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Patterns of swordfish capture in relation to fishing time moon illumination and fishing depth

Pascal Bach [1,*], Philippe S. Sabarros [2], Evgeny V. Romanov [3], Alexis Puech [4], Manuela Capello [1], Vincent Lucas [5]

(1) IRD, UMR 212 EME, CRHMT, 34203 Sète, France
(2) IRD, UMR 212 EME, 97420 Le Port, La Réunion
(3) CAP RUN - ARDA, 97420 Le Port, La Réunion
(4) IFREMER, Rue Jean Bertho, BP 60, 97822 Le Port Cedex, La Réunion
(5) Seychelles Fishing Authority, P.O. Box 449, Mahé, Seychelles

* Corresponding author, email: pascal.bach@ird.fr

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ABSTRACT

Pelagic longline is a fishing gear used worldwide to target large pelagic fish. The longline corresponds to a mainline with hundreds to thousands branchlines equipped with baited hooks. As capture success depends on attraction of fish towards the hooks, a higher catch rate generally corresponds to the deployment of the gear at the right time and depth. Timing and hook depth distribution influence both the catch of target species and bycatch.

In this study we analyzed the patterns of swordfish capture in relation with two major factors of the longline fishing strategy: fishing depth and fishing time. First, we used data collected from a self-reporting project to investigate the relation between catch and maximum fishing depth recorded by temperature depth recorders. Second, we analyzed capture time data obtained from research fishing surveys carried out with a longline equipped with time depth recorders and hook timers.

We found that the nominal CPUE of swordfish varies depending on the maximum fishing depth and the moon luminosity. Also, we demonstrated that the cumulated nominal CPUE rate during fishing time is rather constant. Hooking success and hooking contacts both occurred during a period extending from the late afternoon (i.e. 17:00 to 18:00) to the following morning (i.e. 08:00 to 10:00). However, swordfish captures mostly occurred during the night period with a rather constant cumulated nominal CPUE rate. Contrastingly, bycatch species captures were observed indifferently during the whole soaking period. Nighttime can be considered as an optimal time window for swordfish while mitigating bycatch. Fishing strategy is a determinant factor of fishing success for passive gear while it is often underestimated compared to environmental factors.

Keywords

Swordfish | CPUE | Monitored longline | Temperature Depth Recorder | Hook timer | Scientific surveys | Self reporting data | Boostrap sampling

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1 INTRODUCTION

When fishery-independent approaches of counting animals are impractical fishery biologists use the ratio between the catch and the fishing effort, the so-called catch per unit effort (CPUE), as a proxy of the abundance of the resource (Bishop, 2006). In general when using commercial fishery data capture are synonym as landings. Index of the relative abundance for most exploited stocks are estimated by models (GAMs, GLMs, GLMMs, .. see Maunder and Punt, 2004 for a review) based on time series of CPUE. Those models are performed to standardize catch rate for factors describing (i) the modification of the oceanographic environment that can explain the availability of the resource and (ii) the characteristics of fishing practices driving the vulnerability of the resource. Analyzing the variability of the efficiency of fish capture due to technological differences among a given gear, among vessels or fleets is a way to shift from the nominal fishing effort to the effective one. If the nominal fishing effort can be appreciated as a measure of the fishing power to reach a given yield level, the effective fishing effort can be thought as an instantaneous rate of fishing.

The pelagic longline is a fishing gear used worldwide to target large pelagic fish such as tunas and swordfish. The longline corresponds to a mainline with hundreds to thousands branchlines maintained at the surface by buoys regularly attached. Each branchline has a bait on hook at its extremity. For pelagic longlining, the nominal fishing effort is taken to be proportional to the number of hooks deployed. The advantage of this unit is to be simple, however it does not take into account the complexity of the capture process.

This complexity is especially due to the need of active movements of a fish towards the fishing gear. It involves four stages (Løkkeborg et al., 2014): (i) the availability of the resource, (ii) the accessibility of the resource within the range of the bait odor plume, (iii) the location of the baited hooks, (iv) biting (attack of the baited hooks), hooking and retention of the fish by the hook. Therefore, the longline catching efficiency mainly depends on factors ranged into three categories): (A) bait (chemical and visual attractiveness, time efficiency), (B) natural behaviour and density of the target resource, interactions between catches and environmental conditions (mostly prey environment), and (C) gear and fishing techniques including hook size, hook-spacing, lengths of both mainline and branch line, hook depth distribution, fishing period, soak time and mainline and branch line materials.

A potential change in pelagic longlining concerned the variation of longline setting practices to modify the width of vertical habitat exploited by the gear. During the mid-70s one of the most modifications of fishing practices over time for the Japanese pelagic longline fishery was the shift of hooks to deeper depth strata to target bigeye tuna instead of yellowfin tuna and albacore tuna (Yokawa and Uozumi, 2001; Bigelow et al., 2002; Ward and Hindmarsh, 2007). In the meantime, the occupation of the pelagic habitat by large pelagic fishes changes with the time of the day. Vertical distributions of both predator and their preys match over the time (Josse et al., 1998; Dagorn et al., 2000; Bach et al., 2003). Then, the empirical fisher's knowledge has shaped longline deployment strategies adapted for targeting species (Ward and Hindmarsh, 2008). The last of the soak time and the hauling time were determined through the same empirical process. Timing, soak time and hook depth distribution influence longline catches.

In this study we analyzed the patterns of swordfish capture in relation with two major factors of the longline fishing strategy: fishing depth and fishing time. Our objective is to identify what was the best fishing window in terms catch rate regarding the soak time, the fishing time and the maximum fishing depth.

We analyzed data collected from a self-reporting project (SRP) of the pelagic longline fleet based in La Reunion (Bach et al., 2013) to investigate the relation between swordfish catches, maximum fishing depth recorded by temperature depth recorders (TDRs) and the moon luminosity. Second, we considered data obtained from research fishing surveys carried out with a monitored longline in the southwest Indian Ocean. We analyzed the time of hooking contacts, hooking success (i.e. capture) and swordfish capture inferred from hook timer data to characterize trends of interactions between the longline and the pelagic fishes totally, the swordfish only during the soak time. Based on these results interests to consider the fishing time and the maximum fishing depth for CPUE standardization and management purposes.

2 MATERIALS AND METHODS

2.1 Self-reporting data on exhaustive pelagic longline catches

In order to enlarge observations of fishing activities of La Reunion based-longliners below 20 m LOA where observer cannot embark a self-reporting project (SRP) was launched in May 2011 (Bach et al., 2013) in the frame of the Data Collection Framework (DCF) of the European Union. Fishermen transmit information following dedicated templates describing the fishing gear, the fishing operation, all capture by species or group of species commercialized, kept on board or discarded due to law regulations, the depredation or the economic disinterest.

A total of 923 fishing operations was monitored from 2011 to 2013 and more than 2500 temperature depth profiles were collected (from 2 to 4 temperature depth profiles per set). For each fishing operation, the number of swordfish caught (i.e. commercialized individuals, individuals kept on board, undersized and depredated individuals discarded) was recorded and the swordfish CPUE by set was estimated.

Each depth profile corresponds to records of temperature and depth at the midpoint of the basket mainline expected to be the deepest point of the basket (Bach et al., 2009). Then, the median of depth distributions was considered as a proxy of the maximum fishing depth of the instrumented basket (MDmb) while the mean of these mean values (Dmax) was considered as a proxy of the maximum fishing depth of the fishing operation:

$$Dmax = \sum MDmb / N$$

N = number of depth profiles considered for the fishing set.

As "noisy" effects of capture on the mainline depth series were already shown (Bach et al., 2009) depth profiles recorded on baskets with capture were removed from the dataset.
The moon phase illumination was estimated with the "moonphase" function of the R code of the package r4mfcl developed for working with MULTIFAN-CL (https://code.google.com/p/r4mfcl/source/browse/pkpkg/pkpkg.src/pkpkg/R/moonphase.R?spec=svn14&r=14).
Relationships between the nominal swordfish CPUE and the maximum fishing depth and the moon illumination considered as covariables were examined. In this context, generalized Additive Models (GAM) were considered as an exploratory and visualization tool highlighting the unexpected influence of some covariables on the distribution of responses (Venables and Ripley, 2002). GAM models with nonparametric smoothers allow to capture the shape of relations between the variable of interest (the Nominal swordfish CPUE in our case) and the explanatory variables without restricting these relationships to a linear form.

Data collected from instrumented longline experiments

Data analyzed in our study were collected during 77 instrumented longline fishing operations carried out in the south west Indian Ocean (Figure 1) from 2005 to 2012 as part of the CAPPES research project (Gamblin et al., 2006), the component 4 of the 'SWIOFP' South West Indian Ocean Fisheries Project (Lucas, 2010), the 'MADE' Mitigation of Adverse Ecological Impacts of Open Fisheries (Dagorn et al., 2008) and the PROSPER project (Romanov et al., 2011). As in all longline fisheries targeting swordfish our fishing operations were operated during the night (setting at dusk, hauling at dawn) at depths ranging from 25 m to 100 m (Ward et al., 2000).
The monitored fishing gear was about a ~3.5 mm-diameter nylon monofilament mainline set taut at the back of the boat at the same speed of the boat. In general the longline setting was operated at dusk while the hauling occurred approximately at dawn. For each set about from one fifth to one third of baskets were equipped with a temperature depth recorder (TDR, model Minilog12-TX from Vemco, http://vemco.com/ or model SP2T from NKE Electronic, http://www.nke-marine-electronics.com) preprogrammed with a record frequency of one measurement per minute. The number of branchline per basket was ranged between 5 and 7. TDRs were placed in the middle of the basket, which generally corresponds to the point that will reach the maximum depth (Bach et al., 2009). Branchlines were equipped with a hook timer (HT, Somerton et al., 1988), which is activated when the bait is attacked by a

predator. Both hooking contact and hooking success data were inferred from HT data. The HT recorded the elapsed time between the biting and its recovery on board. The capture time is calculated as the difference between the recovery time and the HT data. The number of hooks deployed was 32082 among which 31046 were equipped with hook timers (i.e. a rate of hook instrumentation of ~97%). The distribution of hooks deployed during the soak time of longline experiments is displayed on the figure 2.

The different hooking rates (hooking contacts, hooking success, bycatch, swordfish) during the soaking time were firstly estimated by set. For a given set, each hourly hooking rates (HR) were calculated regarding the number of available hooks at the end of each hour. The series of cumulated hourly HR (cHR_h) was inferred from HR values and the cumulated HR series (rel_cHR_h) relative to the HR of the fishing operation at the scale of the by hour relatively to the total hooking rate (cumHR)

* $HR_h = N_h / NH_{available}$ where
* $NH_{available}$ = number of hooks in the water – sum of hooking contacts
* $cHR_h = \sum_1^h HR_h$
* $\max HR_h = \sum_1^{end} HR_h$

* $\mathbf{rel\_cHR_h = cHR_h / max\,HR_h}$

For each hour, the sample of relative cumated hooking rates per set (rel_cHR_h) were boostrapped to obtain the mean trend and the associated confidence interval of hooking rates.

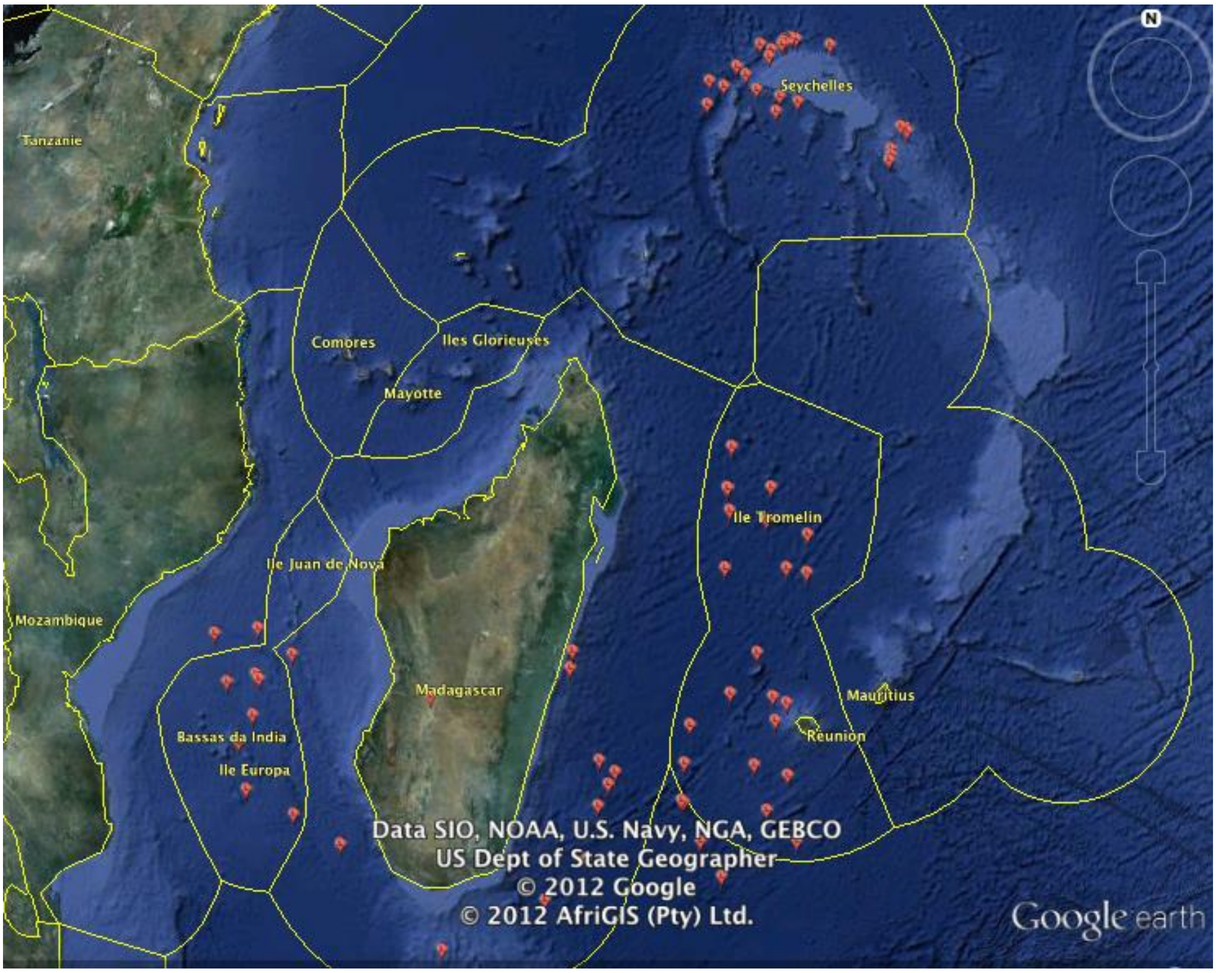

Figure 1 – Geographical distribution of the instrumented longline fishing experiments targeting swordfish carried out the South West Indian Ocean.

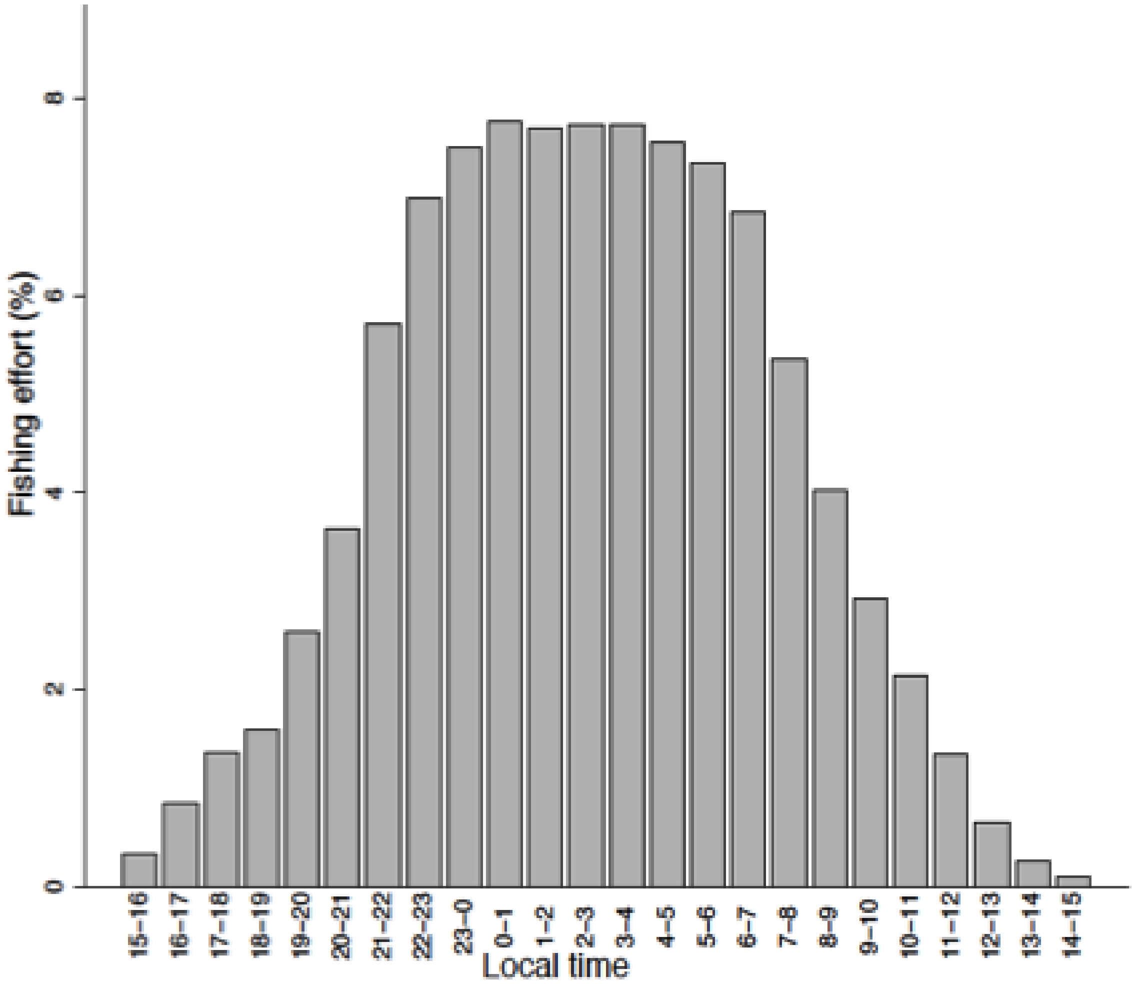

Figure 2 – Distribution of the fishing effort (number of hooks %) deployed during the soak time instrumented longline fishing experiments targeting swordfish.

3 RESULTS

3.1 Maximum fishing depth, the moon illumination and nominal swordfish CPUE

The distribution of fishing sets analyzed displayed an effect of the moon illumination on the fishing activity. The number of fishing sets seems to be linked with lunar phases and they increased during periods of both new moon and full moon (Fig. 3). Similarly to the fishing activity the nominal swordfish CPUE varied with the moon illumination. The deviance explained by the model is 1% but this response is significant, p value = 0.02). The GAM smoother highlighted a significant quadratic response with a catch rate higher during intermediate values of the moon illumination (Fig. 3). Surprisingly, both new moon and above all full moon periods displayed lower CPUE despite a concentration of the fishing effort during this period.

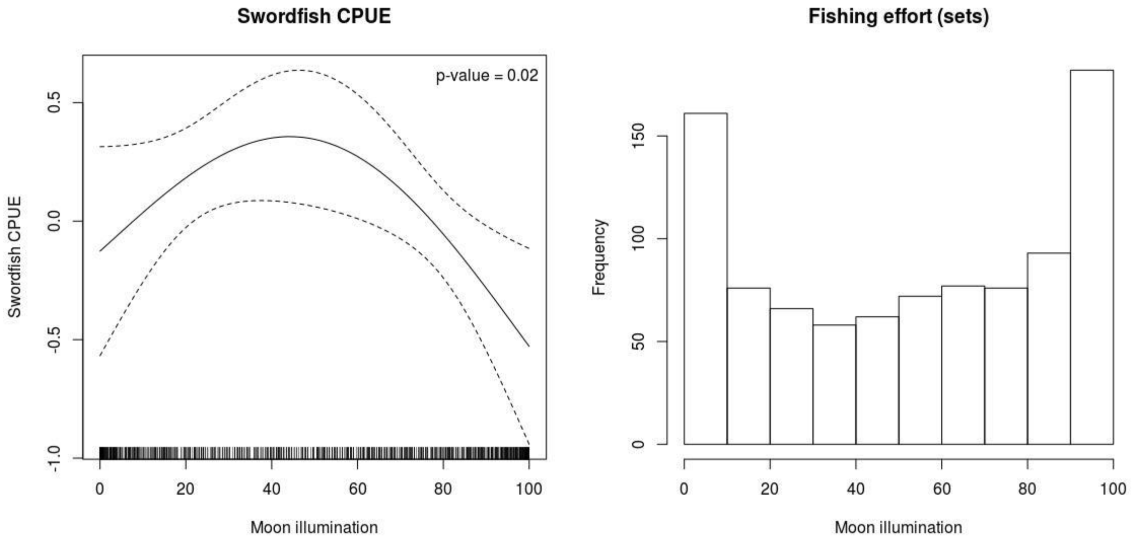

Figure 3. Quadratic response of the swordfish catch per unit of effort and the moon illumination (GAM output, left) and frequency distribution of the number of sets regarding the moon illumination (right).

In a second step, the nominal CPUE of swordfish was analyzed by considering two covariables: the moon illumination and the maximum fishing depth obtained from monitored longline with temperature depth recorders (TDRs). The swordfish nominal CPUE distribution was stratified vertically by depth layers of 10 m and horizontally by 10 % moon illumination (Fig. 4). Kernel densities of both the maximum fishing depths and the swordfish CPUE in relation to the moon illumination were displayed on the Figure 4. The effect of the interaction between the moon illumination and the maximum fishing depth of the longline on the swordfish nominal CPUE was analyzed using a GAM model (cpue ~ s(depth,moon); Fig. 4). Results of the adjustment of the model revealed a significant interaction (edf = 2.943; $p < 0.001$) while the overall deviance explained by the model reached about 15 %. The pattern of the swordfish CPUE highlighted by the model and associated pictures suggested a diagonal ridge of highest CPUE values from lowest to highest values of both moon illumination and maximum fishing depth to highest values. Extrapolating these results in terms of swordfish vertical habitat during nighttime, the availability of swordfish was higher near the surface (20 m) at new moon, at intermediate depths (50-70 m) during lunar transitions and deeper (100 m) at full moon.

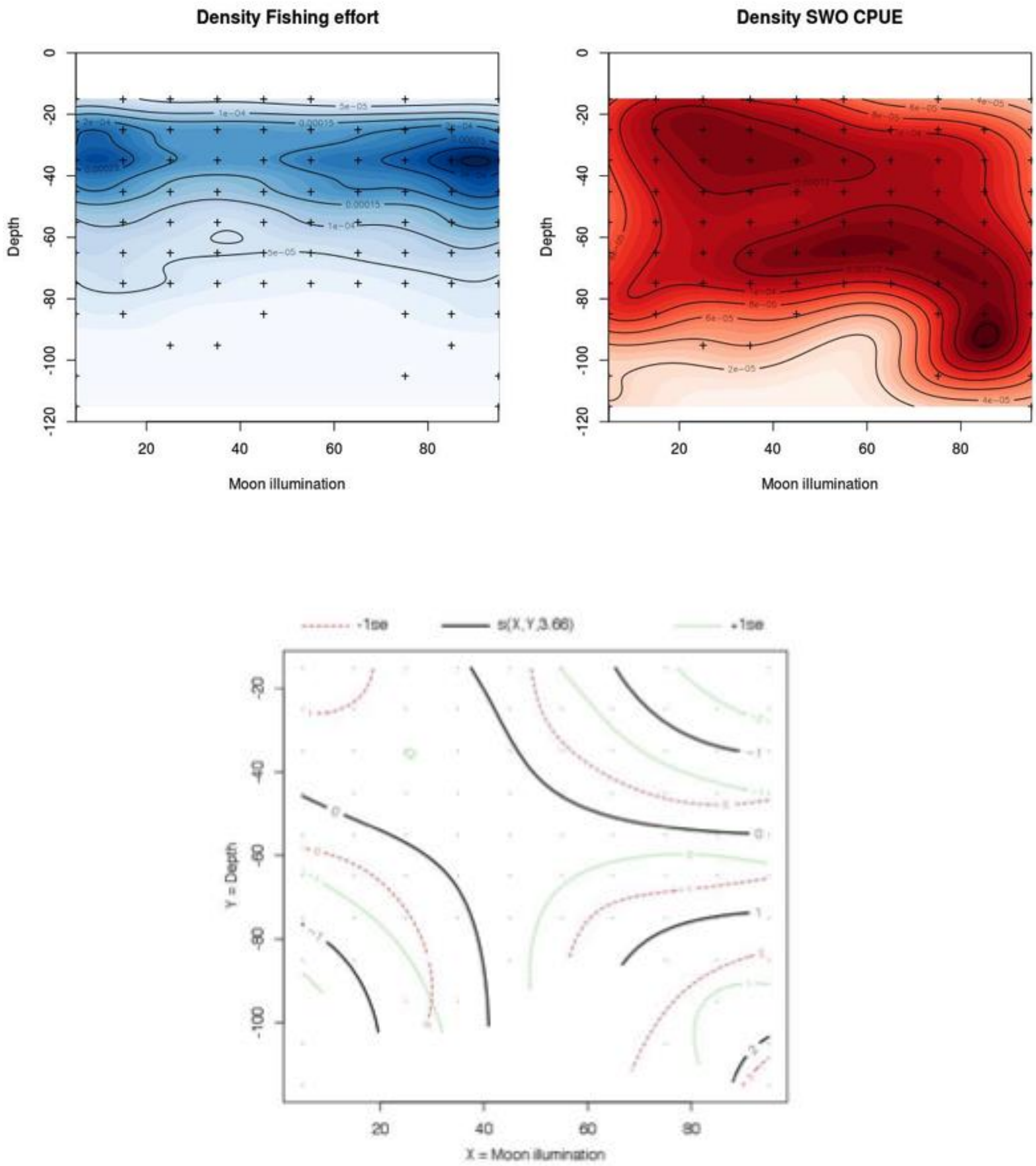

Figure 4. Stratified fishing effort (upper left) and swordfish catch rates density plots (upper right). Model outputs of the interaction between the fishing depth and the moon illumination (GAM analysis) from stratified data (depth strata = 10 m, moon illumination strata = 10%).

3.2 Hooking rates variations during the soak time

Among the 22304 hooks (21190 of them equipped with HTs) deployed during the 56 monitored longline fishing experiments 1337 of them were triggered that corresponds to a rate of hooking contacts of ~6.3 % (hooking contact = triggered HT without capture and hooking success), (Table 1). A total of 420 hooking contacts were successful (hooking success = 2 % and hooking efficiency = 31.7 %). Among them 174 swordfish (= 41 % of capture) and 246 bycatch (= 59% of capture) were caught (Table 1).

Table 1. Presentation of data of interactions between instrumented longline (ILL) fishing sets and the pelagic resources

Number of ILL sets	56
N. hooks deployed	22304
N. Hook-Timers deployed	21190
Hook triggered (hooking contacts)	1337
Hook triggered with capture (Hooking success)	420
Number of swordfish	174
Number of bycatch	246

Hooking contact and hooking success

Profiles of the relative cumulated hooking rate during the soak time for hooking contacts and hooking success were displayed on the figure 5. First of all we observed that the two profiles are very similar. If both contact and success occurred rapidly after the setting of the longline only 10% on contact and success were observed before dawn. The same percentage occurred after dusk and finally 80% of interactions between the pelagic resource and the gear were registered between dusk and dawn. Actually the increase of the hooking started at 21:00 and after a positive linear trend with a slope of 7% was calculated until the dawn.

Hooking rates for bycatch and swordfish

Differently to previous hooking trend described, hooking rates for bycatch and swordfish during the soak time were different. If bycatch occurred immediately during the setting period swordfish capture started at dusk (Figure 6). The rate of swordfish capture stayed constant with a slope of 9% until dawn to reach the total of catches observed at this time period. For bycatch the trend of the cumulated hooking rate displayed two phases during the night. During the first part of the night the rate reached about 3.6% and an increase to about 9% is estimated during the second part of the night. After dawn until the end of the hauling 30% of bycatch were still caught. It must be noted that at 5:00 the level of swordfish caught was 80% compared to 35% for the group of bycatch. After dawn the percentage of catch for each group reached 100% for the swordfish compared to 68% for bycatch.

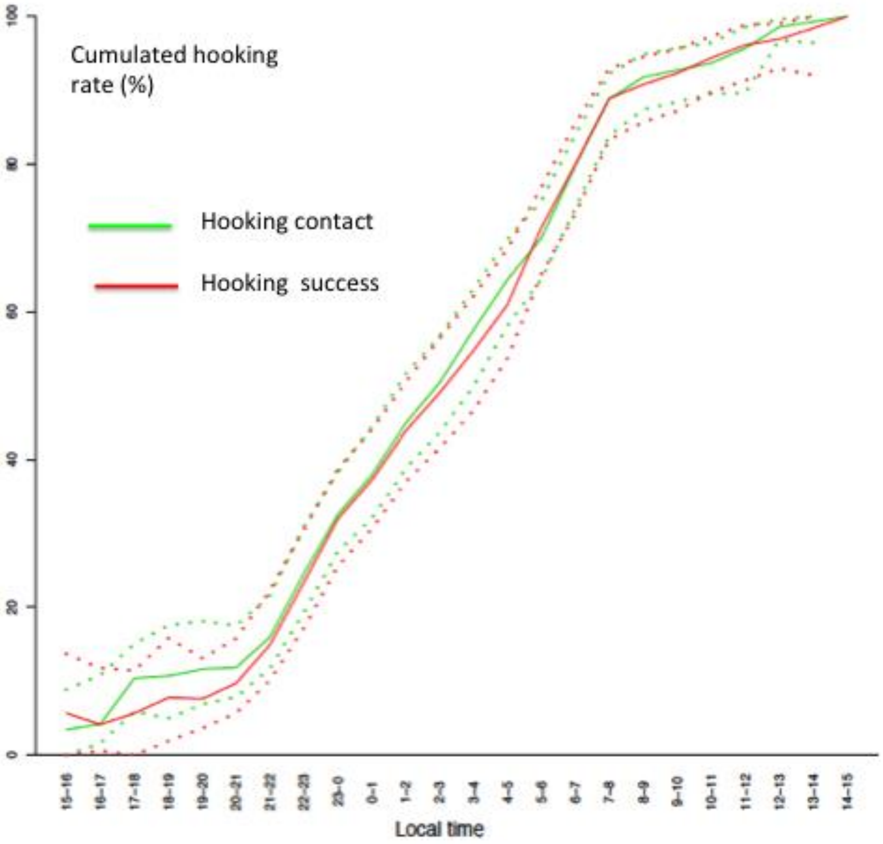

Figure 5. Profiles of the cumulated hooking rate for hooking contacts and hooking success during the soak time of monitored longline fishing experiments.

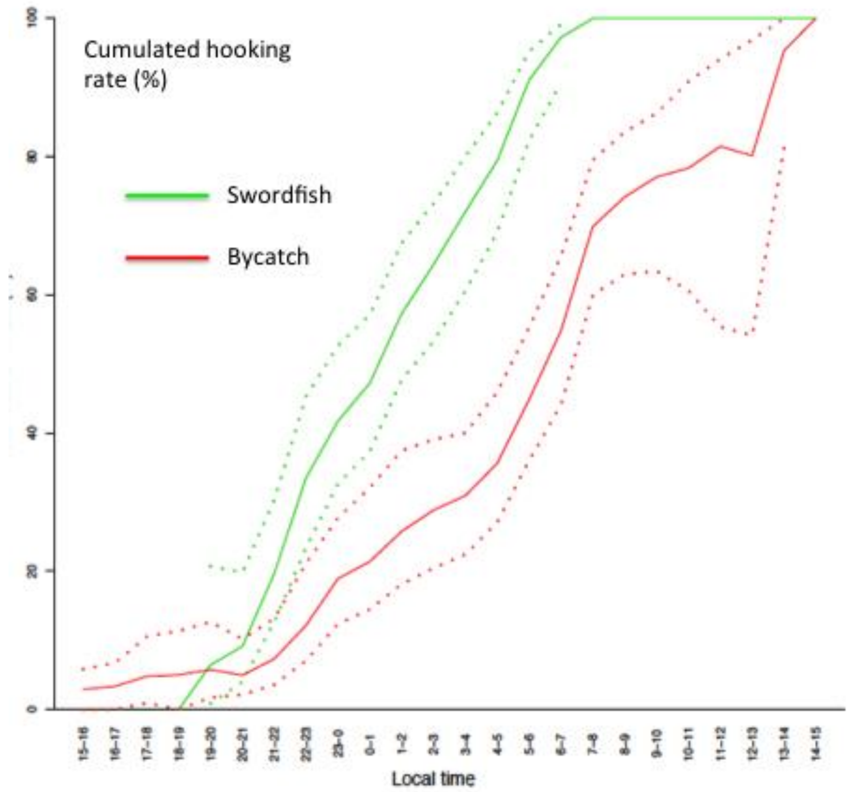

Figure 6. Profiles of the cumulated hooking rate for bycatch and swordfish during the soak time of monitored longline fishing experiments.

4 DISCUSSION

For many of active fishing gears the success of the fishing operation depends mainly on the fish availability that may be controlled by several acoustic devices such as sounder and sonar. For passive gear targeting pelagic dispersed individuals or small aggregations this technology is not effective and in general fishermen scrutinize remote sensing products (sea surface temperature, sea level anomaly, sea surface color) to identify frontal structure accumulating nutrients and preys acting as attractants for large predators. However, even in the right place the result of the fishing operation will still depend on both the time period for deploying the gear and the tactic of the deployment. For pelagic longline fisheries targeting swordfish during nighttime the effect of the moon illumination on the catchability was highlighted in several studies. In general swordfish catchability reaches its maximum at full moon (Draganik and Cholyst, 1988; Bigelow et al., 1999; Neves dos Santos and Garcia, 2005; Sajeevan, 2013). In our study we observed patterns of the fleet activity and the moon illumination matched well illustrating the empirical knowledge of the positive effect of the moon illumination on the catchability. However we found that highest nominal CPUEs correspond to the waxing and waning lunar phases. Same results were observed previously for the same fleet (Guyomard et al., 2004; Poisson et al., 2009). One hypothesis to explain this discrepancy is attributed to differences in the prey availability between oceanographic areas. Thanks to an important dataset of maximum fishing depth profiles of the longline recorded with time depth recorders we found that the discrepancy of our results with the admitted positive effect of the moon illumination of the swordfish catchability is related to a “targeting mismatching”. By maintaining a constant maximum fishing depth whatever the moon phase fishermen always obtained moderate swordfish CPUE while highest rates were observed on shallower set during new moon and deeper set during full moon. This result highlighted the importance of (i) the depth targeting with the pelagic longline and (ii) the importance of the monitoring of the maximum fishing depth to disentangle the different hypothesis explaining catchability variations of resources in pelagic longlining. The diagonal ridge of highest CPUE values from lowest to highest values of both moon illumination and maximum fishing observed is consistent with diel vertical movements of swordfish collected by electronic tagging operations (Abecassis et al., 2012).

The analysis of hooking success of swordfish and bycatch shown different catch rate variation patterns during the soaking time. Bycatch occurred during the whole soaking time from the beginning of the setting to the end of the hauling. On the contrary, swordfish catches occurred only during nighttime from dusk to dawn. On average the capture rate for swordfish during nighttime is constant while we shown two stages of the capture rate for bycatch during the soak time. During the first part of the night this rate is more twice lower than during the second part. Moreover 30% of bycatch were still caught while no individuals of the target species were hauled on board. Moreover from a bycatch mitigation perspective we observed an interesting time threshold at 5:00 when the level of swordfish capture reach 80% of the maximum compared to 35% for the bycatch. Indeed, the observation that swordfish catch stopped at dawn and reach 80% two hours before dawn could have management implications. The question of the fishing profitability and the limitation of the soaking time must be discussed. As Carruthers et al. (2011) we are convinced that "*there may be no trade-off between lower bycatch mortalities and fishing profitability. However, evaluating this trade-off depends upon appropriate measures of soak time*".

5 ACKNOWLEDGEMENTS

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