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Evaluating the efficacy of tropical tuna purse seiners in the Indian Ocean: first steps towards a measure of fishing effort

Alexandra MAUFROY[1], Daniel GAERTNER[1], David M. KAPLAN[2], Nicolas BEZ[1], Maria SOTO[3], Cindy ASSAN[4], Juliette LUCAS[4] and Emmanuel CHASSOT[5]

Abstract

The evaluation of the fishing effort exerted by purse seiners on tropical tuna requires a constant monitoring of the changes in individual fishing power of purse seiners due to changes in vessel characteristics, fishing gears or fishing strategies. Also, since the 1990s, increasing numbers of drifting Fish Aggregating Devices have been used by this fleet. As dFADs contribute to a reduction of search times, traditional measures of fishing effort such as search time or fishing time are inappropriate. Here, using logbook data from the French and the Spanish purse seine fleets over 2003-2014, the effects of the characteristics of purse seiners (length overall, period of construction) and their use of support vessels on the efficiency of purse seiners are analyzed with Generalized Linear Models. 3 dimensions of the efficiency of purse seiners are analyzed at the scale of the month: the average catch per day, the average number of fishing sets per day and the average distance travelled per day. Among others, we find that support vessels contribute to an increase increase of 44.6% of the catch per day, 20.0% of the number of fishing sets per day and 4.5% of the distance travelled per day. In a second step, the results of the GLMs are used to build 3 indexes of fishing effort that are compared to a simple monitoring of the number of EU purse seiners over 2003-2014. Ours result show that this simple index provide a biased image of the evolution of fishing effort for the purse seine fishery. Though preliminary, they indicate that the main components of fishing power should be taken into account when measuring the fishing effort of tropical tuna purse seiners in the Indian Ocean.

Keywords: purse seiners, fishing effort, fishing power, GLM

1. Institut de Recherche pour le Développement, UMR 212 EME (IRD/Ifremer/UM2),
Avenue Jean Monnet, BP 171, 34203 Sète Cedex France
2. Virginia Institute of Marine Science, College of William & Mary, P.O. Box 1346
Gloucester Point, VA 23062, USA
3. Instituto Espanol de Oceanografia, PO Box 1373, S/C Tenerife, Spain
4. Seychelles Fishing Authority, Victoria, Seychelles
5. Institut de Recherche pour le Développement, UMR 212 EME (IRD/Ifremer/UM2), SFA, Victoria, Seychelles

1. Introduction

Over time, all tuna RFMOs have experienced growing concerns regarding the estimates of the increasing fishing efficiency and the associated direct and indirect impacts of the of purse seiner' activities on the tuna resource (Fonteneau et al., 1999, Marsac et al., 2000) as well as on the associated pelagic fauna (Amandè et al., 2012; Filmalter et al., 2013) . In May 2015, this context of growing pressure for management lead IOTC to the adoption of a limitation of the number of active drifting Fish Aggregating Devices (dFADs), artificial floating objects that are deployed at sea to aggregate tropical tuna [Res-15/08] In such a context, it is admitted by the scientific community that estimating the fishing effort exerted by purse seine fleets on tropical tuna stocks is more required than ever. Though necessary for a proper evaluation and management of the impacts of purse seine fishing in all oceans, attempting to quantify the increase in fishing power of the purse seine fleet has always been a challenge (Gascuel et al., 1993; Fonteneau et al., 1999; Bez et al., 2011; Gaertner and Pallares 2002). This evaluation requires a constant monitoring of the changes in individual fishing power of purse seiners due to changes in vessel characteristics, fishing gears or fishing strategies (Le Gall, 2000; Torres-Irineo et al., 2014). Since the beginning of the fishery in the Indian Ocean in the early 1980s, the tropical tuna purse seine fleet has always been highly dynamic and adaptive. Tropical tuna purse seiners have continuously improved their fishing efficiency through the modification of vessel characteristics, the frequent introduction of new fishing devices (Torres-Irineo et al., 2014, Lopez et al., 2014) and the development of new fishing strategies.

This is particularly true when it comes to the massive use of dFADs by purse seiners since the 1990s (Fonteneau et al., 2000; Fonteneau et Chassot, 2014) and the acceleration of this use in recent years (Maufroy et al., 2014). In addition to a typical situation of technological creep experienced in other modern fisheries (Torres-Irineo et al., 2014), the use of dFADs complicated the definition of a index of fishing effort for purse seiners by two mechanisms affecting the catchability. First, because dFADs, and more generally Floating Objects (FOBs, either a natural floating object or a dFAD), contribute to the detection of tuna schools. Indeed, GPS buoys are used to accurately monitor their position (Fonteneau et al., 2000), echosounder buoys to monitor the amount of biomass aggregated under the FOB (Dagorn et al., 2013; Lopez et al., 2014) and support vessels to assist purse seiners in building, deploying and monitoring dFADs (Morón et al., 2001). Traditional measures of fishing effort such as *days at sea* or *fishing time* are therefore inappropriate for purse seiners using a combination of activities on Free Swimming Schools (FSC) or randomly encountered FOBs (random search) and GPS buoy monitored FOBs ("directed" search). Secondly, because FOBs increase the availability of tropical tuna to purse seiners by concentrating schools (accessibility) and increasing the proportion of successful sets (vulnerability, Fonteneau et al., 2013; Miyake et al., 2010).

Here, using information on the efficiency of purse seiners, our objectives are twofold (i) analyze individual differences in fishing efficiency related to the vessel characteristics, the use of supply vessels or to individuals skippers (ii) identify key components of fishing power in order to derive a preliminary measure of fishing effort for the purse seine fleet.

2. Material and Methods

2.1 Efficiency and individual fishing power of purse seiners

The efficiency of a given fishing vessel relates to its ability to optimize its strategies and the use of its fishing devices in order to maximize a certain output over a given period of time. In the case of tropical tuna purse seiners, efficiency relates to different outputs. Three different dimensions of the efficiency of purse seiners were explored in this study:

(i) *catch per day* that describes the ability of purse seiners to maximize their catch over a certain period of time, by maximizing the ability to detect tuna schools and successfully catch detected tuna
(ii) *fishing sets per day* that describes the ability to detect concentrations of tuna schools
(iii) *distance per day* that describes the ability to detect concentrations of tuna schools but also to minimize the “energetic cost” of fishing activities

2.2 Preparation of the data

Logbook data were available for the French and the Spanish purse seine fleets from 1984 to 2014. Such data are generally used in CPUE standardisation analyses at the scale of the fishing set. However, this time scale mainly provides information on the effects of fishers’ tactics, that is to say of their short term decision making (Torres-Irineo et al., 2014). A longer time scale can provide information on the strategies of fishing companies (e.g. their investments in terms of number of purse seiners, number of support vessels, the vessel characteristics or the age of the fleet) and on the strategies of fishers (e.g. the number of active GPS buoys monitoring FOBs) that may have an effect on the efficiency of purse seiners. Logbook data were then used to calculate the efficiency of purse seiners at the scale of the month as the average monthly catch, average number of fishing sets during the month and average distance travelled per fishing day. Only information on the vessels having spent at least 20 days at sea during the month and 100 days at sea during the year was used in the models, to avoid vessels encountering technical problems. Also, one of the Spanish vessels that was known to benefit from the support of an anchored support vessel was eliminated from the dataset.

Information on vessel characteristics were retrieved from IRD and SFA databases. The links between purse seiners and support vessel were obtained through licences of support vessels having operated in Seychelles EEZ from 2003 to 2014 and logbooks of support vessels under the Seychelles flag since. Using this link, a factor variable "support time" was built, with 4 categories of purse seiners:

- 0, if the purse seiner did not have a support vessel
- 1/3 if the purse seiner shared the support vessel with 2 other purse seiners
- 1/2 if the purse seiner shared the support vessel with another purse seiner
- 1 if the purse seiner had its own support vessel

2.3 Individual differences in fishing power

Generalized Linear Models (GLMs) GLMs were used to measure the effects of the purse seiners characteristics (length, carrying capacity, date of construction) and the use of a supply vessel on the efficiency of purse seiners. 3 distinct GLMs were built:

$$GLM1: catch\ rates \sim Year + Month + Year{:}Month + Vessel\ Charact. + Support + \varepsilon\ (Gamma, log\ link)$$

$$GLM2: fishing\ sets \sim Year + Month + Year{:}Month + Vessel\ Charact. + Support + \varepsilon\ (quasipoisson\ log\ link)$$

$$GLM3: distance \sim Year + Month + Year{:}Month + Vessel\ Charact. + Support + \varepsilon\ (Gaussian, log\ link)$$

The variables year, month and the interactions between the month and the year were used to reflect tuna vulnerability and availability to purse seiners and the other variables to measure the effects of the main components of individual purse seiner fishing power on their efficiency. Spatial effects were not included in the models to avoid overfitting due to low numbers of observation. However, as the purse seine fleet is highly seasonal in the Indian (Kaplan et al., 2014; Maufroy et al., 2014), the effect of the month indirectly takes into account the effect of the zone on the efficiency of purse seiners.

Vessel characteristics were described through their length overall (< 72m, 72 to 87 m and > 87m), carrying capacity (<2000 m^3, 2000 to 2700 m^3 and > 2700 m^3) and period of construction (1970s, 1980s, 1990s, 2000s and 2010s). Categorical variables were chosen instead of continuous variables as the effects of vessel characteristics were assumed to be non-continuous processes. As there was a strong correlation between length overall and carrying capacity, only the length overall was included in the models, after ensuring that this variable produced a better fit than the carrying capacity.

Variables were selected in the models through a 'forward/backward' procedure and the most suitable distributions and links used in the GLMs were chosen according to diagnostics plots and information criterion (AIC). GLMs were developed using R *stats* package. To avoid confusions when representing the coefficients of the models, GLMs were fitted with contrasts sum (i.e. the sum of the coefficients was set to 0 instead of using a category as the reference for a given factor variable for which the coefficient would be set to 0) with function *AovSum* of R *FactoMineR* package. To account for unbalanced designs (e.g. only the bigger purse seiners were assisted by support vessels), the Least squares means were computed for each factor with R *lsmeans* package, to analyse the effects of vessel characteristics and the use of support vessels on the efficiency of purse seiners.

2.4. From individual fishing power to indexes of fishing power

The first year of the analysis was used as the reference, as this year most likely corresponds to the lowest fishing power and fishing effort of the period 2003-2014. For a given purse seiner i, the relative fishing power p_i was calculated as the efficiency under constant abundance and vulnerability conditions (Braccini et al., 2012; O'Neill and Leigh, 2007). In the GLMs, the effects of the year, the month and the interaction between the month and the year were used to represent the effects of tropical tuna abundance and vulnerability. Vessel characteristics and the use of support vessels were used to describe individual fishing power of purse seiners. Therefore, p_i was calculated using Eq 1:

$$p_i = L_i + P_i + S_i \quad \text{(Eq 1)}$$

where L_i, P_i and S_i respectively correspond to the estimated effects of the length overall, the the period of construction of the purse seiner and its use of support vessels on the efficiency of purse seiner i when the effects of the abundance and the vulnerability of tropical tunas to purse seining are held constant.

For a given year y, the relative index of fishing power r was estimated using Eq 2:

$$r_y = (\overline{p_\iota})_y / (\overline{p_\iota})_{2003} \quad \text{(Eq 2)}$$

where $(\overline{p_\iota})_y$ corresponds to the average relative fishing power of purse seiners active in the Indian Ocean on year y and $(\overline{p_\iota})_{2003}$ corresponds to the average relative fishing power of purse seiners active in the Indian Ocean during the year of reference 2003.

The same methodology was applied using the 3 GLM models. Results were compared to a simple index based on the evolution of the number of EU purse seiners, relative to the number of EU purse seiners operating in the Indian Ocean in 2003.

3. Results

3.1 Evolution of vessel characteristics: 1984-2014

Over time, the size of purse seiners gradually increased for all European purse seiners (Figure 1). During the 1980s, purse seiners were on average 66.1 meters long (s.d. 8.6). There was as clear shift in the size of vessels during the 2000s and their size reached an average length of 87.8 meters (s.d. 13.6) in recent years. French and Spanish fishing fleets adopted different strategies since the beginning of the fishery in the 1980s, Spanish vessels being larger (83.1 m, s.d. 13.7) than French vessels (70.6 m, s.d. 10.4). Also, the characteristics of French vessels tended to be more homogeneous than those of the Spanish fleet.

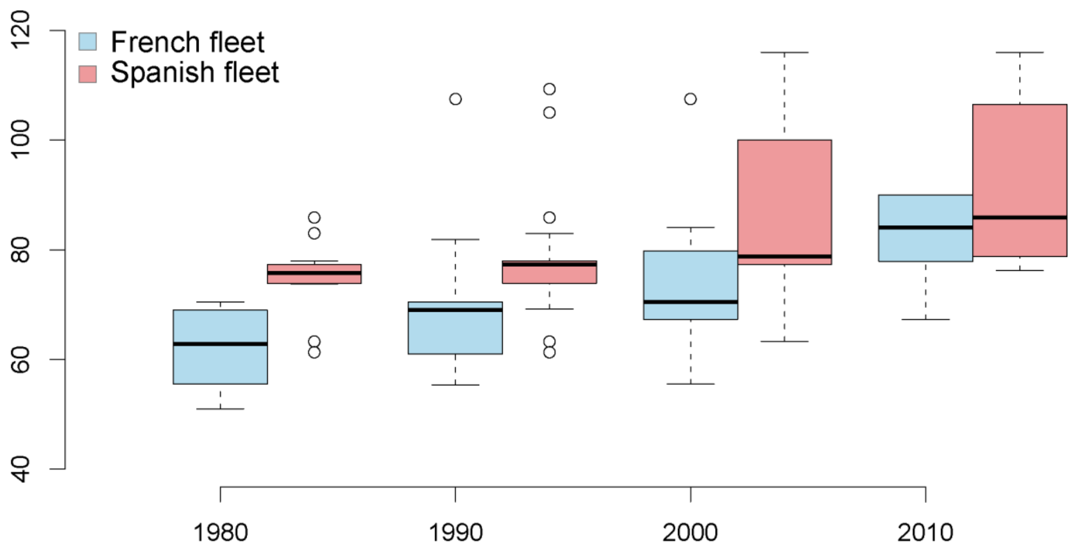

Figure 1: *evolution of the size of UE purse seiners (meters) per decade and per fleet*

The carrying capacity also increased from decade to decade with an average of 1200 m^3 during the 1980s (s.d. 380) and 2000 during the 1990s (s.d. 613), and was highly correlated to the length overall of purse seiners (pearson correlation coefficient of 0.9). The magnitude and range of variation of the capacity of Spanish vessels was on average more important compared to French vessels. Though the evolution of the size of the purse seiners and their storage capacity seemed generally correlated, this was not the case for French vessels in recent years. During the 2010s, a new French fishing company began to operate in the Indian Ocean with a slightly different strategy. As this company produces deep frozen tuna, some of the most recent French purse seiners are fish-processing vessels. Also, only medium and large size purse seiners benefited from support vessels (Figure 2).

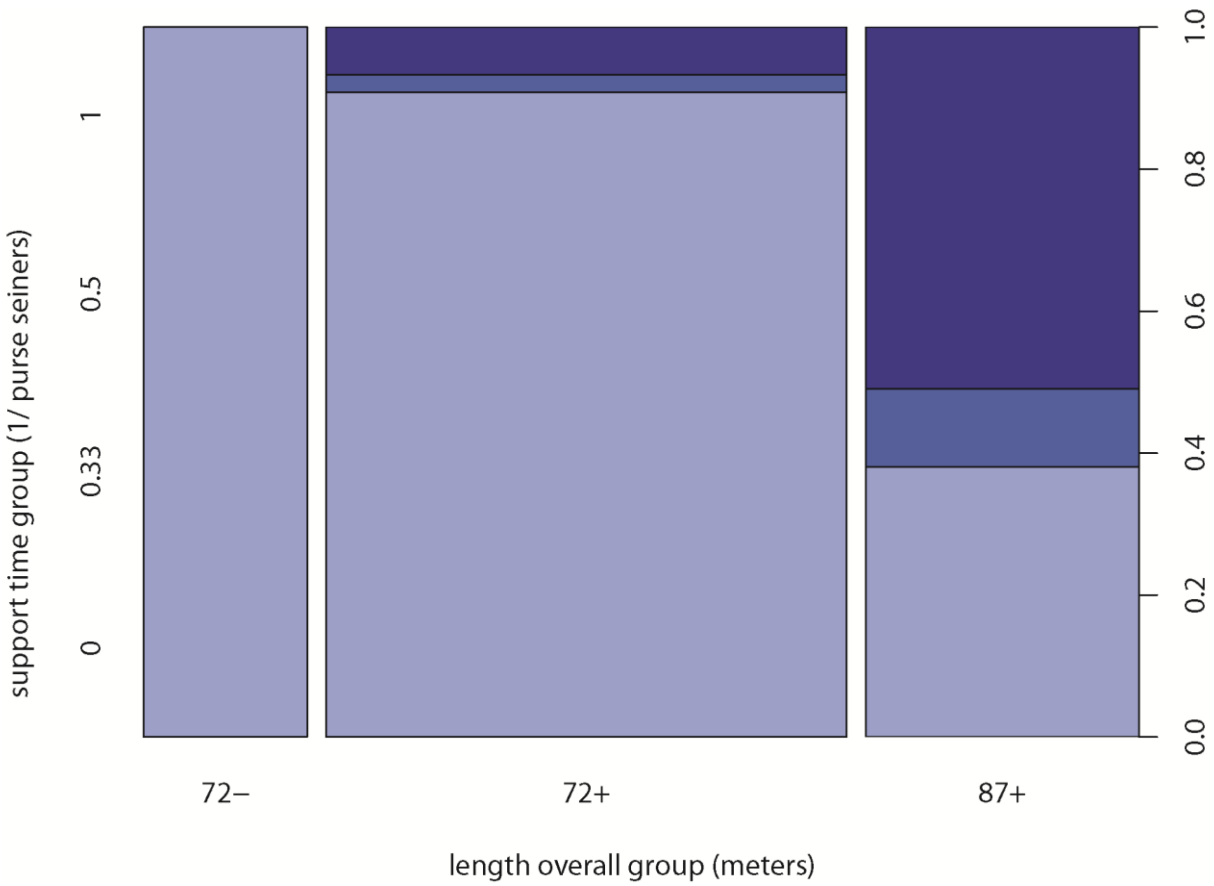

Figure 2: *relationship between the size of purse seiners and their use of support vessels*

3.2. Efficiency of purse seiners

Catch per day

The model GLM1 explained 48.4% of the deviance in catch per day of purse seiners from 2003 to 2014. The effects of the year, the month, the interaction between the month and the year, vessel characteristics (length overall and period of construction) and the use of a support vessel on catch per day were all significant (α=5%, Appendix A). The effects of the abundance and the vulnerability explained 36.3% of the deviance in catch per day while the effects related to the fishing power of purse seiners explained 12.3%. Catch per day increased with the length overall of the vessels, purse seiners of less than 72 meters catching 23.6 tons per day when purse seiners of 82 meters and more caught 29 tons per day, corresponding to an increase of 5.4 tons per day or 23% of the daily catch of purse seiners (Figure 3). Support vessel also contributed to greater catches over 2003-2014. A purse seiner with no support vessel caught an average of 22.2 tons per day, when a purse seiner sharing its support vessel with two other purse seiners caught 4.7 tons more on a daily basis and a purse seiner with its own support vessel caught 9.5 tons more per day, that is to say 44.6% more than purse seiners without a support vessel. Finally, catch per day progressively increased with the period of construction of purse seiners except for the most recent vessels that were built during the 2010s. Purse seiners built during the 1970s caught 27.0 tons per day on average while purse seiners of the 2000s improved these levels of catch by 2 tons (+39.7%). A difference of 8.3 tons per day occurred between purse seiners of the 2000s and purse seiners of the 2010s. The latter purse seiners all corresponded to one of French fishing company, whose strategy was principally based on FSC fishing.

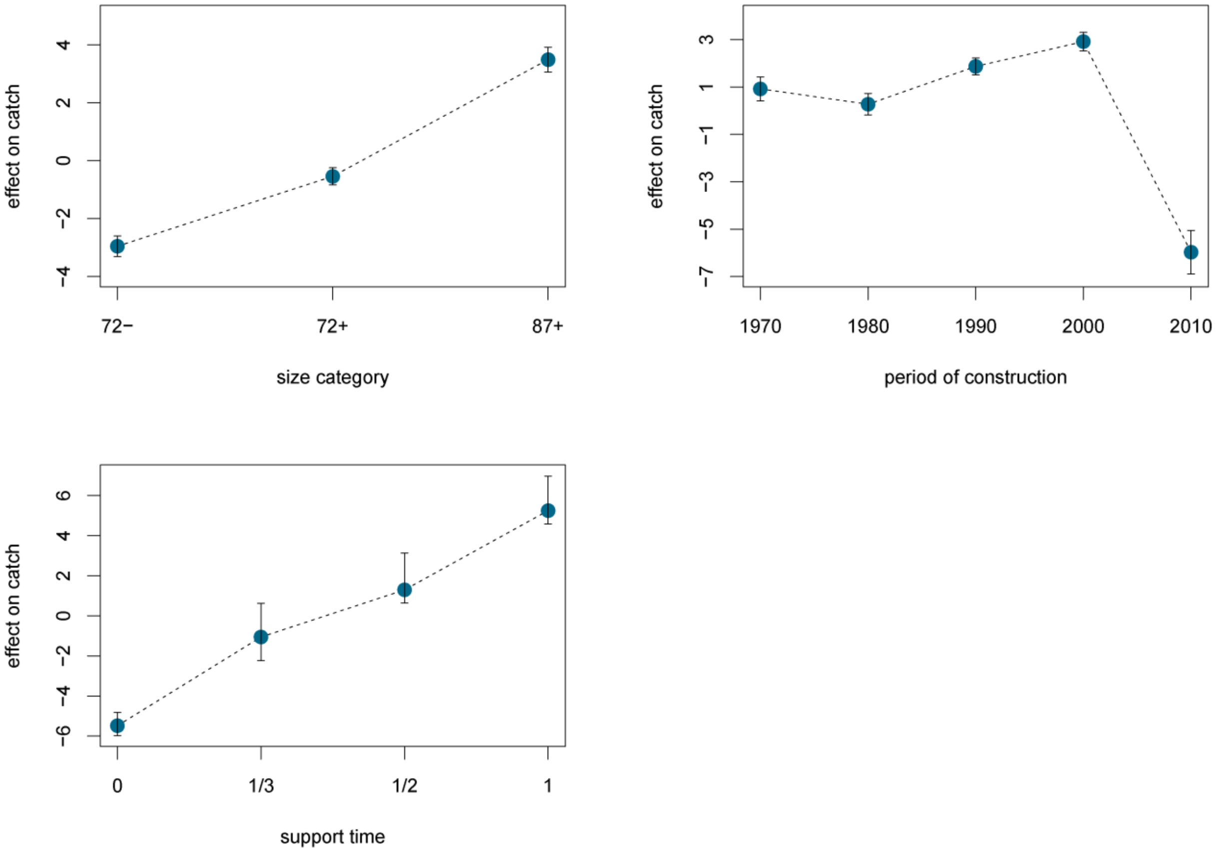

Figure 3: *effects of the size category, period of construction and support vessels on the daily catch per day of purse seiners over 2003-2014 (model GLM1)*

Fishing sets per day

The model GLM2 explained 38.9% of the deviance of the fishing sets per day of purse seiners from 2003 to 2014. The effects of the abundance and the vulnerability explained 28.4% of the deviance in fishing sets per day while the effects related to the fishing power of purse seiners explained 10.4%. The effects of vessel size, vessel capacity, period of construction and support vessel time on the fishing sets per day were all significant (Appendix B). Similarly to catch per day, the number of fishing sets per day increased with the size of purse seiners. Purse seiners of 87 meters and more realized 0.68 fishing sets per month (20.4 fishing sets per month) when smallest purse seiners realized 0.65 fishing sets per day, representing an increase of 5.2%%. Again, except for the most recent purse seiners adopting a FSC strategy, the most recent purse seiners improved their efficiency with a difference of 0.1 fishing sets per month (+21.4%) between the purse seiners built during the 1970s and those built during the 2000s. On average, purse seiners of the 2010s realized 25.7% less fishing sets per month than the more efficient purse seiners of the 2000s. Benefiting from a support vessel also increased the number fishing sets per day, with a difference of 0.12 fishing sets per day (+20%) between vessels with no support vessel and purse seiners having their own support vessel (supply time =1), though purse seiners sharing their support vessels with 2 other purse seiners tended to be the least efficient (-4.9% fishing sets per day compared to supply time =0), probably due to a competition between purse seiners.

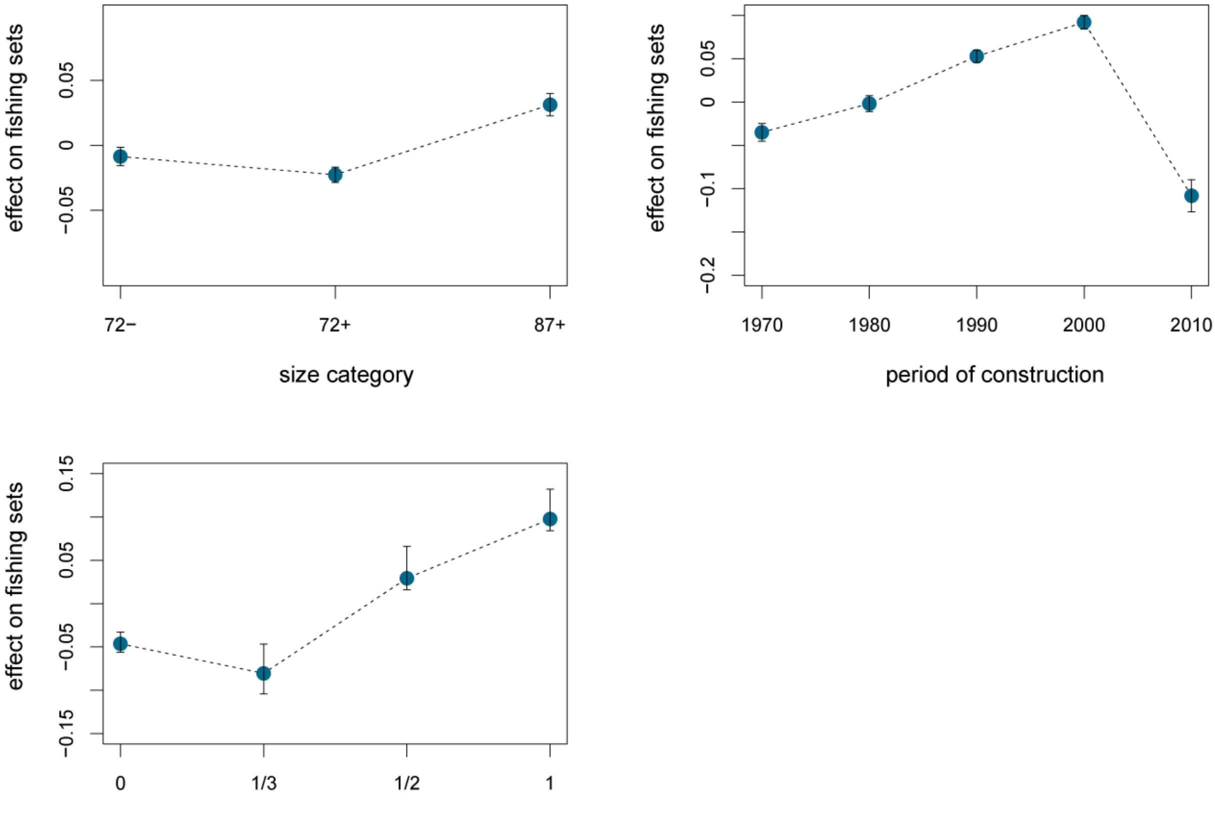

Figure 4: *effects of the size of purse seiners, period of construction and support vessels on the daily number of fishing sets over 2003-2014 (model GLM2)*

Distance per day

The model GLM3 explained 40.8% of the deviance of the distance per day of purse seiners from 2003 to 2014. The effects of the abundance and the vulnerability explained 25.2% of the deviance in distance per day while the effects related to the fishing power of purse seiners explained 15.6%. Travelled distance increased with the size of purse seiners, the smallest purse seiners travelling on average 204.0 km per day when the largest purse seiners travelled 272 km (+33.4%). Faster and larger purse seiners were therefore able to increase their search areas, suggesting that such purse seiners were more efficient in terms of exploration of the Indian Ocean. At the same time, the distance decreased with the age of the vessels. Purse seiners of the 2010s were the most efficient at reducing the distance per day, with 71.3 km less travelled on a daily basis, compared to purse seiners of the 1970s. The most recent vessels were therefore less efficient in terms of the surface the explored per day but more efficient at reducing the cost of their fishing activities in terms of fuel consumption. Finally, the distance increased for purse seiners with a support vessel. Purse seiners with no support vessel travelled 10.3 km (-4.5%) less than purse seiners having their own support vessel. Differences between purse seiners with a support vessel were relatively small with daily distance ranging from 236.4 to 239.3 km, with even a small decrease for purse seiners having their own support vessel. As support vessels contribute to purse seiners' searching activities and allow purse seiners having greater numbers of dFADs, this suggests that purse seiners benefiting from a support vessel travelled longer distances to visit FOBs and zones of presence of presence of FSC, reported by purse seiners or detected with echosounder buoy-equipped FOBs, but could also avoid visiting some FOBs without aggregated tuna.

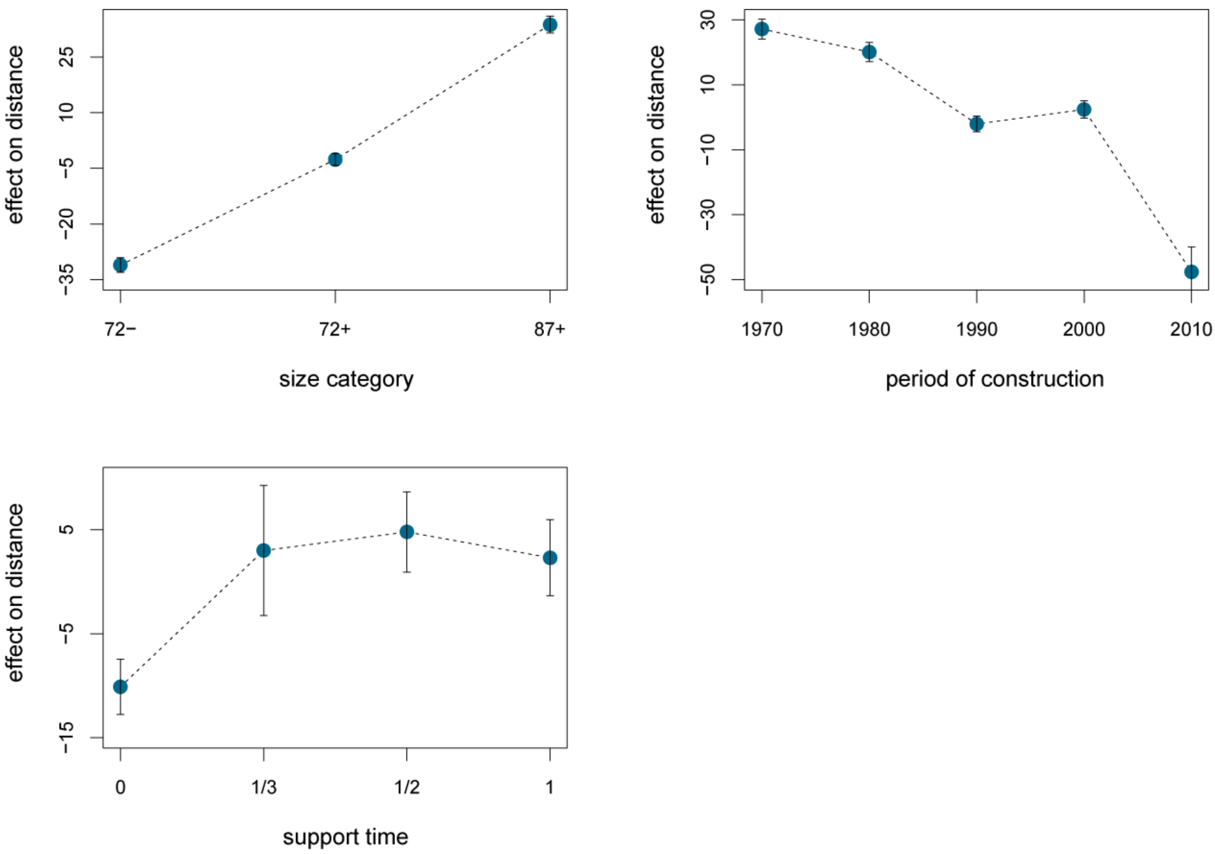

Figure 5: *effects of size of purse seiners, period of construction and support vessels on the distance per day over 2003-2014 (model GLM3)*

3.3 Relative indexes of fishing power

From 2003 to 2014, the number of EU purse seiners varied between a minimal number of 26 purse seiners in 2010 and 2011 and a maximum of 40 purse seiners. The number of purse seiners increased over 2003-2007 and decreased after 2008. Due the piracy some vessels left the Indian Ocean for the safer Atlantic Ocean (Chassot et al., 2010). This very simple index of fishing effort tends to indicate that the fishing effort of purse seiners has been reduced from a factor 0.68 that is to say reduced from 32.5% between 2007 and 2014. Relative indexes of fishing power based on catch per day, fishing sets per day and distance per day provided a different point of view on the recent evolution of the purse seine fishery (Figure 6). Over 2003-2014, indexes of fishing power derived from GLMs continuously increased. The index of fishing power based on catch per day increased of 172.4% during this period, while the index based on the number of fishing sets increased of 95% and the index based on distance increased of 115%. Indexes based on daily catch and number of fishing sets per day had very similar trends though the index derived from on catch per day increased faster than the index derived from the number of fishing sets per day. The index based on the distance had a slightly different evolution, following the index based on fishing sets per day until 2008 and increasing faster in 2008 to follow the index based on catch.

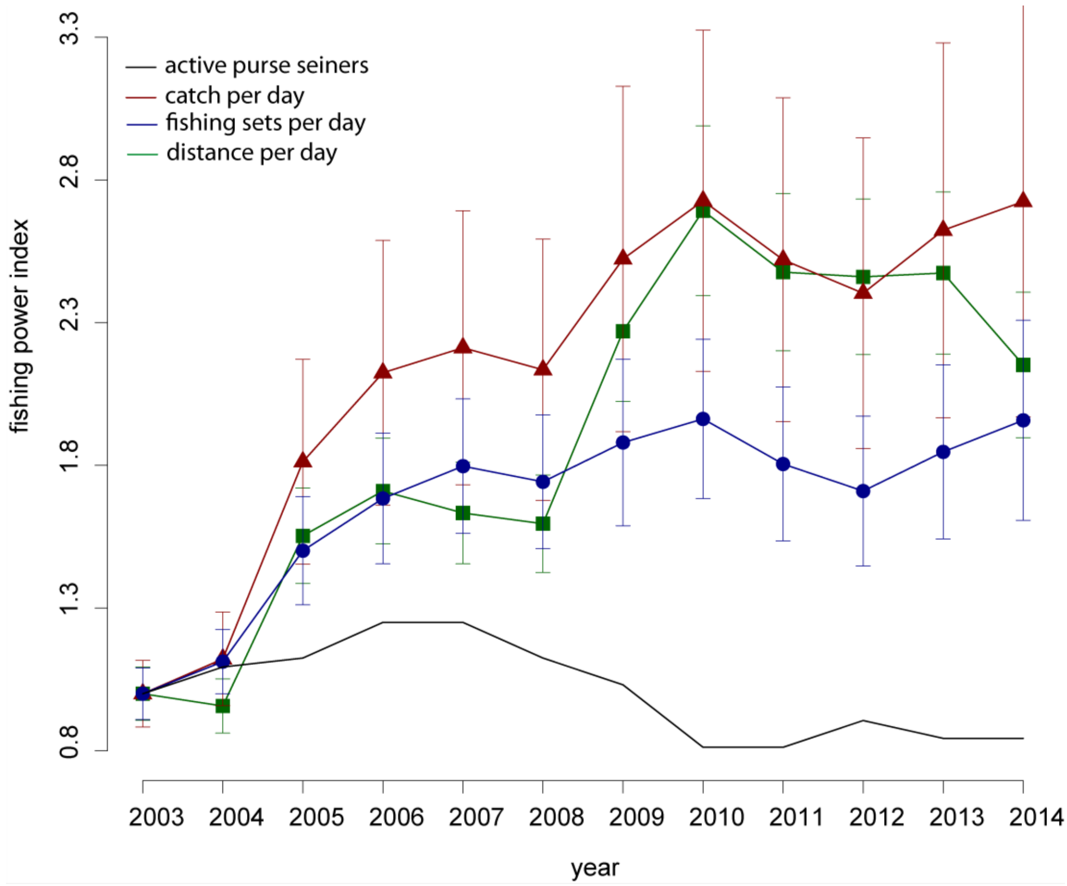

Figure 6: *relative indexes of fishing effort based on the number of purse seiners, catch per day, fishing sets per day and distance between fishing sets.*

Discussion

Here, three dimensions of the efficiency of EU purse seiners (catch per day, fishing sets per day and distance per day) were analysed with GLMs to assess the evolution of their fishing power over 2003-2014. These dimensions were chosen to represent the ability of purse seiners to optimize their catch, their detection of tuna schools and the surface covered by searching activities. The GLMs were built with a common form:

$$GLM\colon efficiency \sim Year + Month + Year\colon Month + Vessel\ Charact. + Support + \varepsilon$$

where the effects of the year, the month and the interaction between these two variables were used to represent the evolution of tropical tuna abundance and while the characteristics of the purse seiners and their use of support vessels were used to reflect changes of individual fishing power of purse seiners. A similar approach is generally adopted when standardizing CPUEs, except that the objective of CPUE standardization is to standardize CPUEs with respect to the effect of individual fishing power of purse seiners (e.g. Katara et al 2014). Our objective here was the opposite as we aimed at standardizing purse seiner efficiency with respect to the effects of tropical tuna abundance.

The 3 GLMs explained from 38.9% to 48.4% of the total deviance in the different measures of efficiency of purse seiners. To avoid high levels of variability of efficiency at the scale of fishing sets (effects of the tactics of purse seiners, Torres-Irineo et al., 2014), the choice was made to analyse average daily catches, average daily number of fishing sets and average distance per day which may explain these relatively high levels of deviance explained by the models. Also, the choice was made not to include spatial effects, which may also have contributed to these high levels of deviance explained by these simple models. However, some improvements of the models may be necessary, such as the inclusion of a skipper effect or a Floating Object use (FOB) effect. In recent years, the use of FOBs was almost multiplied by 5 in the Indian Ocean (Maufroy et al. 2014). This certainly contributed to an increase of the fishing power of purse seiners. For future analyses, detailed positions of GPS buoys used by French purse seiners are available and quarterly declarations of FOB use by EU purse seiners may be used. In the present study, this effect should be partially captured by the effect of support vessels that contributed to an increase of 44.6% of the catch per day, 20.0% of the number of fishing sets per day and 4.5% of the distance travelled per day. Part of the effect of FOB could also have been captured in the effects of the length overall and carrying capacity of the purse seiners, as larger vessels may require on higher number of FOBs to reach profitability.

In the 3 models, the largest and most recent purse seiners and those benefiting from a support vessel were the most efficient, with some exceptions due to some particular strategies. For example, purse seiners built during the 2010s all belong to the same fishing company aiming at producing tuna of higher quality rather than high volumes of catch, resulting in lower levels of catch, number of fishing sets and distance per day, in relation to a greater proportion of activities on FSC. Among variables related to individual fishing power of purse seiners, the length overall of purse seiners explained the highest levels of deviance (Appendices A, B, C) but the use of support vessels (GLM1), the period of construction of the purse seiners (GLM2) and their carrying capacity (GLM3) also explained a relatively important proportion of the deviance in the efficiency of purse seiners. As a consequence, additional information such as the number of support vessels used by the purse seine fleet may be necessary in the documents reported annually by EU fleets to the IOTC, as this information is not provided yet (e.g. Chassot et al. 2014).

The results of the GLMs were used to build relative indexes of fishing power. Assessing the changes in fishing power generally requires the use of a reference category of vessels with a stable catchability over time (Marchal et al., 2002). In the case of tropical tuna purse seiners, such a category cannot be identified, as purse seiners benefited from continuous improvement of onboard technologies (Lopez et al., 2014; Torres-Irineo et al., 2014, Gaertner and Pallares 2002) and continuously increased their use of GPS buoys and dFADs (Maufroy et al. 2014). Instead, the relative values of the indexes of fishing power were obtained by using the first year of the analysis as the reference year (Braccini et al., 2012; O'Neill and Leigh, 2007). Comparing the indices of fishing power to the evolution of the number of purse seiners active in the Indian Ocean from 2003-2014 indicated that using the number of purse seiners as a measure of nominal fishing effort was inappropriate for the EU purse seine fleet due to fishing power creep. Though preliminary, our results indicate that the main components of fishing power should be taken into account when measuring the fishing effort of tropical tuna purse seiners in the Indian Ocean. Depending on the index of fishing power, an increase of 95.8% to 172.4% occurred. Indexes based on catch per day and fishing sets per day gradually increased over the study period, except in 2008 when some purse seiners left the Indian Ocean due to piracy (Chassot et al., 2010). These common trends indicate that catch per day and fishing sets per day evolved similarly over 2003-2013, higher number of fishing sets generating higher catches. Future analyses will be carried on the average catch per fishing set to confirm these results.

The index based on the distance travelled by purse seiners did not exactly provide the same information as the two other indexes of fishing power. This index is the most complicated, as it provided two opposite images of the purse seine fleet. Indeed, a purse seiner would be more efficient in terms of catch when the distance travelled per day increases, as increasing the distance allows exploring wider areas, though we cannot reject the assumption that the aid brought by a supply could reduce also the number of FAD visits. However, a purse seiner would also be less efficient in terms of fuel consumption when travelling higher distances. The index followed the index based on fishing sets per day until 2008 and increasing faster in 2008 to follow the index based on catch. From 2008 to 2014, due to piracy, purse seiners probably had to modify their searching strategies which may have resulted in higher travelled distance.

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Appendix A: Details on the model GLM1 (catch per day)

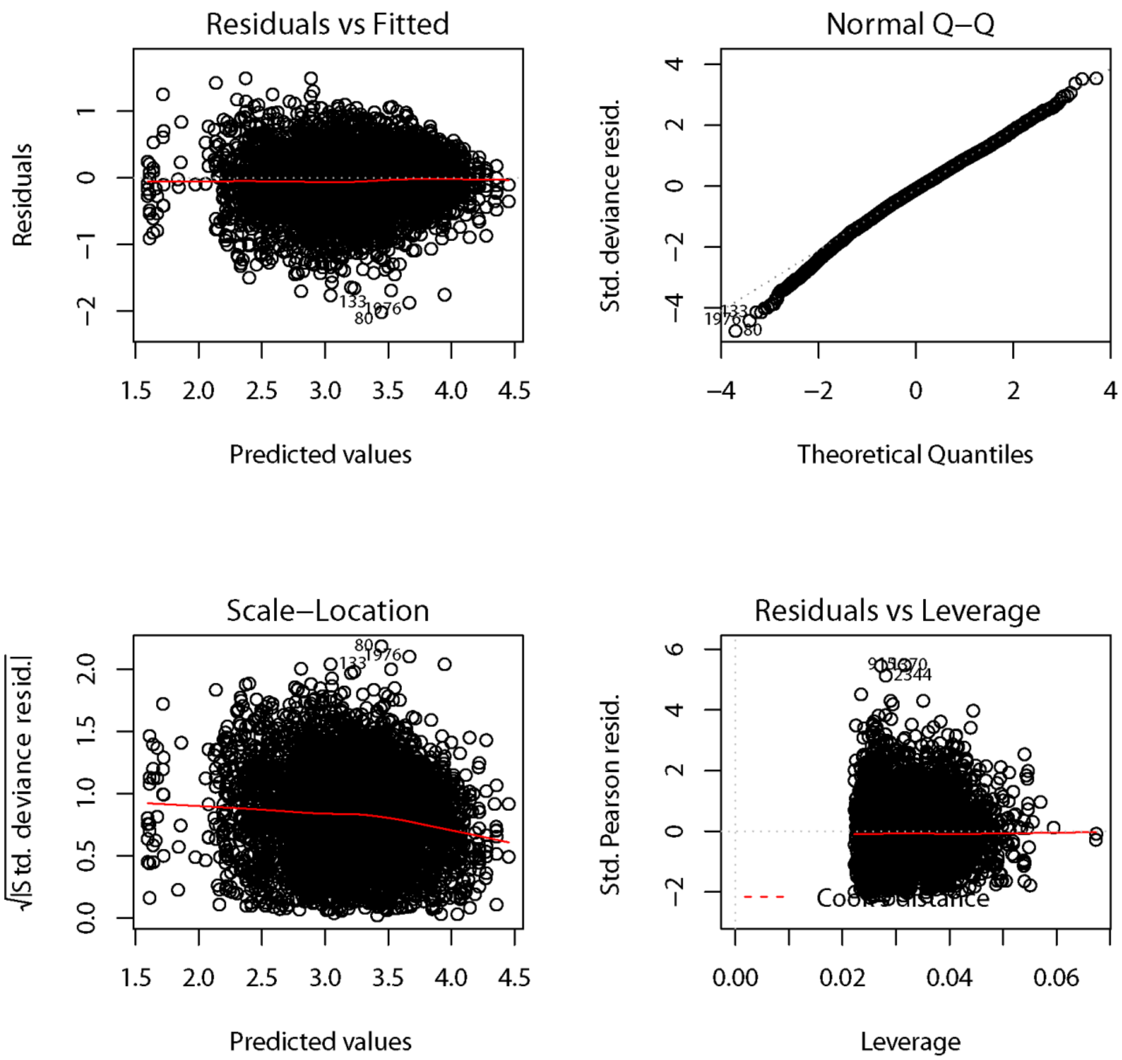

Figure A1-a: *diagnostic plots of model GLM1*

```
Model: Gamma, link: log

Response: catch_per_day + 1

Terms added sequentially (first to last)


             Df Deviance Resid. Df Resid. Dev
NULL                          4787    1865.82
year         11  147.947      4776    1717.87
month        11  237.899      4765    1479.97
loa_group     2  138.102      4763    1341.87
init_group    4   50.478      4759    1291.39
supply_time   3   37.762      4756    1253.63
year:month  121  291.787      4635     961.84
```

Figure A1-b: *analysis of deviance table for the model GLM1*

Appendix B: Details on the model GLM2 (fishing sets per day)

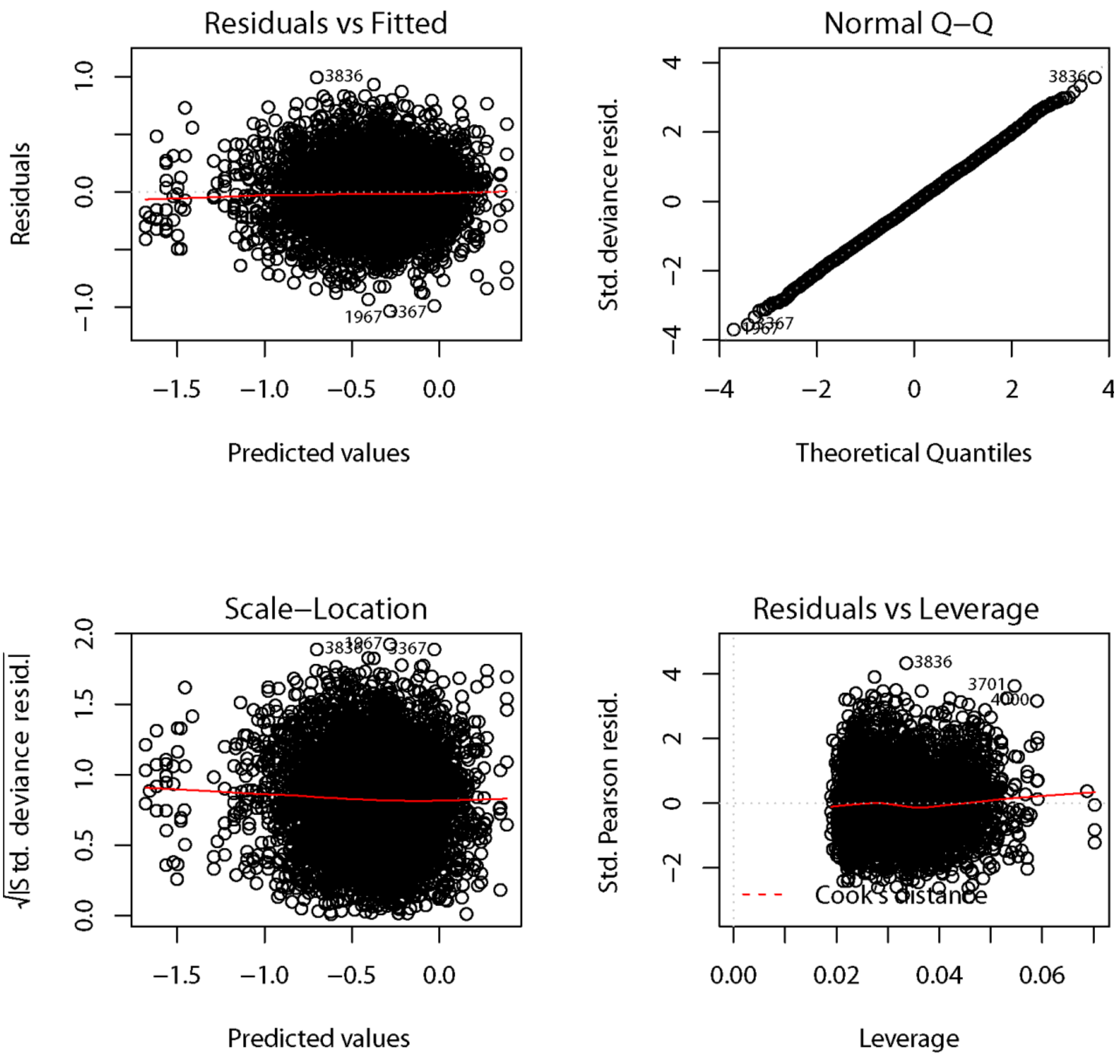

Figure B1-a: *diagnostic plots of model GLM2*

Model: quasipoisson, link: log

Response: sets_per_day

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev
NULL			4787	621.57
year	11	39.852	4776	581.72
month	11	62.702	4765	519.01
loa_group	2	32.583	4763	486.43
init_group	4	26.649	4759	459.78
supply_time	3	6.445	4756	453.34
year:month	121	73.683	4635	379.65

Figure B1-b: *analysis of deviance table for the model GLM2*

Appendix C: Details on the model GLM3 (distance per day)

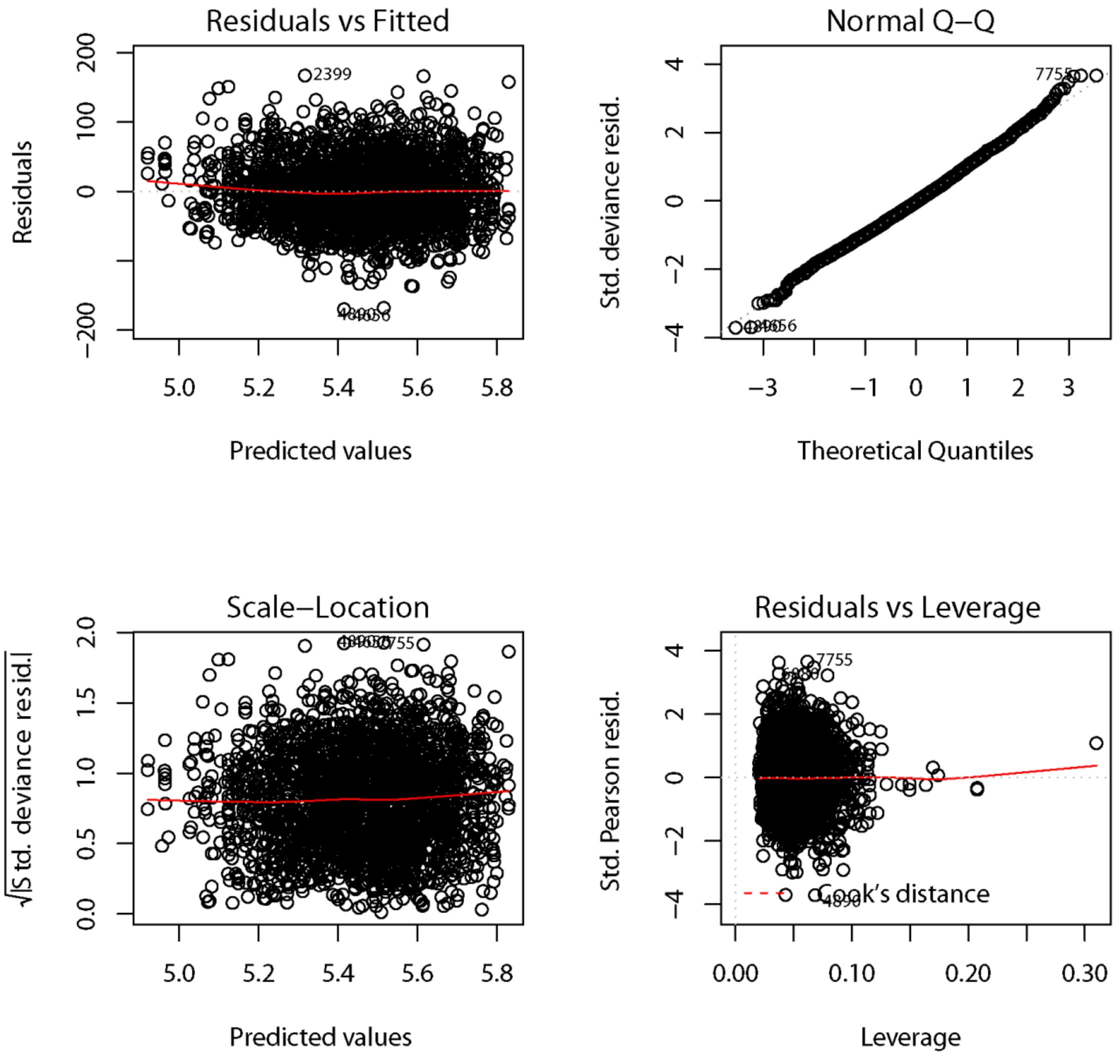

Figure C1-a: *diagnostic plots of model GLM2*

```
Model: gaussian, link: log

Response: distance_per_day

Terms added sequentially (first to last)


             Df Deviance Resid. Df Resid. Dev
NULL                          2531    9027892
year          9   303278      2522    8724614
month        11   721405      2511    8003209
loa_group     2  1003390      2509    6999819
init_group    4   371963      2505    6627856
supply_time   3    33566      2502    6594289
year:month   99  1252748      2403    5341542
```

Figure C1-b: *analysis of deviance table for the model GLM3*