined) was faster and more regular in the lower deck than on the upper deck (**Figure 2, Figure S1)**. It is also important to note that the large majority (81.88 %) of the discarded individuals were sorted below deck (see Table 2).

In the lower deck, most individuals arrived on the discard belt within the first 20 minutes. The total number of sorted individuals quickly increased one minute after $\mathbf{T_0}$ (when the first brailer opens) and then steadily decreased to reach its minimum around 30 minutes. The maximum of discarded individuals was found in the first 10 minutes, with a peak at around 4-5 minutes after $\mathbf{T_0}$ (**Figure 2a**). On the upper deck, the maximum number of individuals was found between the 5th and 12th minutes. However, other smaller peaks were also found between 20 and 30 minutes or even between 40 and 50 minutes. Cumulative counts indicated that only 60 % of the individuals were sorted within the first 20 minutes on the upper deck compared to 90 % in the lower deck (**Figure 2b**).

Results also indicate large differences among species or groups of species in terms of timing on the upper deck (**Figure 2a**). For example, DOL seems to be mainly sorted at the beginning of catch handling operations compared to other species such as CNT which seems to be discarded throughout the sorting process in small peaks. In addition, cumulative counts per minutes showed that shark species (FAL, RSK) appeared to be sorted in priority on the upper deck as 80% of the individuals were released in the first 7 minutes. In comparison, it took more than 30 minutes to sort 80 % of non-chondrichthyes (MZZ-Osteichthyes).

In the lower deck, prioritization of species was less obvious as all individuals were supposedly placed on the discard belt and released at sea in their order of appearance. The highest proportions of discards were found for CNT, RRU, TUN and MSD species and these species were present in small peaks during all parts of the sorting operations. Though in smaller proportions, it is still interesting to note that major tuna species (SKJ, TUS) and silky shark (FAL) seem to be released relatively quickly in the lower deck. Indeed, cumulative counts per minutes indicated that 80 % of these species or group of species are sorted in less than 10 minutes (**Figure 2b**).

3.2. Total sampling duration

The effect of sampling duration on the extrapolated total number of discarded individuals was compared to observed counts on the upper (**Figure 3a**, **Table 3**) and lower decks (**Figure 3b**, **Table 4**). Results suggest that more sampling time is needed in the lower deck than on the upper deck to improve the precision and robustness of estimates. Overall, the median and mean bias of the extrapolated number of discarded individuals remains higher in the lower deck than on the upper deck due to larger number of individuals sorted below deck (**Tables 3, 4**). In addition, the variance of extrapolated numbers (illustrated by the confidence intervals which decreases with increasing sampling time in both locations) is wider in the lower deck for short sampling durations. Finally, more sampling time is needed in the lower deck than on the upper deck to minimize the absolute bias (**Figure 3**). For example, it takes 5 minutes of total sampling to stabilize the mean bias (below 5 individuals) on the upper deck and around 11 minutes total sampling to stabilize the mean bias (below 10 individuals) in the lower deck (**Table 3, 4**). However, it seems to take less sampling time on the lower deck to obtain an acceptable level of variability compared to the upper deck. Indeed, the mean coefficient of variation (CV) of the extrapolated total number of discarded individuals in the lower deck stabilize after 15 minutes of random sampling and remains low for increasing sampling time for all 50 fishing sets. In comparison, it takes more than 25 minutes of sampling to reach the same value of dispersion (CV = 0.2) on the upper deck.

The results for the most common species and group of species are presented in **Figure S3a** for the upper deck and **Figure S3b** for the lower deck. Overall, results confirm that it takes more time for the CV of all species to stabilize on the upper deck than in the lower deck, and the difference between species is more pronounced on the upper deck than in the lower deck.

On the upper deck, DOL, RSK and CNT have overall similar trends in CV. CVs of these groups decreased slowly (without a clear inflexion point) and reach ~0.5 around 22 minutes of sampling. In comparison, WAH, RRU and TUN only reach the same value (CV=0.5) after 25 minutes, 27 minutes and 37 minutes of sampling respectively. However, these results cannot really be interpreted by species because the number of individuals recognized by species in this analysis is too low compared to the lower deck (see **Table 2** and discussion).

In the lower deck, the dispersion stabilized between 15 and 20 minutes of sampling (**Figure 2, Figure S3b**) for the most common bycatch species: CNT, MSD and RRU as well as for the TUN group. For CNT, the coefficient of variation (CV < 0.4) stabilized around 15 to 20 minutes. After 15 minutes of sampling, the mean bias stabilized to a minimum of approximately 5 individuals. For MSD, the dispersion stabilized after 15 minutes of sampling (mean bias ~2 individuals) and for RRU between 15-20 minutes of sampling (mean bias ~ 3 individuals). The maximum absolute bias is clearly higher for CNT (about 25-30 individuals) compared to for MSD and RRU (less than 15 individuals). For DOL, WAH and FAL the dispersion stabilized after a slightly longer sampling duration, around or above 20 minutes, compared to the most common species (**Figures S2, S3**). However, the variability in the mean bias and the maximum bias were in general lower, except for FAL. For DOL, the dispersion stabilized within 20 minutes of sampling though the mean bias was already stable after 10 minutes. The mean bias was below 2 individuals and maximum bias less than 10 individuals. We noted similar patterns for WAH, where the dispersion seemed to stabilize within 15-20 minutes with a maximum bias less than 3 individuals. Finally, for RSK/FAL, bootstrap results indicate a large variety of cases but the dispersion still stabilized within 20 minutes of sampling with a maximum bias that is less than 3 individuals.

3.3. Sampling sequences

Figure 4 shows the comparison of the absolute bias for the estimation of the total number of discarded individuals for sampling sequences of 1 to 4 minutes. In all cases, the bias decreased with the total sampling duration as well as associated confidence intervals. Despite marginal differences, the absolute bias of discard estimates and confidence intervals are comparable among the four tested sampling sequences. Note that between 2 to 20 minutes of total sampling the mean CV of the 1-minute-sequence strategy remains slightly below the CVs of the 2-, 3- and 4-minutes strategies, but this difference is not important. Moreover, the overlap of confidence intervals of 2, 3 and 4 minutes suggests that these differences are not significant and therefore that the duration of repeated sequences has no effect on discard estimates.

4. DISCUSSION

This study contributes to further describing the patterns in the discarding process of French tropical tuna purse seiners operating in the Indian Ocean and is the first to detail the sorting flow in both time (i.e. during the whole duration of sorting operations) and space (i.e. on the upper vs in the lower deck). Results notably show that the patterns in the sorting flow differ between the upper and lower decks, which may be due to the presence of a discard belt in the lower deck that contributes to the homogenisation and acceleration of the sorting flow of individuals. As shown in our first study on French vessels (Briand et al., 2018b), a peak of discards in the lower deck occurs within the first 10 minutes of sorting, followed by a decrease (Briand et al., 2018b). As the first brailers are usually fuller than the following ones, the volumes of sorted bycatch are greater in the early part of sorting operations. In terms of sampling by on-board observers or reviewing of EMS records by electronic observers, this suggests that it is crucial for observers to prioritize the observation of the lower deck to monitor discards at the beginning of sampling operations just after T_0 (when the first brailer opens) in order to obtain accurate estimates of discards.

Sampling simulations showed that sampling a total of 15-20 minutes in the lower deck (not necessarily consecutive minutes) is sufficient to obtain robust estimates of the total number of discarded individuals as well as the number of discarded individuals per species after extrapolation. These results are similar to our previous study for another combination of vessels and FOB sets (Briand et al., 2018b). For rarer species, including the ones that were not investigated in this study, longer sampling time would certainly be necessary to reduce the risk of missing their occurrence and thereby obtain robust estimates. Our results also suggest that longer sampling durations would be necessary on the upper deck to decrease the dispersion and obtain precise estimates of the total number of discarded individuals. However, these results cannot be validated at the species level in the present study as the number of individuals identified per species is too low. Indeed, it is important to note that due to camera distance, most of individuals were categorized as Osteichthyes (non-chondrichthyes) within the MZZ group and a large part of these individuals may belong to one or the other species previously cited. This lack of identification implies that bootstrap trends per species on the upper deck should be taken with caution. In addition, on-board observers need to choose a strategic position to correctly sample discards and the lower deck is main location of bycatch sorting operations (~82% of the discards sorted in the lower deck). Thus, it is crucial that on-board observers spend most of their time in the lower deck to sample the main flow of discards. However, the monitoring of bycatch discards from the upper deck that includes the exhaustive count of released sensitive species (sharks, large rays and turtles) still needs to be done. This task could be achieved with the help of the fishing crew or through EMS recordings (fishing trips with an on-board observer to cover non-sensitive species and with EMS to cover sensitive species) when the on-board observer is below deck. However, further improvement of camera configuration is still required on the upper deck to avoid dead angles and allow correct identification of discarded individuals at the species level. This would imply a higher number of cameras or cameras recording with at a higher resolution in the discarding areas.

Among the 50 fishing sets covered in this study, sorting operations lasted less than 20 minutes for 22 fishing sets (**Table 1**) which means that in such cases, sampling the entire sorting operations exhaustively may be necessary. Though this should not be a problem for electronic observers (that can review EMS records multiple times), this does not however take into account how much fish on-board observers can handle in real time, nor the configuration of the lower deck that is not always adapted to correctly sort samples of discards. For sorting operations lasting more than 20 minutes, our results indicate that the mean bias would stabilize and remain low after 15-20 minutes of sampling (depending on species). A protocol based on a total sampling duration of 20 minutes seems therefore reasonable for robust estimations of discards for both on-board and electronic observers as proposed in the earlier study. In the case of electronic observers, as the cost of EMS observer programs is generally lower than those of on-board observation, an exhaustive review of EMS records is probably preferable to obtain observed counts rather than estimates of discards. For on-board observers, sampling at least 15-20 minutes on lower deck and then spending the rest of the time on the upper deck might be a good method to help them monitor sensitive species release.

In addition, it is worth noting that very few individuals were present during the first minute of sorting operations. This may be explained by the delay between the moment when the brailer opens on the deck and the moment when the first individuals arrive on the discard belt in the lower deck. In previous studies for the French and Italian purse seiners, we noted that some species peaked at specific moments of the sorting process, notably DOL and WAH near the end of sorting operations (Briand et al., 2018b). Although this trend was not found on lower deck in the present study, we found that DOL and WAH needed slightly more sampling time than other species. The individuals of such species are indeed sometimes pre-sorted and retained on the upper and the lower deck for crew consumption and then individuals in excess are discarded when sorting operations are nearly finished. In terms of sampling protocol, this may indicate that sampling throughout the sorting process including the last minutes of sorting operations may be necessary to improve discard estimates of these species.

Simulations using sampling sequences of 1 to 4 minutes suggested that the length of sequences does not have much effect on the accuracy of estimates. Sampling with one random minute sequences appears to give slightly lower CV than the other sampling methods but may not be feasible in practice for on-board observers. In comparison, sampling by sequences of 2 to 4 minutes seems a reasonable and pragmatic method especially for on-board observers that alternatively collect data on the upper and lower decks.

Finally, it should be noted that the present study was only carried out with data collected on purse seiners operating in the Indian Ocean. Considering that bycatch composition and quantities may be different from one ocean to the other (Hall and Marlon, 2013), notably in the Atlantic Ocean where the amount of bycatch is generally greater (Briand et al., 2018a), it would be interesting to complement this study with data from the Atlantic Ocean to identify potential differences in the patterns identified here.

5. CONCLUSIONS

EMS is a promising alternative tool for monitoring discards of tuna and non-target species for the tropical tuna purse seine fisheries that allow developing and optimising sampling protocols as shown in this study. In line with our previous study, we propose an optimal sampling protocol in which on-board observers sample a total of 20 minutes in random sequences of 2 to 4 minutes (at convenience) including the last minutes if possible, on lower deck. This sampling method would be applicable for the entire French fleet of tropical tuna freezer purse seiners operating in Indian Ocean and could be used by on-board observers for sorting operations longer than 20 minutes. Note that for large fishing sets, observers might spend extra time on the upper deck (in addition to lower deck sampling) to monitor the release of sensitive species. We also propose to improve the monitoring of the discarding process at the species level on the upper deck by adding new cameras to enhance the overall observation and give observer programs complementary and accurate information on bycatch and sensitive species populations.

6. ACKNOWLEDGEMENTS

We would like to thank *Thalos* teams for their technical support on EMS both on-board and on land. We also thank CFTO fleet managers and crew members for their collaboration on the OCUP program and electronic monitoring program studies. Finally, we thank Oceanic Développement (including W. Le Dantec) for providing counts per minute datasets.

7. REFERENCES

Amandé, M.J., Ariz, J., Chassot, E., Pierre, C., Delgado de Molina, A., Gaertner, D., Murua, H., Pianet, R., Ruiz, J., 2011. By-catch and discards of the European purse seine tuna fishery in the Atlantic Ocean : estimation and characteristics for 2008 and 2009. Col. Vol. Sci. Pap. ICCAT 66.

Botsford, L.W., Castilla, J.C., Peterson, C.H., 1997. The Management of Fisheries and Marine Ecosystems. Science 277, 509–515. https://doi.org/10.1126/science.277.5325.509

Briand, K., Bonnieux, A., Dantec, W.L., Couls, S.L., Bach, P., Maufroy, A., Relot-Stirnemann, A., Sabarros, P.S., 2018a. Comparing electronic monitoring system with observer data for estimating non-target species and discards on French tropical tuna purse seine vessels - ICCAT presentation | Bycatch Management Information System (BMIS). https://www.iccat.int/en/pubs_CVSP.html.

Briand, K., Sabarros, P.S., Maufroy, A., Relot-Stirnemann, A., Le Couls, S., Goujon, M., Bach, P., 2018b. Improving the sampling protocol of electronic and human observations of the tropical tuna purse seine fishery discards | IOTC. Presented at the Working Party on Ecosystems and Bycatch 14-18, p. 19.

Briand, K., Sabarros, P., Maufroy, A., Vernet, A.-L., Yon, A., Relot-Stirnemann, A., Bonnieux, A., Goujon, M., Bach, P., 2020. Overview of fishing and sorting operations aboard French purse seine vessels in Indian Ocean using Electronic Monitoring Systems. IRD, Sète, France.

Chavance, P., Batty, A., McElderry, H., Dubroca, L., Dewals, P., Cauquil, P., Restrepo, V., Dagorn, L., 2013. Comparing observer data with video monitoring on a French purse seiner in the Indian Ocean (No. 09–43). IOTC, WPEB.

Davies, S.L., 2002. Guidelines for developing an at-sea fishery observer programme, FAO Fisheries Technical Paper. Rome.

Efron, B., Tibshirani, R., 1993. An Introduction to the Bootstrap., Chapman&Hall/CRC. ed, Monographs on Statistics and Applied probability. Boca Raton, Floride, U.S.A.

Emery, T., Noriega, R., Williams, A., Larcombe, J., 2019. Measuring congruence between electronic monitoring and logbook data in Australian Commonwealth longline and gillnet fisheries. Ocean and Coastal Management 168, 307–321. https://doi.org/10.1016/j.ocecoaman.2018.11.003

Emery, T., Noriega, R., Williams, A., Larcombe, J., Nicol, S., Williams, P., Smith, N., Pilling, G., Hosken, M., Brouwer, S., Tremblay-Boyer, L., Peatman, T., 2018. The use of electronic monitoring within tuna longline fisheries: implications for international data collection, analysis and reporting. Reviews in Fish Biology and Fisheries. https://doi.org/10.1007/s11160-018-9533-2

Gilman, E., Weijerman, M., Suuronen, P., 2017. Ecological data from observer programmes underpin ecosystem-based fisheries management. ICES Journal of Marine Science 74, 1481–1495. https://doi.org/10.1093/icesjms/fsx032

Gilman, E., Schneiter, E., Brown, C., Zimring, M., Heberer, C., 2018. Precision of Data from Alternative Fisheries Monitoring Sources Comparison of Fisheries-dependent Data Derived from Electronic Monitoring, Logbook and Port Sampling Programs from Pelagic Longline Vessels Fishing in the Palau EEZ (Technical Report). TNC Indo-Pacific Tuna Program. https://doi.org/10.13140/RG.2.2.18328.70403

Gilman, E., Castejón, V., Loganimoce, E., Chaloupka, M., 2019. Capability of a pilot fisheries electronic monitoring system to meet scientific and compliance monitoring objectives. Marine Policy. https://doi.org/10.1016/j.marpol.2019.103792

Goujon, M., Maufroy, A., Relot-Stirnemann, A., Moec, E., Amandé, M.J., Cauquil, P., Sabarros, P.S., Bach, P., 2018. Collecting data on board French tropical tuna purse seiners with common observers: results of Orthongel's voluntary observer program OCUP in the Atlantic Ocean (2013-2017). Collective Volume of Scientific Papers = Recueil de documents scientifiques - ICCAT 74, 3784–3805.

Hall, M., Marlon, R., 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO Fisheries and Aquaculture Technical Paper No. 568. https://doi.org/10.13140/2.1.1734.4963

Hosken, M., Williams, P., Smith, N., 2016. Update on the Implementation of Electronic Monitoring (EM) and Electronic Reporting (ER) Technologies in the WCPO (report). WCPFC, Bali, Indonesia.

IRD-Ob7, 2016. Manuel à l'usage des observateurs embarqués à bords des thoniers senneurs tropicaux: Instruction pour la collecte de données (No. Version 1.4.). IRD, Sète, France.

ISSF, 2016. Purse Seine Observer Training (French) / Manuel de Formation Pour les Observateurs des Pêcheries de Thon à la Senne [WWW Document]. ISSF Guidebooks. URL http://www.issfguidebooks.org/downloadable-guides/purse-seine-observer-training-french-manuel-de-formation-pour-les-observateurs-des-pcheries-de-thon-la-senne (accessed 7.29.19).

Justel-Rubio, A., Restrepo, V., 2017. Computing a Global Rate of Non-Target Species Catch (Bycatch) in Tropical Tuna Purse Seine Fisheries. https://doi.org/10.13140/RG.2.2.14222.36169

Poisson, F., Vernet, A.L., Seret, B., Dagorn, L., 2012. Good practices to reduce the mortality of sharks and rays caught incidentally by the tropical tuna purse seiners. | Bycatch Management Information System (BMIS).

Restrepo, V., Ariz, J., Ruiz, J., Justel-Rubio, A., Chavance, P., 2014. Updated Guidance on Electronic Monitoring Systems for Tropical Tuna Purse Seine Fisheries. (ISSF Technical Report 2014-08).

Ruiz, J., Batty, A., Pierre, C., McElderry, H., Restrepo, V., Sharples, P., Santos, J., Urtizberea, A., 2014. Electronic monitoring trials on in the tropical tuna purse-seine fishery. ICES Journal of Marine Science 72, 1201–1213. https://doi.org/10.1093/icesjms/fsu224

Ruiz, J., Justel-Rubio, A., Krug, I., Restrepo, V., Hammann, G., Gonzalez, O., Legorburu, G., Alayón, P.J., Bach, P., Bannerman, P., Galán, T., 2017. Minimum standards for the implementation of electronic monitoring systems for the tropical tuna purse seine fleet 818–828.

Sabarros, P.S., 2020. Manuel à l'usage des observateurs embarqués à bords des thoniers senneurs tropicaux: Instruction pour la collecte de données (No. Version 2.1). IRD, Sète, France.

Table 1. Number of fishing sets by (anonymized) vessel, fishing trip and sorting time categories (in minutes).

Vessel	Trip	10-20	20-30	30+	Total
V1	1a,1b	12	7	2	21
V2	2	4	3	5	12
V3	3a,3b	2	3	0	5
V4	4a,5a	1	3	0	4
V5	6,7a,7b	3	2	3	8
		22	18	10	50

Table 2. Number of observed discarded individuals by species a) on the upper deck and b) in the lower deck.

a)

FAO code	Scientific name	Common name	N discarded
MZZ	Osteichthyes	Marine fishes nei	3453
CNT	Canthidermis maculata	Rough triggerfish	165
RSK	Carcharhinidae spp	Requiem sharks nei	104
DOL	Coryphaena hippurus	Common dolphinfish	87
RRU	Elagatis bipinnulata	Rainbow runner	73
FAL	Carcharhinus falciformis	Silky shark	19
WAH	Acanthocybium solandri	Wahoo	13
TUN	Thunnini	Tunas nei	12
BIL	Istiophoridae	Marlins,sailfishes,etc. nei	11
GBA	Sphyraena barracuda	Great barracuda	7
XXX*	Unknown	Unknown	5
TUS	Thunnus spp	True tunas nei	3
BAO	Platax teira	Longfin batfish	1
BEN	Belonidae	Needlefishes, etc. nei	1
COM	Scomberomorus commerson	Narrow-barred Spanish mackerel	1
CXS	Caranx sexfasciatus	Bigeye trevally	1
KYP	Kyphosus spp	Kyphosus sea chubs nei	1
MSD	Decapterus macarellus	Mackerel scad	1
UKK	Uraspis spp	Cottonmouth jack	1

b)

FAO code	Scientific name	Common name	N discarded
CNT	Canthidermis maculata	Rough triggerfish	5544
TUN	Thunnini	Tunas nei	3447
RRU	Elagatis bipinnulata	Rainbow runner	2250
MSD	Decapterus macarellus	Mackerel scad	1737
MZZ	Osteichthyes	Marine fishes nei	1474
SKJ	Katsuwonus pelamis	Skipjack tuna	905
DOL	Coryphaena hippurus	Common dolphinfish	746
TUS	Thunnus spp	True tunas nei	476
KYP	Kyphosus spp	Kyphosus sea chubs nei	425
WAH	Acanthocybium solandri	Wahoo	300
FAL	Carcharhinus falciformis	Silky shark	183
FRZ	Auxis spp	Frigate and bullet tunas	95
BAO	Platax teira	Longfin batfish	77
UKK	Uraspis spp	Cottonmouth jack	72
LOB	Lobotes surinamensis	Tripletail	39
GBA	Sphyraena barracuda	Great barracuda	35
ALM	Aluterus monoceros	Unicorn leatherjacket filefish	30
CXS	Caranx sexfasciatus	Bigeye trevally	17
YTL	Seriola rivoliana	Longfin yellowtail	15
ALN	Aluterus scriptus	Scribbled leatherjacket filefish	8
BEN	Belonidae	Needlefishes, etc. nei	5
KAW	Euthynnus affinis	Kawakawa	2
XXX*	Unknown	Unknown	2
RSK	Carcharhinidae spp	Requiem sharks nei	1

Table 3. Summary of bootstrap statistics (N = 100 without replacement) for the total number of species averaged over the 49 analyzed fishing sets on the upper deck with increasing total sampling duration in minutes (CIsup = 95% upper confidence interval; CIinf = 95% lower confidence interval; CV = Coefficient of variation).

Duration	Max	Median	Mean	CIsup	CIinf	CV Mean	CV CIsup	CV CIinf
1	118,46	8,48	16,68	94,84	0,12	1,90	2,99	0,99
2	116,68	3,40	10,11	47,26	0,08	1,34	2,31	0,64
3	42,30	3,53	7,47	36,56	0,16	1,06	1,61	0,55
4	27,54	3,10	5,18	25,21	0,14	0,91	1,75	0,41
5	18,78	2,88	4,40	17,00	0,07	0,79	1,34	0,35
6	24,08	2,60	4,97	21,64	0,06	0,70	1,13	0,32
7	18,81	1,96	3,49	14,61	0,04	0,63	1,19	0,23
8	14,13	2,53	3,59	13,52	0,05	0,58	0,85	0,17
9	43,77	2,44	4,77	21,17	0,12	0,52	1,03	0,12
10	15,87	1,87	3,27	14,39	0,00	0,47	0,85	0,00
11	49,59	2,42	4,45	18,41	0,00	0,46	0,86	0,01
12	27,30	3,32	4,36	12,70	0,00	0,44	0,78	0,11
13	25,24	1,22	3,62	17,75	0,02	0,42	0,77	0,07
14	16,19	1,85	2,81	12,00	0,02	0,40	0,70	0,15
15	14,84	1,24	2,84	14,71	0,05	0,39	0,63	0,14
16	18,73	1,19	2,91	18,51	0,06	0,36	0,60	0,12
17	20,38	0,89	2,28	11,32	0,12	0,34	0,58	0,06
18	17,48	0,87	2,07	13,80	0,00	0,33	0,57	0,00
19	17,67	1,52	2,60	16,54	0,06	0,32	0,52	0,17
20	19,82	1,20	2,69	9,51	0,03	0,29	0,46	0,16
21	21,36	1,30	2,43	12,32	0,02	0,28	0,52	0,14
22	6,23	1,05	1,86	5,98	0,04	0,27	0,49	0,14
23	14,90	1,12	1,83	7,98	0,04	0,25	0,46	0,11
24	11,95	1,23	2,08	11,43	0,07	0,23	0,41	0,08
25	15,64	0,82	1,75	8,94	0,01	0,21	0,41	0,04
26	23,18	0,44	2,27	13,38	0,00	0,20	0,42	0,00
27	27,68	0,80	2,46	17,90	0,00	0,19	0,38	0,00
28	22,35	1,04	2,71	15,38	0,02	0,19	0,36	0,06
29	14,08	0,68	1,92	9,35	0,06	0,17	0,35	0,03
30	6,47	0,60	1,45	6,16	0,00	0,16	0,33	0,00
31	14,90	0,79	1,98	11,35	0,02	0,16	0,31	0,02
32	17,58	0,44	2,23	12,67	0,00	0,15	0,32	0,00
33	9,67	0,47	1,77	7,41	0,04	0,17	0,29	0,07
34	7,87	1,09	1,74	7,25	0,00	0,16	0,29	0,02
35	11,48	0,48	2,37	11,02	0,02	0,15	0,28	0,01
36	15,11	0,95	2,22	11,26	0,01	0,15	0,27	0,02
37	5,59	1,63	1,91	5,40	0,01	0,15	0,26	0,08
38	5,96	0,27	1,56	5,77	0,04	0,14	0,25	0,05
39	14,83	0,45	2,43	11,78	0,01	0,12	0,27	0,01
40	5,19	0,57	1,48	5,18	0,00	0,11	0,24	0,00
41	7,89	1,39	2,27	7,21	0,03	0,13	0,24	0,02
42	6,21	0,56	2,33	6,12	0,03	0,12	0,21	0,01
43	5,95	0,95	2,10	5,76	0,14	0,11	0,22	0,01
44	9,83	0,56	2,32	9,12	0,23	0,12	0,19	0,04
45	3,59	1,35	1,48	3,42	0,05	0,10	0,18	0,01
46	2,28	0,24	0,77	2,23	0,05	0,10	0,17	0,04
47	4,01	0,91	1,24	3,58	0,12	0,09	0,17	0,01
48	6,54	1,06	1,72	5,87	0,17	0,09	0,14	0,05
49	3,44	0,49	0,93	3,12	0,03	0,08	0,16	0,01
50	0,80	0,42	0,41	0,79	0,01	0,08	0,16	0,00
51	0,98	0,64	0,57	0,98	0,02	0,07	0,14	0,00
52	4,21	0,09	1,46	4,01	0,08	0,09	0,14	0,07
53	1,89	0,43	0,81	1,81	0,11	0,08	0,13	0,05
54	1,90	0,08	0,66	1,81	0,00	0,04	0,09	0,00
55	1,52	0,77	0,77	1,48	0,05	0,06	0,08	0,03
56	0,79	0,40	0,40	0,77	0,02	0,03	0,06	0,00
57	0,51	0,51	0,51	0,51	0,51	0,04	0,04	0,04
58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 4. Summary of bootstrap statistics (N = 100 without replacement) for the total number of species averaged over the 50 analyzed fishing sets in the lower deck with increasing total sampling duration in minutes (CIsup = 95% upper confidence interval; CIinf = 95% lower confidence interval; CV = Coefficient of variation).

Duration	Max	Médian	Mean	CIsup	CIinf	CV Mean	CV CIsup	CV CIinf
1	226,08	21,16	35,38	147,82	0,10	1,38	2,56	0,80
2	424,68	10,94	30,64	182,84	0,65	0,94	1,65	0,54
3	192,25	11,10	24,78	114,40	0,44	0,75	1,49	0,39
4	149,43	10,64	20,60	110,75	1,07	0,62	1,18	0,34
5	170,57	6,38	17,50	109,67	0,12	0,54	1,01	0,29
6	111,33	5,77	15,26	97,86	0,16	0,47	0,86	0,25
7	128,16	5,23	12,11	38,01	0,27	0,42	0,84	0,21
8	53,01	5,22	9,86	46,05	0,16	0,37	0,73	0,19
9	43,27	3,58	7,96	41,33	0,20	0,35	0,75	0,14
10	79,97	5,80	10,03	60,15	0,04	0,30	0,69	0,10
11	52,70	4,43	8,47	45,72	0,00	0,29	0,64	0,00
12	39,30	2,32	6,58	28,25	0,00	0,26	0,56	0,00
13	55,86	3,88	8,91	55,12	0,00	0,25	0,50	0,00
14	37,00	3,44	7,34	29,02	0,45	0,24	0,51	0,09
15	47,47	2,24	7,40	37,66	0,01	0,21	0,48	0,03
16	55,55	2,50	8,02	48,61	0,00	0,20	0,41	0,00
17	56,54	3,41	7,44	38,18	0,00	0,19	0,43	0,00
18	36,07	2,47	7,08	31,51	0,00	0,18	0,40	0,00
19	45,04	3,36	8,27	44,75	0,05	0,18	0,40	0,04
20	59,39	2,61	7,59	41,63	0,00	0,17	0,39	0,00
21	26,59	5,61	6,46	22,84	0,00	0,17	0,36	0,05
22	31,66	3,45	5,33	24,07	0,01	0,16	0,36	0,03
23	35,36	3,94	7,95	33,06	0,13	0,15	0,38	0,03
24	35,49	3,20	7,95	33,41	0,00	0,13	0,32	0,00
25	18,53	1,51	4,00	16,49	0,00	0,12	0,33	0,00
26	20,00	4,20	5,60	17,45	0,00	0,13	0,30	0,00
27	27,29	4,74	8,67	25,71	0,28	0,13	0,30	0,04
28	19,44	0,97	3,81	16,16	0,00	0,11	0,29	0,00
29	10,93	2,03	3,93	10,51	0,12	0,13	0,29	0,05
30	13,55	7,37	6,00	12,92	0,15	0,12	0,28	0,01
31	6,99	2,68	2,69	6,61	0,01	0,12	0,25	0,01
32	19,59	1,51	5,43	17,49	0,18	0,12	0,25	0,04
33	22,39	3,17	6,11	20,32	0,46	0,11	0,23	0,03
34	17,76	1,46	4,33	16,01	0,01	0,10	0,21	0,01
35	16,09	1,27	3,07	13,67	0,24	0,11	0,22	0,03
36	12,61	1,61	3,42	11,76	0,00	0,09	0,20	0,00
37	7,82	1,65	3,07	7,63	0,37	0,11	0,21	0,05
38	7,81	0,26	2,47	7,63	0,06	0,09	0,18	0,04
39	7,75	0,46	1,96	7,13	0,15	0,09	0,17	0,04
40	1,54	0,62	0,71	1,51	0,02	0,07	0,18	0,00
41	4,69	0,75	1,81	4,55	0,17	0,07	0,15	0,03
42	3,71	0,24	0,93	3,40	0,01	0,06	0,16	0,00
43	1,11	0,21	0,38	1,06	0,00	0,05	0,14	0,00
44	1,35	0,68	0,68	1,31	0,06	0,10	0,15	0,04
45	1,93	1,54	1,54	1,91	1,17	0,09	0,14	0,04
46	5,03	2,51	2,51	4,90	0,13	0,07	0,13	0,00
47	1,14	1,14	1,14	1,14	1,14	0,13	0,13	0,13
48	3,11	3,11	3,11	3,11	3,11	0,11	0,11	0,11
49	3,18	3,18	3,18	3,18	3,18	0,12	0,12	0,12
50	0,59	0,59	0,59	0,59	0,59	0,11	0,11	0,11
51	1,68	1,68	1,68	1,68	1,68	0,11	0,11	0,11
52	0,12	0,12	0,12	0,12	0,12	0,11	0,11	0,11
53	0,86	0,86	0,86	0,86	0,86	0,09	0,09	0,09
54	1,92	1,92	1,92	1,92	1,92	0,08	0,08	0,08
55	1,70	1,70	1,70	1,70	1,70	0,07	0,07	0,07
56	0,32	0,32	0,32	0,32	0,32	0,07	0,07	0,07
57	0,66	0,66	0,66	0,66	0,66	0,05	0,05	0,05
58	0,87	0,87	0,87	0,87	0,87	0,05	0,05	0,05
59	0,75	0,75	0,75	0,75	0,75	0,03	0,03	0,03
60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

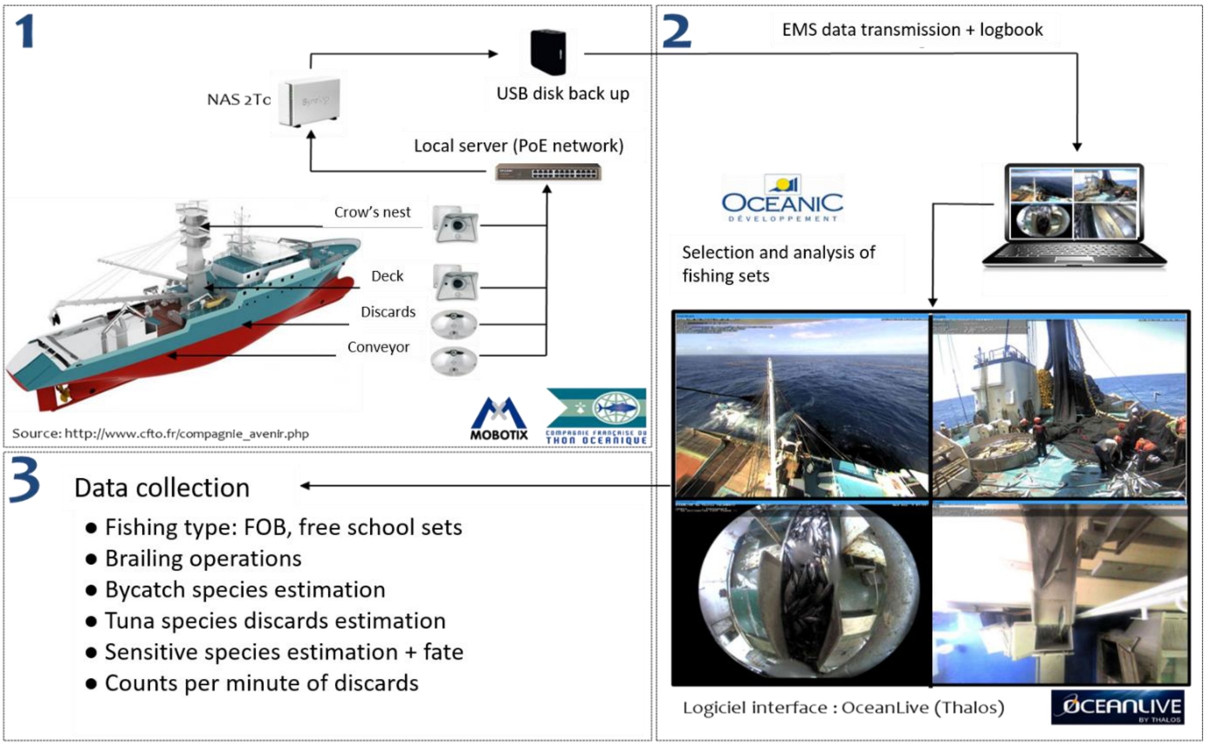


Figure 1. Schematic representation of the EMS installation on French purse seine vessels and the overall process of electronic observer data collection.

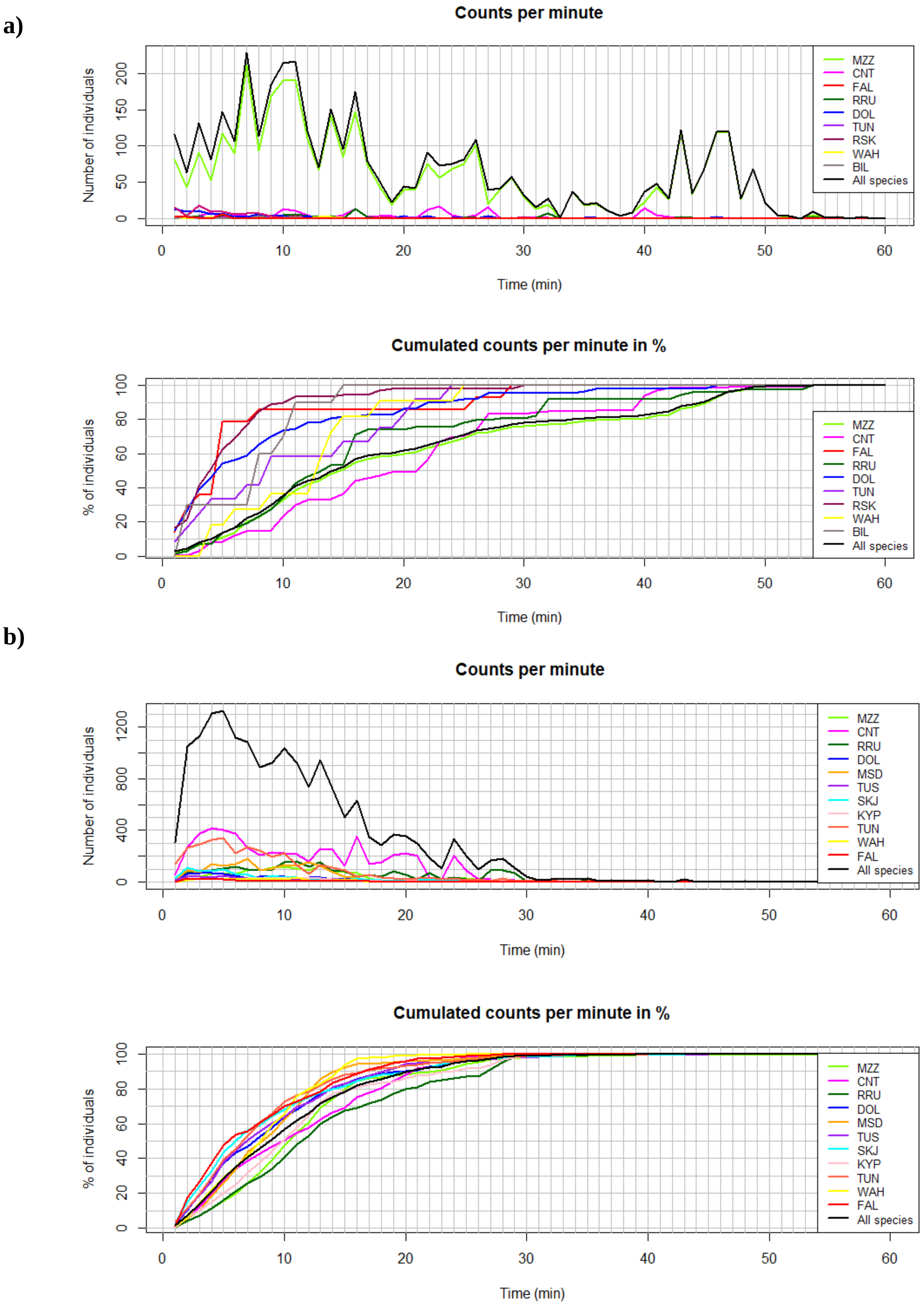


Figure 2. Counts per minute and cumulated percentage of discarded individuals combining all 50 fishing sets a) on the upper deck and b) in the lower deck. Total numbers of individuals are displayed with the solid black line and counts for the most common species are displayed in solid colored lines.

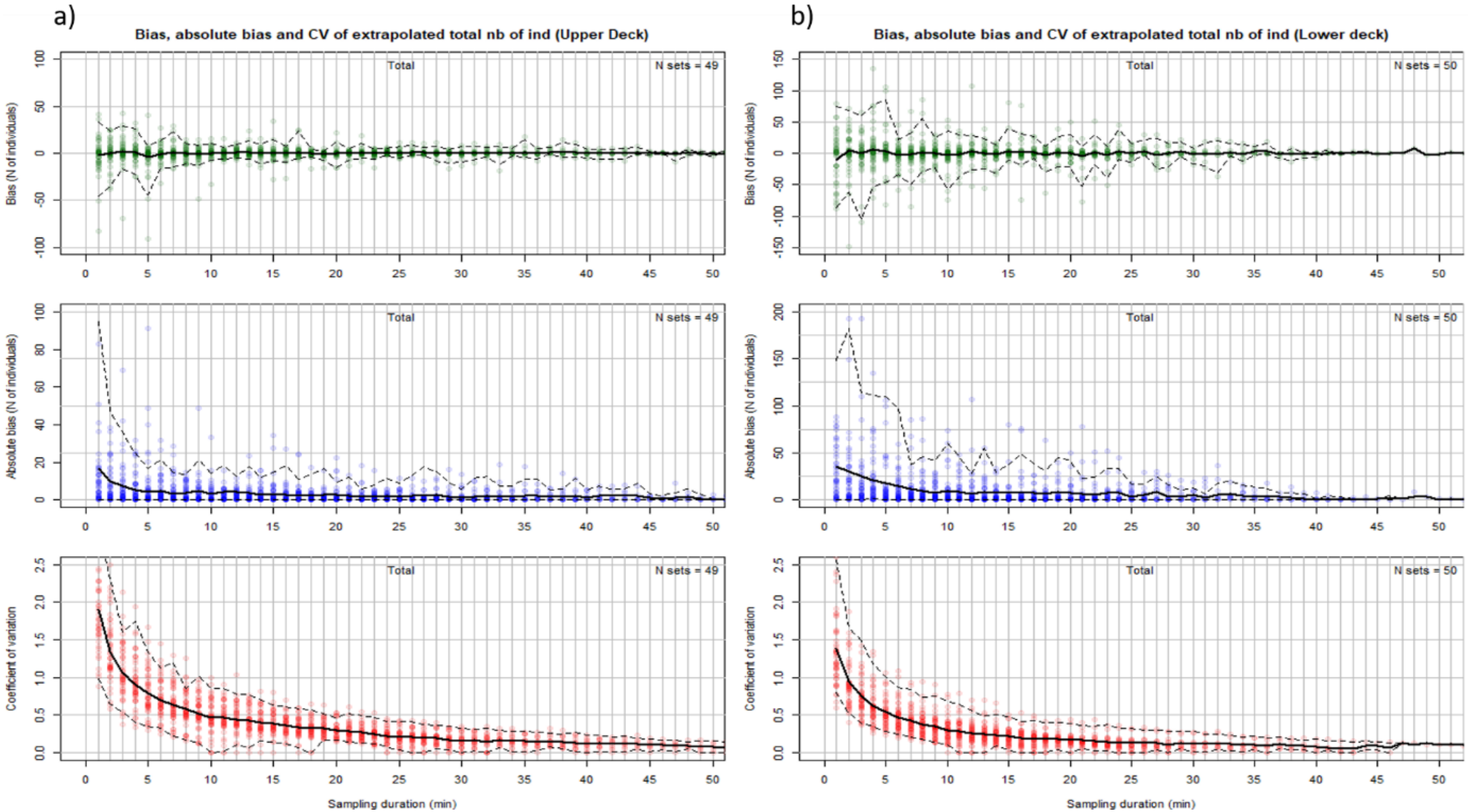


Figure 3. Bias, absolute bias and coefficient of variation (CV) of the total number of discarded individuals estimated as a function of sampling duration for a) the upper deck (N = 49) and b) the lower deck (N=50). The bias and CV were calculated over e 100 bootstrap iterations (resampling without replacement) for each fishing set. The solid line represents the mean and the broken lines the 95% confidence intervals.

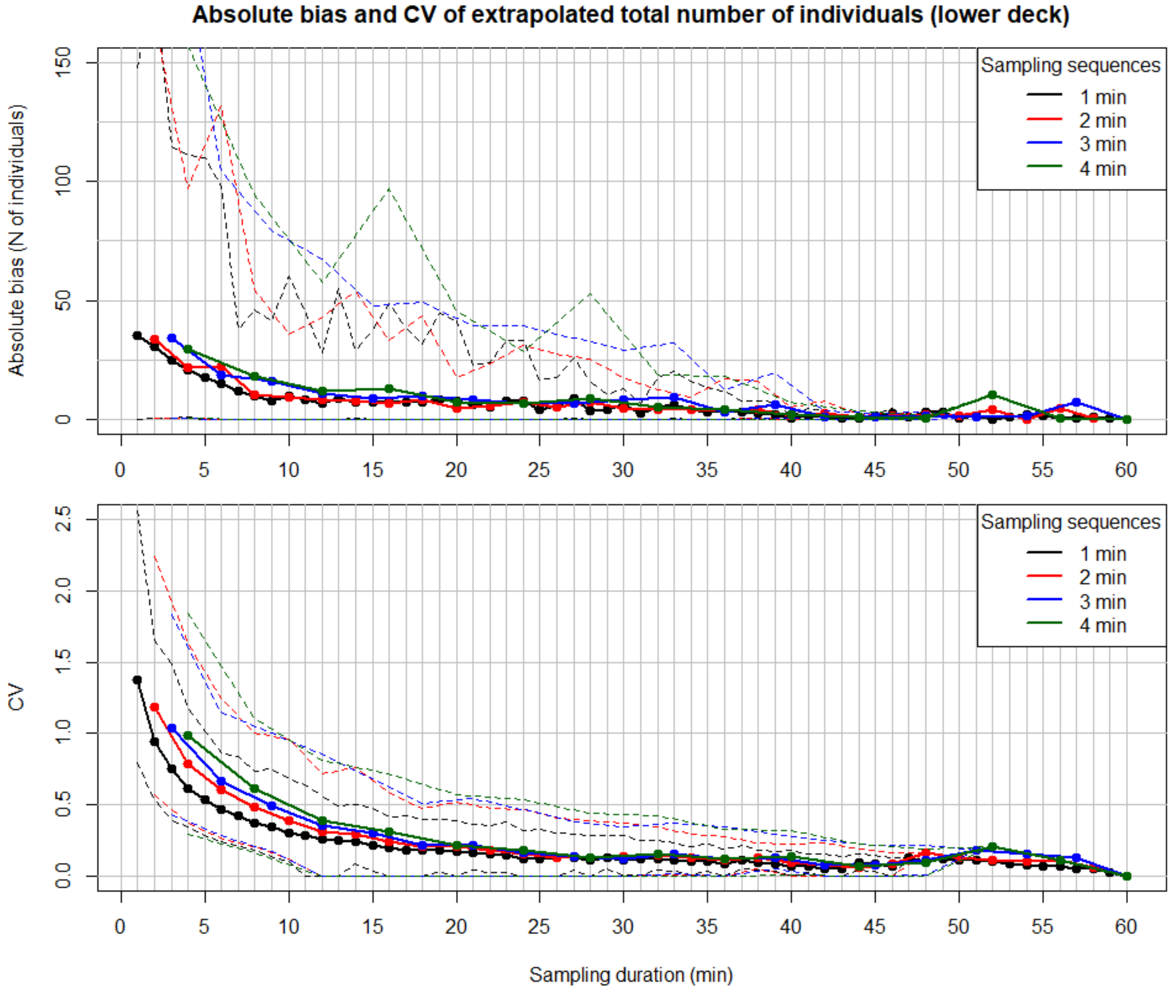
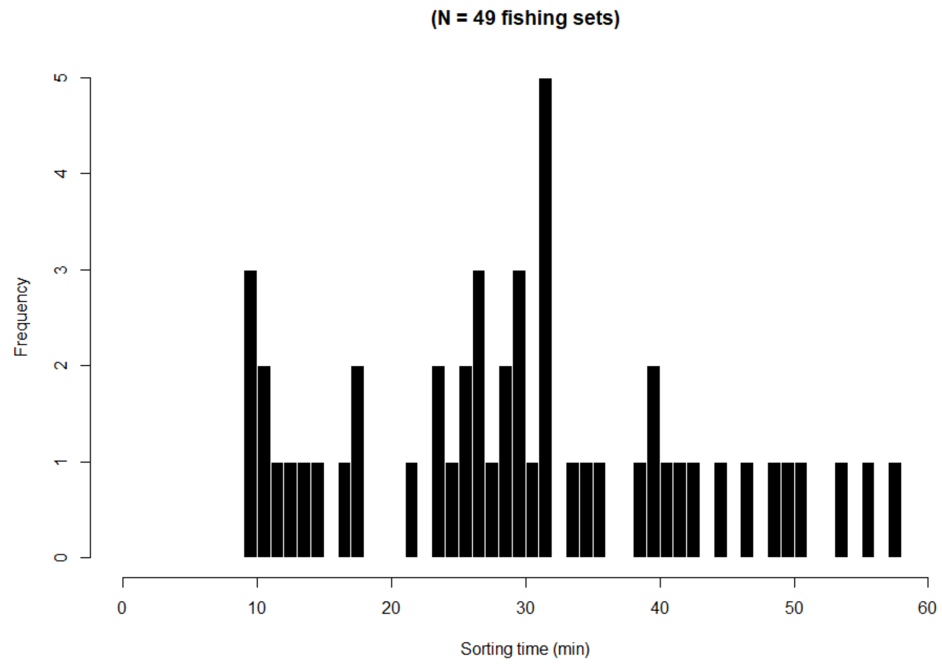


Figure 4. Mean absolute bias and CV of the total number of discarded individuals of the lower deck estimated as a function of cumulated sampling duration when randomly sampling sequences are 1, 2, 3 and 4 minutes.

SUPPLEMENTARY MATERIAL

a)



b)

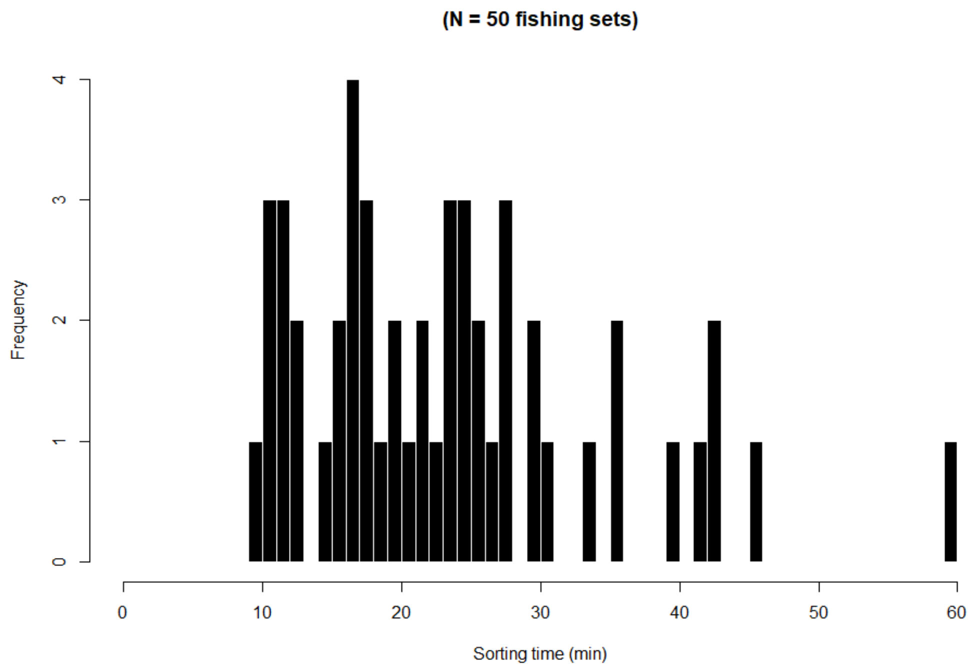


Figure S1. Distribution of the duration of sorting operations (discards sorting time) in minutes on a) the upper deck and b) in the lower deck.

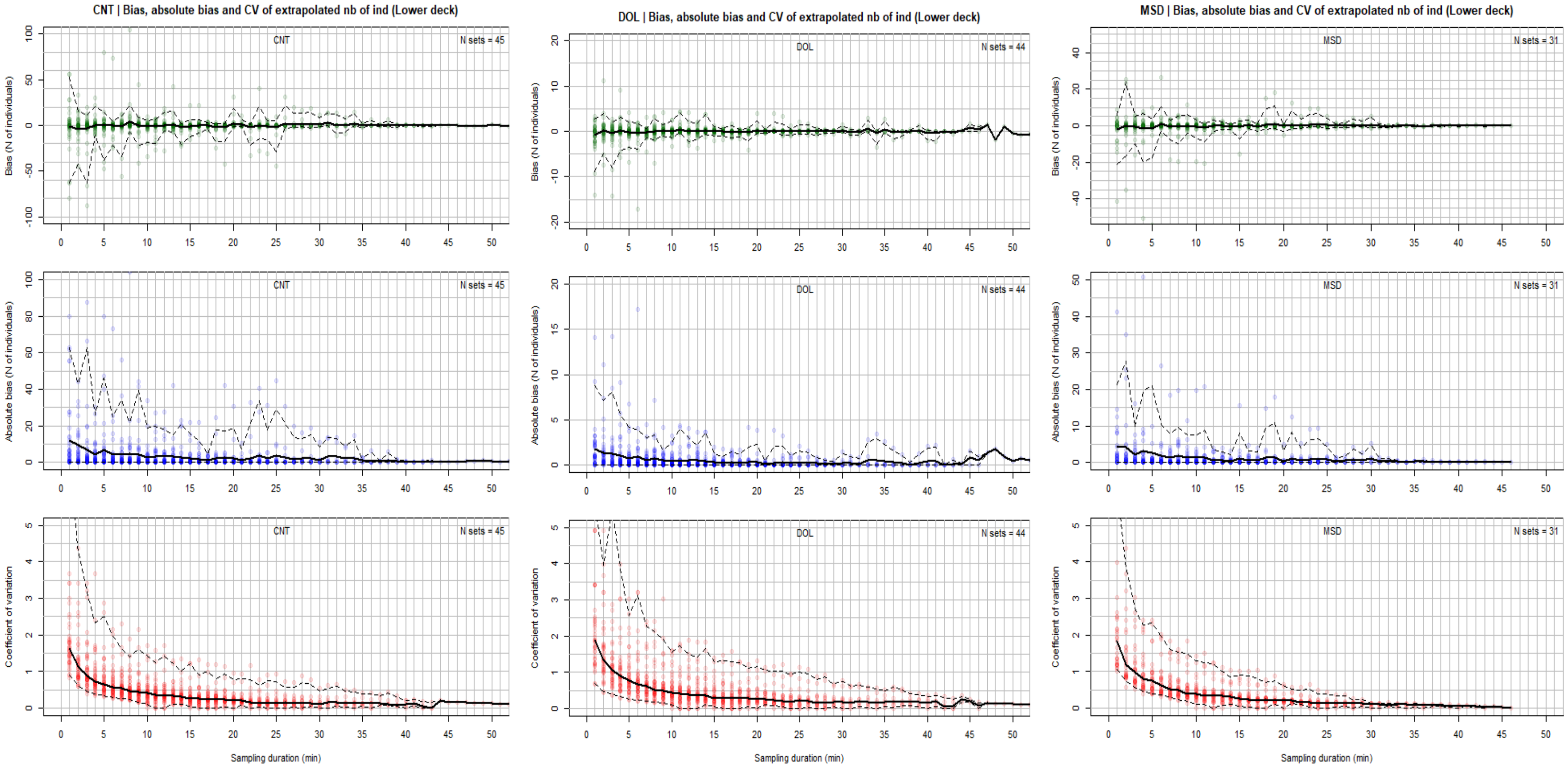


Figure S2. Bias, absolute bias and coefficient of variation (CV) of the extrapolated number of discarded CNT, DOL, MSD, RRU, WAH and FAL as a function of sampling duration in the lower deck. The bias, absolute bias and CV were calculated over 100 bootstrap iterations (sampling random minutes without replacement) for each fishing set. The solid line represents the mean and the broken lines the 95% confidence interval. The scale of Y-axes may differ among species.

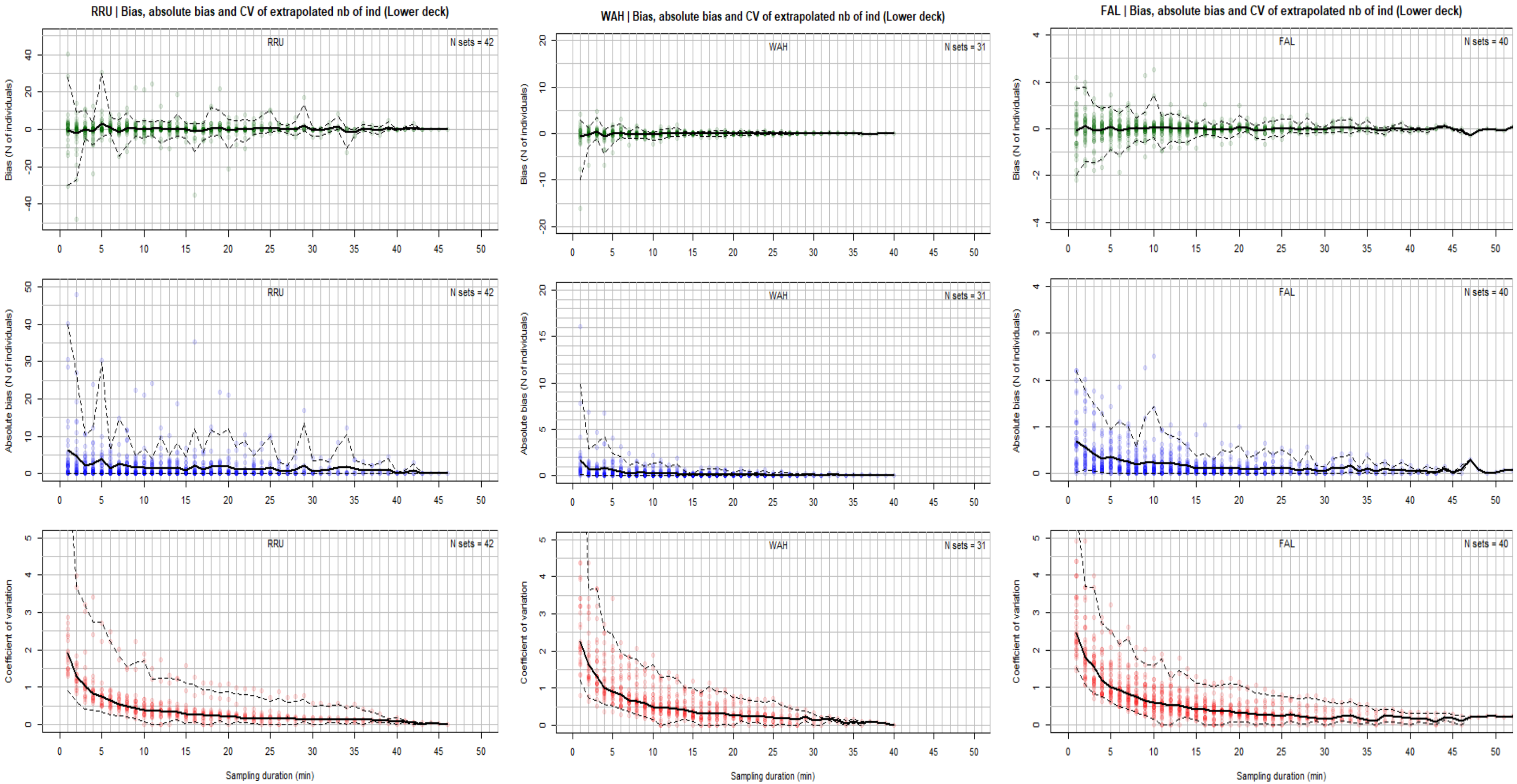


Figure S2 (continued). Bias, absolute bias and coefficient of variation (CV) of the extrapolated number of CNT, DOL, MSD, RRU, WAH and FAL as a function of sampling duration in the lower deck. The bias, absolute bias and CV were calculated over 100 bootstrap iterations (sampling random minutes without replacement) for each fishing set. The solid line represents the mean and the broken lines the 95% confidence interval. The scale of Y-axes may differ among species.

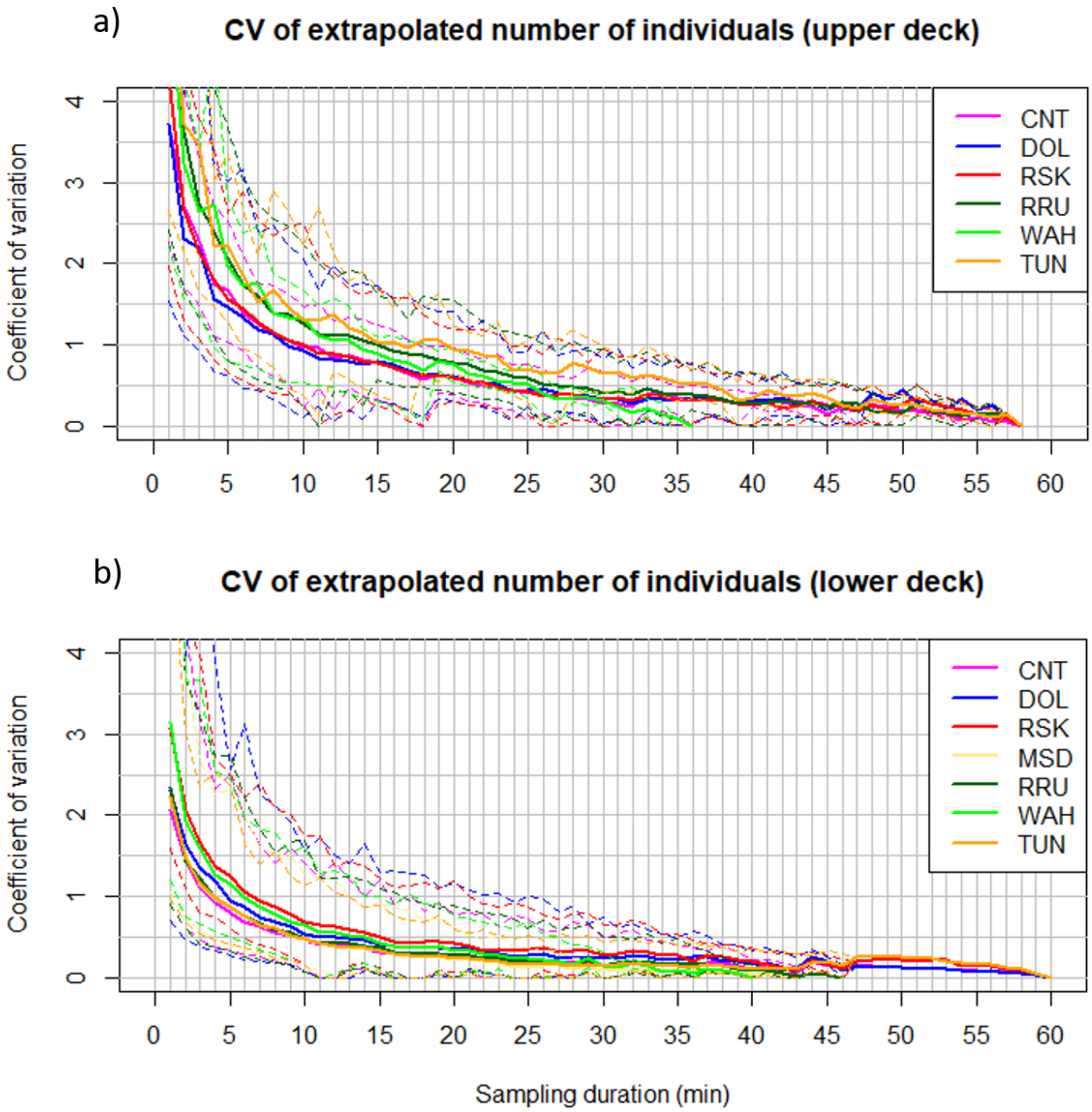


Figure S3. Coefficient of variation (CV) of the extrapolated number of discarded individuals per species (CNT, DOL, RSK, MSD, RRU, WAH) and group of species (TUN) a) on the upper deck and b) in the lower deck as a function of sampling duration.