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

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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 purse seiners' characteristics (length, the size of the wells, period of construction) and their use of support vessels on the efficiency of purse seiners are analyzed with GLM models. 3 dimensions of the efficiency of purse seiners are analyzed: monthly catch rates, monthly frequency of fishing sets and monthly distance of fishing sets. Among others, we find that support vessels contribute to an increase in catch rates (+10 tons per day) and in distance between fishing set. In a second steps, the results of the GLM models 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

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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 communauty 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 rates* that describe 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) *number of fishing sets* that describe the ability to detect concentrations of tuna schools

(iii) *traveled distance* 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 the 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 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, size of the wells, date of construction) and the use of a supply vessel on the efficiency of purse seiners. 3 distinct GLMs were built:

GLM1 *catch rates + 1 ~ Year + Month + Year:Month + Vessel Characteristics + Supply + ε*
(Gamma, log link)

GLM2 *fishing sets freq ~ Year + Month + Year:Month + Vessel Characteristics + Supply + ε*
(quasipoisson, log link)

GLM3 *~ Year + Month + Year:Month + Vessel Characteristics + Supply + ε*
(gaussian, identity 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 3 categorical variables:
- length overall (< 80m, 80 to 90 m and > 90m)

- size of the wells (<1250 m^3, 1250 to 1850 m^3 and >1850 m^3)
- 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.
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* and *FactoMineR* packages. In order to use the coefficients for the calculations of fishing effort indexes, 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).

3.4. From individual fishing power to a measure of fishing effort

The 3 GLM models were used to build individual indexes of fishing effort for each purse seiner and each year as following:

$$Relative\ effort_i = Length_i + Capacity_i + Age_i + Support_i$$

where each component of fishing effort correspond to individual values of the effects of the vessel characteristics and their use of a supply vessel in the GLMs.

Using each GLM model, a relative index of fishing effort was obtained by summing individual measures of relative fishing effort. The 3 relative indexes of fishing effort were then rescaled to 1-2 for comparison purposes. This arbitrarily scale was chosen to avoid misinterpretation of the results, by avoiding negative or null values. They were compared to the number of EU purse seiners over 2003-2014, the most simple indicator reported every year to the IOTC by EU fleets.

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.

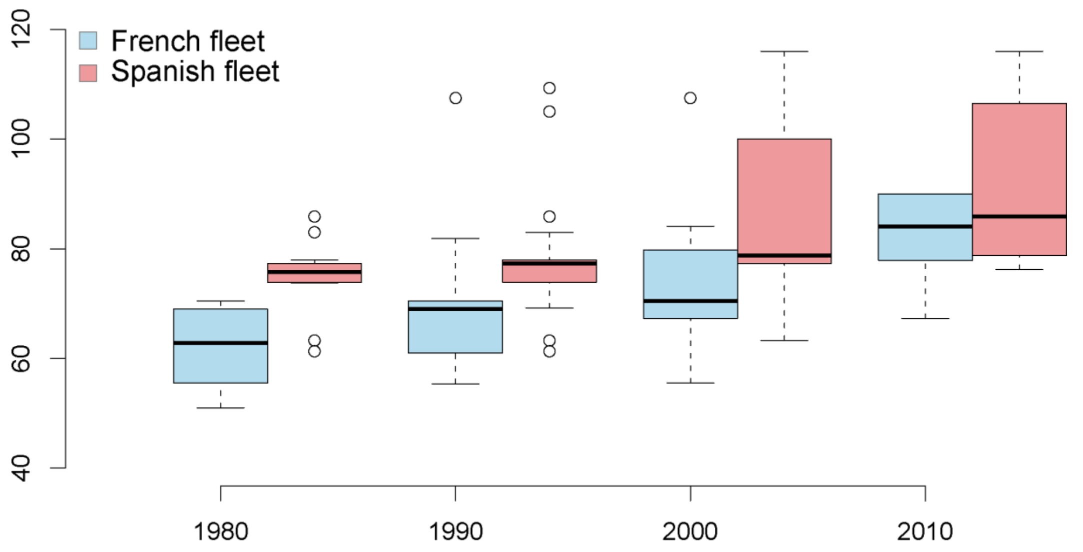

Figure 1: *evolution of the size of UE purse seiners (meters) per decade and per fleet*

The size of wells 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). The capacity of Spanish vessels was on average more important and more variable than the capacity of French vessels (Figure 2). Though the evolution of the size of the vessels 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. To deal with this new category of vessels, both the effect of the size and of the storage capacity of purse seiners were used explanatory variables in the models.

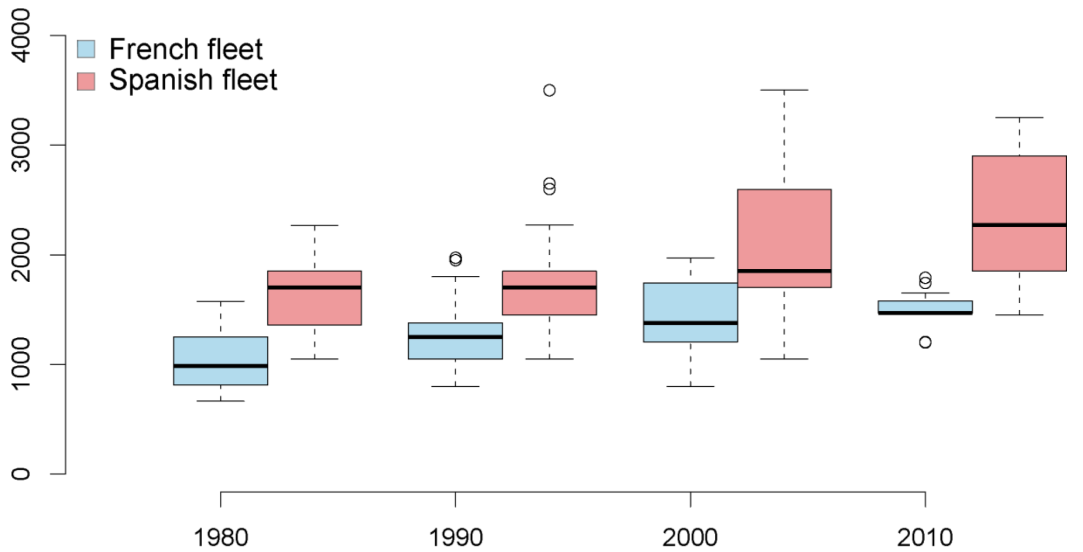

Figure 2: *evolution of the capacity of UE purse seiners (size of wells in m^3) per decade and per fleet*

3.2. Efficiency of purse seiners

Catch Rates

The model GLM1 explained 61% of the deviance in the catch rates of purse seiners from 2003 to 2014. The effects of the year, the month, the interaction between the month and the year, the vessel characteristics and the use of a support vessel on catch rates were all significant (α=5%). Catch rates increase with the length overall of the vessels, purse seiners of length 80 meters catching 3.7 tons per day less than purse seiners of 90 meters and more. They also increased with the size of the wells, vessels with a capacity of 1850 m^3 and more catching 3.3 tons per day more than the smaller purse seiners (less than 1250 m^3). The conclusion could be drawn for the effect of support vessels as purse seiners benefiting from a support vessel had improved catch rates. Sharing a supply vessel with two other purse seiners improved catch rates of 2.7 tons per day (as compared with purse seiners with no support vessel) and befitting from a “full time” support vessel allowed to increase catch rates of 10.4 tons per day over 2003-2014. Finally, catch rates progressively increase with the period of construction of purse seiners except for the most recent vessels that were built during the 2010s. These vessels mainly correspond to the French fishing company whose strategy was mainly a FSC strategy until recently.

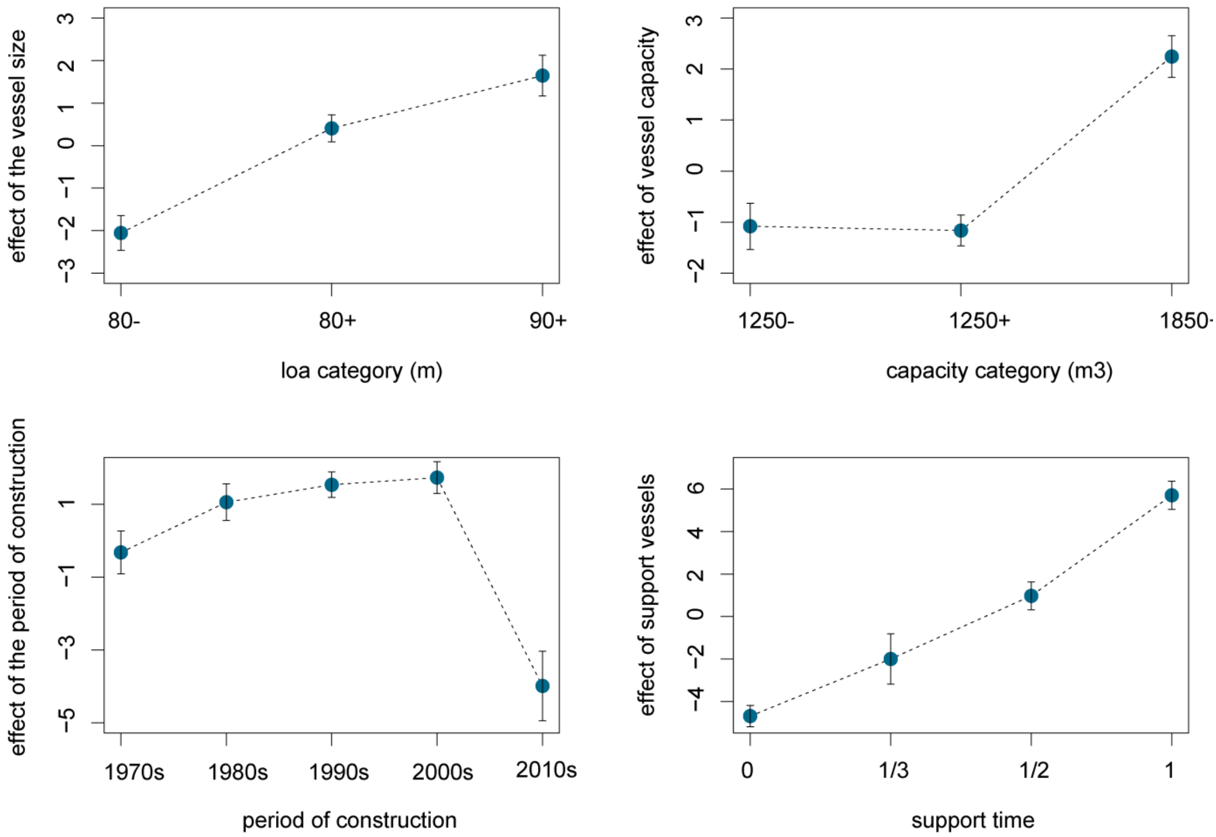

Figure 3: *effects of the length overall (loa), size of the wells (capacity), period of construction and supply vessels on the daily catch rates of purse seiners over 2003-2014 (model GLM1)*

Frequency of fishing sets

The model GLM2 explained 39.1% of the deviance of the frequency of fishing sets of purse seiners from 2003 to 2014. Overall, the effects of vessel size, vessel capacity, period of construction and support vessel time on the frequency of fishing sets were small. They were converted to the scale of the month (30 days) to facilitate interpretation. Similarly to catch rates, the frequency of fishing sets increased with the size of purse seiners, though the effects were not as important as those observed on catch rates. Purse seiners of 90 meters and more realized 1.8 fishing sets per month than the smallest category of purse seiners. Contrary to what was expected, the frequency of catch rates slightly decreased with the size of the wells, with a difference of 1.3 fishing sets per month between vessels of less than 1250 m^3 and vessels of 1250 m^3 to 1850m^3. Again, except for the most recent vessels adopting a FSC strategy, the most recent vessels improved their frequency of fishing sets from 3.6 fishing sets per month between vessels built during the 1970s and those built during the 2000s. Benefiting from a support vessel also increased the frequency of fishing sets, with a difference of 4.4 fishing sets per month between vessels with no support vessel and vessel having a “full time” support vessel, though purse seiners sharing their support vessels with 2 other purse seiners tended to be the least efficient.

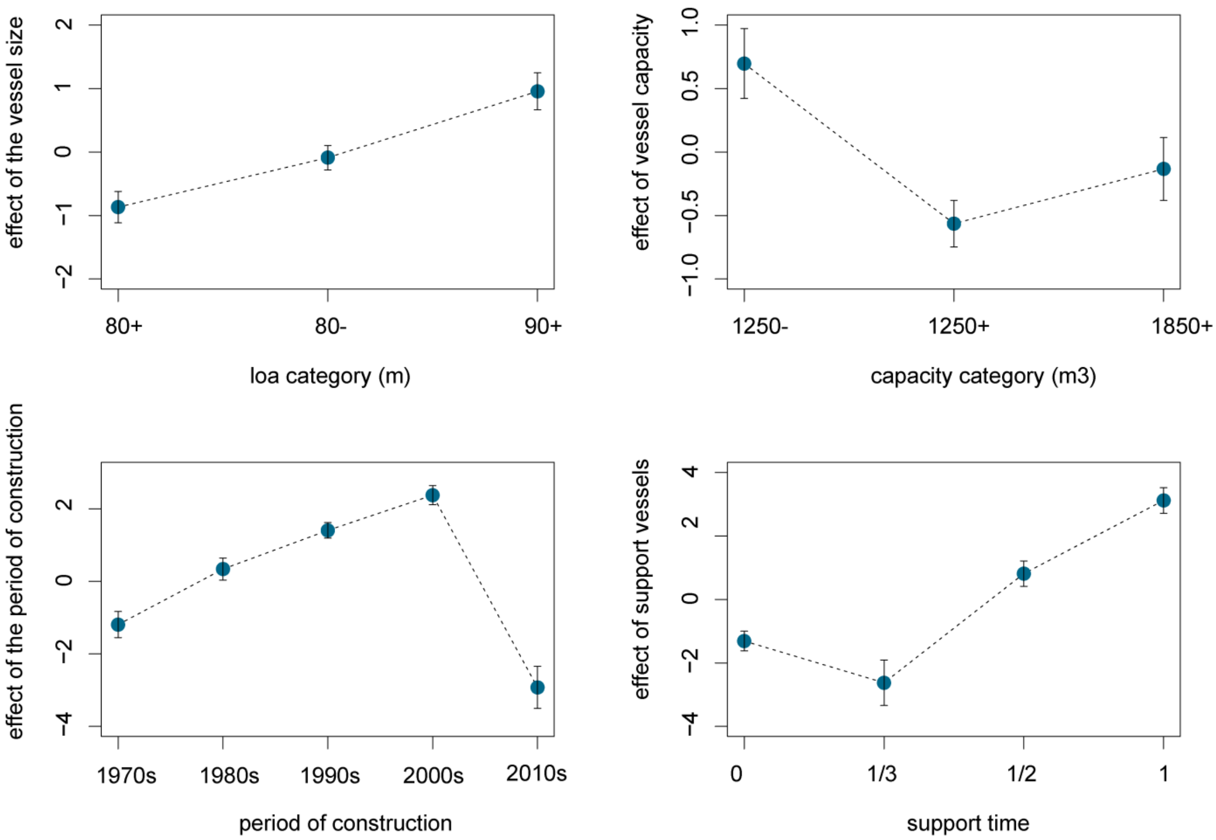

Figure 4: *effects of the length overall (loa), size of the wells (capacity), period of construction and supply vessels on the monthly frequency of fishing sets over 2003-2014 (model GLM2)*

Distance beetwen consecutive fishing sets

The model GLM3 explained 41.4% of the deviance of the distance between consecutive fishing sets of purse seiners from 2003 to 2014. The distance between consecutive fishing sets increased with the length overall of purse seiners. On a daily basis, vessels of 90 meters and more travelled 39.8 km more than the vessels of less than 80 meters. The distance also increased with the size of the wells, with 28.7 km more per day at sea for the vessels of 1850 m^3 and more. Faster and bigger purse seiners were therefore able to increase their search areas, suggesting that such purse seiners were more efficient in terms of exploration. At the same time, the distance decreased with the age of the vessels. Vessels of the 2010s were the most efficient at reducing the distance between consecutive fishing sets, with 71 km less travelled on a daily basis, compared to vessels of the 1970s. This suggests that the most recent vessels are more efficient at rapidly detecting tuna schools without having to change of search area. Finally, the distance increased with the support time. Purse seiners with no support vessel travelled 13.4 km less than purse seiners having their own support vessel. As support vessel 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.

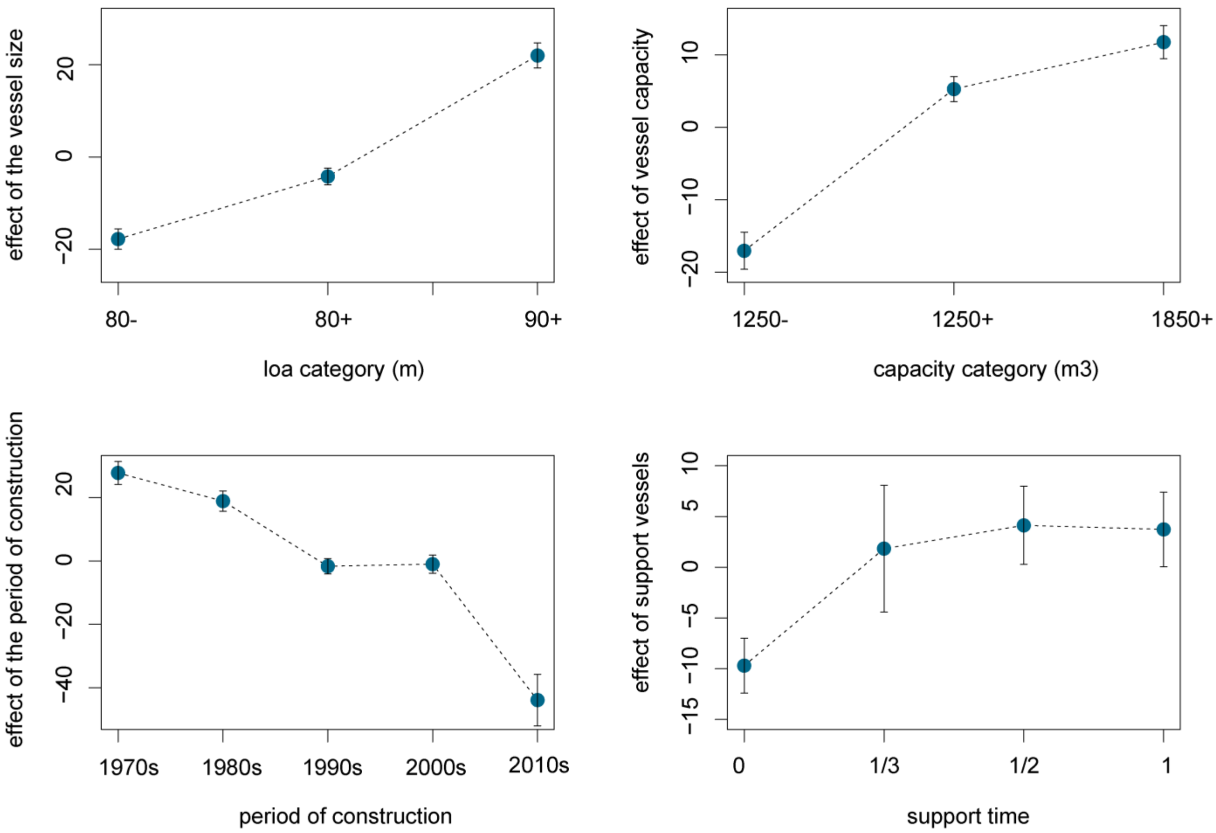

Figure 5: *effects of the length overall (loa), size of the wells (capacity), period of construction and supply vessels on the monthly frequency of fishing sets over 2003-2014 (model GLM3)*

3.3 Relative indexes of fishing effort

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 threat some vessels indeed 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 decreased since 2008, while all other indexes provide a different vision of the evolution of the purse seine fishery over 2003-2014.

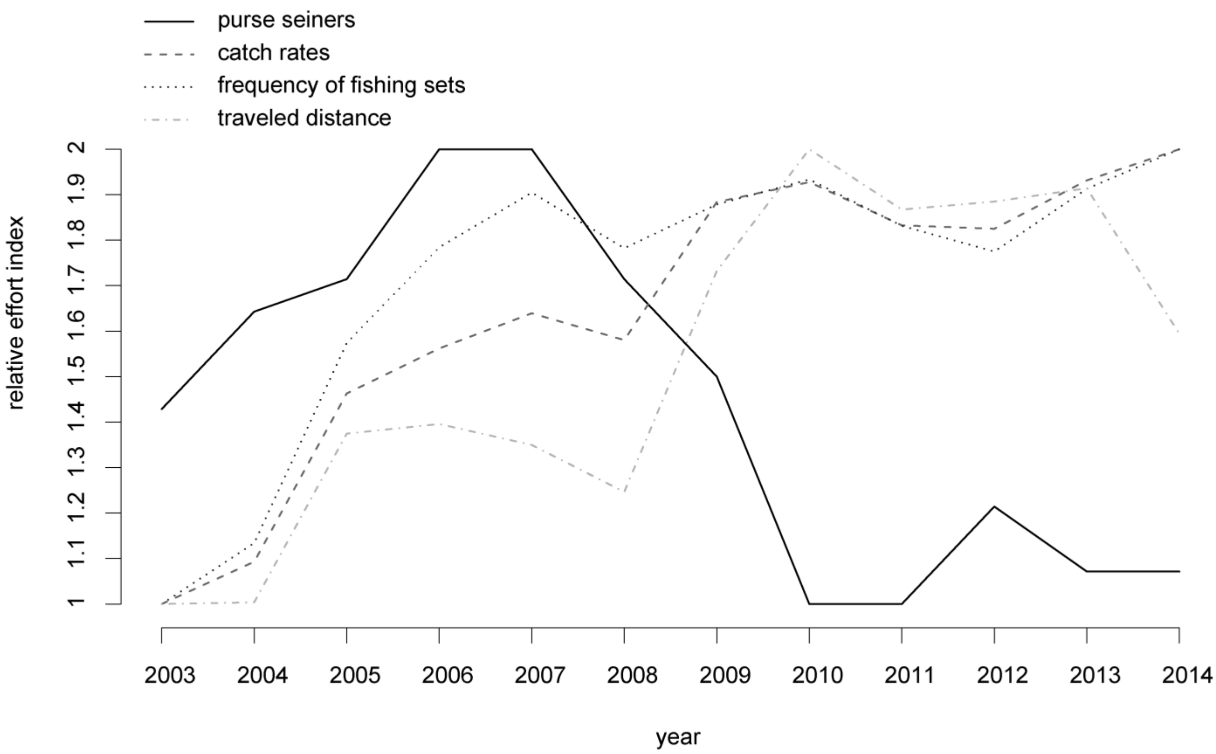

Figure 6: *relative indexes of fishing effort based on the number of purse seiners, catch rates, frequency of fishing sets and distance between fishing sets.*

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