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STANDARDIZED CATCH RATES FOR YELLOWFIN (*Thunnus albacares*) AND SKIPJACK (*Katsuwonus pelamis*) FOR THE EUROPEAN PURSE SEINE FLEET OF THE INDIAN OCEAN, 1984-2007.

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ABSTRACT

Standardized yellowfin and skipjack catch rates of the European purse seine fleets in the Indian ocean from 1984 to 2007 using generalized linear models are presented. Different indexes based on logbooks data for the yellowfin free school catch and yellowfin and skipjack FAD catch have been standardized considering time-space strata, vessel category, as well as environmental effects as explicative variables.

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1. Introduction

Purse seine (PS) fishing in the Indian Ocean was initiated in the late 1970s by several experimental cruises organised by Japan, Mauritius, and France. By the end of 1983, notably after the successful French surveys that covered 20 months, it became obvious that tuna resources of the West Indian Ocean could be successfully exploited with the PS technique. Then the number of purse seiners increased dramatically from December 1983 (10 vessels) to May (35 vessels), and December 1984 (45 vessels). Since then, the total fleet showed a marginal increase in numbers, with 53 vessels in 2007 (Pianet et al. 2008). The PS fleet considered in this paper is made of European vessels *sensu stricto* (French and Spanish vessels) and other vessels flying non-European flags but working in close conjunction with European seiners and using the same fishing strategies.

Standardized catch rates or catch per unit of effort (CPUE) are generally used to approximate stock abundance. In the Indian Ocean, longline-derived indices are traditionally used for yellowfin (*Thunnus albacares;* YFT) stock assessment. The longline (LL) fishery exploits only the adult fraction of the stock, whereas the PS fishery exploits a large size/age span, from juveniles aggregated on fishing aggregating devices (FADs) to adults of similar sizes as those taken by the LL, on free schools (FSC). This particularity is the cause of some difficulty to use the PS data in the generalized linear model (GLM) standardization procedure, and it is necessary to discriminate between the fishing mode and consider spatial and temporal patterns related to the species life cycle. Another difficulty is due to the increase in fishing power of the PS fleets, a composite factor that is not well tackled and generally biases CPUE trends. Indeed, few papers on PS catch rates standardization have been presented at the IOTC working parties, the latest one being Soto et al (2005) for YFT. Regarding skipjack (*Katsuwonus pelamis*; SKJ), the other major species taken by the PS, there was no previous attempt to standardize catch rates using GLMs.

In the present analysis, several statistical models based on different datasets and fishing efforts were used to standardize catch rates of SKJ and YFT caught by the European PS fishing fleet, including consideration to the environment. Including environmental covariates for PS CPUE standardization is a first attempt in the Indian Ocean, to account for potential effects of changes in catchability related to changes in environmental conditions. The main objectives were to: i) define a standard protocol for standardizing PS CPUE in the case of free and FAD-associated school fishing, ii) assess the environmental effects on PS CPUE, and iii) estimate CPUE time series for SKJ and YFT during 1984-2007.

2. Materials and methods

2.1. Data

Fishing mode. 2 fishing modes were considered: free schools (FSC) and FAD-associated schools that include both natural logs and manned rafts. Tuna schools caught in the vicinity of seamounts were considered as FAD-associated schools because tuna species composition of the catch under seamounts has been shown to be very similar to sets made under FAD (Pallares and Hallier 1997). Fonteneau (1991) has however described the particularity of tuna schools associated with seamounts and some authors have considered seamounts as a specific fishing mode, for instance for estimating bycatch of billfish in the Atlantic Ocean (Gaertner et al. 2002). Overall, fishing modes were known for 50% of the fishing records in the logbooks, but the proportion was much less for the first 15 years (from 30% in 1984 to 50% in 1998) than now (64% for 2000-2007). The remaining proportion of sets was allocated among the 2 fishing modes based on the relative proportion of catch between free and FAD-associated schools by month and 1 degree square calculated for the whole series.

Catch data. Catch data were derived from detailed logbook information and size sampling done on purse seiners from the European Union and other flags working in close cooperation with EU vessels. For consistency in catch/effort time series (e.g. fishing experience in the use of technical equipment and knowledge of the fishing zones), the 27 purse seiners that spent at least 15 years in the Indian Ocean during 1984-2007 were considered in the analysis. 2 main fleets were considered: (i) French and French-associated purse-seiners including vessels from France, Ivory Coast, Liberia, Italy, Mayotte, and a few vessels from the Seychelles and St Vincent, (ii) Spanish and Spanish-associated purse-seiners including vessels from Spain, Panama, Malte, Belize, Dutch Antillas, and all Seychelles and St Vincent flag vessels other than those reported as French-associated ones. The distinction between those fleets is considered to account for two main fishing strategies. French and associated vessels give a priority to FSC, although they also seed FADs and catch associated-schools, while Spanish and associated vessels are more organized into the FAD fishing activity, especially with the use of supply vessels that were introduced in the mid-1990s and increased in number from 9 in 1999 to 13 in 2006 (Sarralde et al. 2006).

No weight category was considered for SKJ while 3 weight categories were considered for YFT based on size frequency data available for the period 1984-2007: < 10 kg, 10-30 kg, > 30 kg. Monthly catch-at-size matrices were first computed for each fishing mode (FAD or FSC) along a 5° grid based on extrapolated size samples. Then, weight categories were assigned size limits based on the most recent and comprehensive length-weight relationship available: 20-78 cm, 80-112 cm and > 112 cm for categories 1, 2, and 3, respectively (Marsac et al. 2006). The mean weight of YFT taken on FAD and FSC differs substantially (Fig. 1)

Effort data. 2 types of fishing effort were used according to the type of fishing mode and spatial scale considered. Daily GPS positions in degrees and minutes recorded in logbooks were used to estimate daily fishing times, expressed in searching days, calculated indirectly from estimated time spent setting the nets. For FAD, either the searching time or the number of positive sets was used as fishing effort depending on the model considered. For FSC, searching time was used as fishing effort in all models considered (Table I).

Seasons. The climatology of the Indian Ocean is characterized by a strong seasonal signal related to the monsoon system. The seasonal variability can also be magnified by El Nino-Southern Oscillation (ENSO) or Dipole (IOD) events (e.g. Krishnamurthy and Kirtman 2003). In addition, purse-seine fishing exhibits seasonal shifts across the WIO, a consequence of changes in the spatial distribution of the vessels and fishing modes throughout the year (Marsac 1992). 2 seasons, each associated with a major fishing mode, were then considered to estimate consistent catch/effort time series in terms of targeting: July-October for FAD-associated fishing and December-February for FSCs.

Areas. 2 major fishing areas in the WIO were considered to account for the spatial reallocation of fishing effort and fishing mode throughout the year when standardizing CPUE data: (i) an area north of the Equator (NEQ) of latitude 0°-10°N and longitude 40°E-80°E where the targeted tunas are SKJ and small YFT (< 10 kg) under FADs, and (ii) an area south of the Equator (SEQ) of latitude 0°-10°S and longitude 40°E-80°E where the targeted tunas are large YFT on FSC. The average proportion of FAD versus FSC catch over the whole period analysed is given in Fig. 2. The seasonal pattern of catches for each area is presented in Fig.3 as a justification to the season-area stratification.

Environmental data. The depth of isotherm 20°C (m; D20) was calculated from the GODAS (Global Ocean Data Assimilation System) of the NOAA-NCEP (National Center for Environmental Prediction). The depth of isotherm 20°C is not provided directly from the model outputs. Therefore, we interpolated the depth of isotherms within the water column from 5 to 300 m (26 levels) and retained that of 20°C. The resolution of the monthly GODAS products used is 1° in longitude and 0.33° in latitude. Sea surface chlorophyll-a concentration (SSC; mg m^{-3}) was computed from monthly composites provided as SeaWiFS product by the Goddard Space Flight Center (NASA). The initial resolution of those data being 9 km, data was aggregated and an average concentration by 1° longitude and 0.33° latitude was then computed. Chlorophyll concentration was log-transformed because of the highly skewed distribution of the values. These environmental variables were used to describe the major oceanographic features of the 2 oceanic regions of interest and included as covariates in the GLMs (see below) following preliminary analyses based on linear regression and generalized additive models to investigate for the relationships between these predictors.

2.2 Statistical models

The standardization procedure used was the GLM in R statistical software package (R Development Core Team 2008). The GLM method (McCullagh and Nelder 1989) was applied to 2 categories of datasets based on: (i) logbook data, (ii) aggregated data by spatial stratum (1° longitude and 0.33° latitude) and by month (Table I). Depending on the observed CPUE data distribution, the GLM approach assumed a lognormal or delta-lognormal error distribution. When the proportion of zeros was higher than 10%, the delta-lognormal model was applied. The abundance indices were obtained from GLM analysis. On one side, a positive CPUE was estimated from yearly average fitted values of the lognormal model. On the other side, estimated proportions of catches were estimated from yearly average fitted values of the binomial model. The CPUE index for each species was finally calculated as the product of year average fitted values of lognormal model and binomial models. Variance of the indices were calculated using the Delta method (Casella and Berger 2002), based on the Taylor development of the function $g(m,p)=mp$, where m is the estimator of CPUE from the lognormal model and p the estimator of proportion of positive catches, assuming that both estimators are independent. In addition, a bias correction was applied to the lognormal estimates (Laurent 1963):

$$cpue = e^{\mu+\sigma^2/2}$$

where μ is the vector of estimated values in the scale of the linear predictor and σ^2 is the deviance of the residuals of the model. In general, model evaluation and diagnosis were carried out through residual analysis (McCullagh and Nelder 1989). For the delta models, diagnostic plots were presented for each component of the most relevant models. For the lognormal and binomial components, QQ-plots and Chi-squared residuals against year were presented for each species, respectively.

A stepwise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability in each model. A Chi-squared test was used to evaluate the statistical significance of an additional factor (McCullagh and Nelder 1989). Further, the corresponding percentage of deviance explained by each factor relative to the maximum model was estimated to obtain a profile of the most important explanatory factors in the model. A statistically significant variable may in some instances be omitted from the model if the amount of variation explained by the variable is small in relation to the complexity that it adds (Stefanson 1996). The final models included the Year factor interaction plus a selection of other explanatory factors and interactions that explained more than 5% of the deviance percentage in the models.

Models applied to logbook data. 5 delta GLMs were developed based on catch and effort data derived from logbooks (Table I). In all models, the year (YR) was used as a factor to analyse interannual variability and predict annual trends in CPUE from model outputs (see above). The other covariates considered were:

- MO, the month used as a factor to analyse the CPUE variability across months within the time-period considered,

- VESSEL, a categorical variable combining the fleet (French or Spanish type) and the size category to account for differences in fishing strategies, vessels, and holding capacity. 4 vessel categories were initially considered: 300-750 tjb, 750-1250 tjb, 1250-2300 tjb, and > 2300 tjb[3]. Due to data selection, the French type fleet was only composed of the first 3 size categories while the Spanish type fleet was only concerned by the 2 intermediate size categories,

- NSET, the total number of sets, including FAD and FSC sets, to account for the degree of tuna school concentration. This variable can also be considered as an index of vessel fishing power since powerful vessels generally have many devices aboard and this can be reflected in the number of sets made per day, and consequently in their daily catches.

- D20, the depth of 20°C isotherm. This information is only by space-time strata, then we allocate to the individual set the D20 value of the strata where the set is made.

Models applied to aggregated data. 6 GLMs were developed based on catch and effort data aggregated at a scale of 1° longitude and 0.33° latitude (Table I). All models included a year (YR) effect for estimating standardized CPUE and the other covariates:

- MO, the month used as a factor to analyse the CPUE variability across months within the time-period considered,

- DNS the proportion of days with no set; small values indicate a rather continuous sequence of sets in the stratum considered,

- PROPFSC (in the NEQ, i.e. FAD area) and PROPFAD (in the SEQ, i.e. FSC area) are given to account for the fishing effort deployed on the alternate (and non-primary) fishing mode. They represent the proportion of catch on FSCs and FAD-associated schools respectively.

- D20 and CHL, respectively depth of 20°C isotherm and surface chlorophyll content

3. Results

3.1. Patterns of the physical and biological environment

In the NEQ area, the striking oceanographic feature is the development of a strong seasonal upwelling off

3 1 tjb = 1 tonneau de jauge brute = 2,832 m^3

Somali coast. The upwelling is triggered at the onset of the southwest monsoon (June) and remains active till the end of September (Swallow and Fieux, 1982). There are 2 offshore diversions of the monsoon current, at 4°N and at 10°N (Brown et al 1980). On average, SST in July is below 22°C at the coast (Fig. 4a) but transient cells of colder water (16-17°C) can be found at the coast. Two large standing gyres are created as the circulation goes circling. The largest one, known as the Great Whirl, is located from 5°N to 10°N. In its centre, the thermocline (as depicted by the depth of 20°C) is almost 200 m deep (Fig. 4b). The biological production resulting from the upwelling is driven offshore from the 2 core areas where the current diversions occur (Fig. 4c). These main physical and biological features persist during almost the whole fishing season, up to October. The average pattern of D20 and PS catch is represented in Fig. 5. The largest catches are located along the southern limb of the Great Whirl. There, the surface circulation may trap floating objects and keep them in chlorophyll-enriched waters (note the spatial overlap with the chlorophyll enhancement shown in Fig. 4c). We do not see drastic changes across the years for the D20, as the summer monsoon triggers a strong and clear response from the ocean (upwelling and standing gyres offshore) whatever the strength of the monsoon.

In the SEQ area, when the PS fleets are targeting free schools (mostly yellowfin spawners) from December to February, the SST is high (> 28°C), very homogeneous spatially from India to Madagascar (Fig. 6a). A temperature gradient is formed off the Somali coast as the southward Somali current transports cooler waters (<26.5°C) from the North Arabian Sea (a region that is under the influence of the boreal winter cooling). Similarly to the southwest monsoon, a thermocline ridge is observed from 8°-10°S, as depicted by D20 shallower than 60 m (Fig. 6b). The surface chlorophyll pattern matches that of SST, with higher production along the African coast compared to the southeastern part of the region (Fig. 6c). In the PS fishery area during the free schools season, the chlorophyll content at the surface is very low (< 0.2 $mg.m^{-3}$). Although oligotrophic conditions prevail at the surface, Vialard et al (2009) have shown a very strong deep chlorophyll maximum associated with the thermocline gradient and much before, Piton and Magnier (1975) had measured high levels of nitrates in the same core layer. Therefore, biological enrichment of intermediate trophic levels is possible within the mixed layer. Free school catches are mostly found in association with the thermocline ridge, with higher catch levels on the northern edge (Fig. 7) within the Equatorial counter-current that is active from December to April.

3.2. Skipjack

For the GLMs performed on skipjack nominal CPUE from logbook data selected in the NEQ area and using searching time as fishing effort unit, all covariates included in the lognormal and binomial models were statistically significant (Table II). Year was the factor explaining the highest proportion of deviance (> 40%) in both the binomial model explaining the proportion of positive CPUE and in the log-normal model explaining the values of CPUE when a set was not null. Although statistically significant, the month factor explained a small percentage of deviance (less than 5%), showing the good homogeneity and stability of the CPUE during the July-October period.

Vessel category was the second most informative factor for explaining the variability in the proportion of skipjack positive catches and catch rates, accounting for 21% and 10% of deviance, respectively (Table II). The significant interaction effect with year, estimated relative to the small French vessels in 1984, showed that the effects of vessel category varied through time, the effects showed similar patterns between the French and Spanish fleets, being quite stable during 1984-1995 and exhibiting a decreasing trend thereafter (Fig. 8). The medium size French vessels (750-1250 tjb) showed the lowest effect on skipjack CPUE. Large size French vessels (1250-2300 tjb) and medium and large size Spanish vessels had very similar effects on skipjack CPUE (Fig. 8).

The effect of the daily number of sets was higher on the observed positive values of CPUE than on the probability of positive observed catches (Table II). This suggested that the levels of catch rates were increased when several successive fishing sets were made in the same day. The depth of 20º C isotherm was statistically significant in the lognormal and binomial models but explained a small percentage of the deviance, less than 5% in both models (Table II). Therefore, accounting for this environmental effect when estimating standardized CPUEs did not modify the variations in skipjack abundance through time.

The final model selected to predict yearly variations in CPUE (Table II) mainly modified the nominal CPUE for the 1984-1998 time period while nominal and standardized CPUEs were very similar thereafter (Fig. 9). GLM results showed a strong decline of the standardized CPUE from almost 1 in 1984 to less than 0.4 in 1997-1998. The standardized CPUE then showed an increase to a maximum of 1 in 2003 followed by a sharp decline to about 0.5 in 2007.

Covariates included in the GLM based on logbook data selected in the NEQ area and using positive sets as fishing effort unit were all significant. The CPUEs expressed in t per positive set were modeled using the lognormal error model, as observed catches were all positive. There were major differences in the standardized CPUE for the initial period 1984-1992 according to the type of fishing effort, i.e. whether the effort was expressed in searching time or positive set (Fig. 10). Trends and interannual variations in CPUE were very similar for the period 1993-2007.

The different GLMs performed on aggregated data yielded almost no difference between nominal and standardized SKJ CPUE, whether expressed in t per searching day or positive set.

3.3. Small yellowfin (< 10 kg)

All covariates included in the lognormal and binomial models performed on small YFT nominal CPUE expressed in t per searching day and based on logbook data were statistically significant (Table III). Year was the most significant covariate, explaining about 85% and 65% of total deviance in the binomial and lognormal models, respectively. There was almost no significant difference between months in the proportion of positive CPUEs. By contrast, the month factor explained about 5% of deviance in the lognormal model, showing some variability between July and October in small YFT CPUEs. These monthly variations were not constant over years as shown by the significant year:month interaction effect that explained 14% of the model deviance (Table III). The vessel category effect appeared less important than for skipjack, explaining 6.6% and 4.7% of deviance in the binomial and lognormal models, respectively. The year:vessel interaction effect was significant in both models and the yearly effects of vessel category, expressed relative to the small French vessels in 1984, showed similar patterns as for SKJ but with a less marked decline over time (Fig. 11). Although statistically significant, the depth of 20° isotherm considered in the GLMs explained a very small proportion of the model deviance (> 1%) and did not modify the standardised CPUEs.

GLM results showed no clear trend in standardized CPUE through the whole period 1984-2007 with high interannual variations (Fig. 12). Standardized CPUE were higher than nominal CPUE in the period 1984-1995 with a declining trend and were characterized from the mid-1990s to the mid- 2000s by an increasing trend and high annual fluctuations. Standardised and nominal CPUE were very similar from the mid-1990s, showing that covariates included in the model to account for changes in fishing power were not informative enough to explain the variability in nominal CPUEs during this period. As for SKJ, GLM standardization based on aggregated data did not modify nominal CPUE, suggesting that models based on mean CPUE calculated at the scale of a statistical rectangle of 1° longitude and 0.33° latitude were not appropriate for extracting CPUE yearly trends that could be used as indices of abundance.

3.4. Large yellowfin (> 30 kg)

GLMs performed on CPUE for large YFT caught in free schools derived from logbook data showed a significant effect of year, number of sets, month, vessel category, and associated interaction effects (Table IV). The year effect explained most of the deviance of the model explaining the proportion of catch (79%) while it explained 38% for the lognormal model. There were some variations in positive CPUE between months (8% deviance explained). By contrast with the SKJ and small YFT caught under FAD in the NEQ area, the depth of 20° isotherm did not explain any variability in large YFT CPUE (Table IV).

Compared with fishing under FAD showing a decreasing trend of the interaction effect between year and vessel category with time, the vessel category for large YFT showed a strong increasing trend from the early 1990s to the mid 2000s, with large inteannual variability dor the 3 years 1998-2000 (Fig. 13). The increasing trend was similar for the 4 categories considered and would suggest that the effects of the size of the vessel (and associated characteristics such as speed and holding capacity) on CPUE would increase through time. Such a common increasing trend might be due to the constant improvement of fishing power through time that would affect all vessel categories in a similar manner. While the effect of the 4 vessel categories showed similar values throughout the 1990s, the remaining categories in the 2000s, i.e. medium and large French vessels and medium Spanish vessels, showed different effects on large YFT CPUE (Fig. 13).

The final model selected to predict yearly variations in CPUE (Table IV) mainly modified the nominal CPUE for the period 1984-1990 while nominal and standardized CPUEs were very similar thereafter (Fig. 14). Overall, the GLM shows no particular trend of the standardized CPUE for large yellowfin.

4. Discussion

The estimation of abundance indices from purse-seine catch and effort data is a challenging task, mainly because of the difficulty of defining a proper unit of effort and of the multispecies character of tropical tuna fisheries. The estimation of an effective fishing effort based on nominal effort is particularly difficult regarding the strong dependence between searching time and technological equipment and human skills that are highly variable in time and space (Gaertner and Pallares 1999). In addition, the development of FAD-associated fishing since the mid-1990s complicates the notion of fishing effort as the fishing sets mainly depend on the availability to detect the FADs that can be equipped with satellite transmitters. The changes in fish targeting through time according to tuna availability and international market prices is also a major factor to deal with when using CPUE to derive annual abundance indices (ref). In this context, the present analysis is a first step to explore catch-effort datasets available for the period 1984-2007, identify major factors affecting CPUE, and to define a standard methodology to estimate abundance indices for the tropical purse-seine fishery of the Indian Ocean.

The absence of information on technology aboard fishing vessels that could be used as covariates in the statistical models is presently an impediment to consider GLM outputs as good proxies of tuna abundance, particularly in the last decades where fishing power is known to have greatly improved through the acquisition of radars, sonars, satellite mapping tools, etc.

4.1. CPUE trends

The CPUE trends exhibited by skipjack and small yellowfin caught on FADs are rather different. Where they show a regular decline during the first years of the fishery (till 1998) for skipjack, a very slight declining trend is shown during the same period for yellowfin. It should be recalled that more than 70% of the catch on FADs are skipjack and trends might be more clear for this species, compared to yellowfin that may have more opportunities to escape (especially in depth) from the skipjack school. This behavioural component should be further investigated to be in a better position to compare trends for those two species.

The vessel category corrects for the first time period 1984-1996 when the major changes in fishing vessels and total fishing capacity took place (arrival of new vessels, etc.). The following period (1996-2004)is characterized by the increase in the annual component of the CPUE that might reflect the changes in technology (FADs) and the introduction of supply vessels at the end of the 90s. The last decline in 2007 might be due to the shrinking of the fishing grounds because of piracy acts off Somali.

The standardized CPUE for large yellowfin taken during the spawning season in the SEQ fluctuates with no clear trend. The very first years are raised from the nominal CPUE but no further correction is brought by the GLM from 1991 onwards. This pattern remains very difficult to explain and no strong inference can be made as major technological improvements are not accounted for in the present procedure.

4.2. Fishing power and efficiency

The significant effect vessel category included both the differences in fishing practices between the French and Spanish fleets and the differences in vessel size, reflecting factors such as holding capacity and speed for instance (Gaertner and Pallares 1999). Vessel effect also is including the skipper effect; usually best vessels are driven by the best skippers.

Major changes in vessel size took place in the 1980s. In the second half of 1990s, larger vessels (90 m length) were launched. The most recent ones reach more than 2000 tjb. Along with the size of vessels, the fishing technology improved substantially, with the introduction of the first bird radars and sonars in 1986, FAD tracking buoys in 1990 and assistance of supplies vessels towards the end of the 90s. Those equipments have also greatly improved over time with higher detection capabilities.

The vessel effect is clearer than environmental effects in the GLM results. The differences between trends in CPUE for each vessel category are more obvious on FADs than FSC (Fig. 8, Fig. 11 and Fig. 13). This could be explained by the use of supplies and higher investment in buoys and FADs by the Spanish vessels than the French vessels.

More sets can be realised in a single day: on FADs, the tracking of buoys can help defining the most appropriate tactic to visit several FADs. Our analysis suggest that the number of set realised in a day have a positive effect on the CPUE for all species.

4.3. Protocol for standarizing PS CPUE

Two kinds of fishing data have been analyzed, log book data and aggregated data, to estimate CPUE indices and explore the effects of environmental variables on CPUE. As a result, log book data are always more informative and provide better signal to explain the changes in the CPUE indices than aggregated data. It is common in working with log book data to have many zero observations of catches and in this case, Delta approach is appropriate to standardize the CPUE.

As the amount of log book data is considerable, limiting space and temporally the observations to the fishing area/season contributes to improve the estimates of the abundance indices. Also, a threshold that limits the observations only to vessels that have been operating more than 15 years provides the possibility to analyze the evolution of fishing power in terms of vessel category.

Also, different kinds of effort have been considered in the definition of CPUEs of juveniles fished on FADs. GLMs approaches for different cases (Table I) show similar results in trends of CPUE. Although, nominal CPUE differs if searching day or positive sets are considered as nominal effort (Fig 8). Positive sets limit the data only to a subset of positive catches, so many informative observations are deleted. Searching time is probably a more adequate measure of nominal effort to consider in the standardization procedure.

The new standardization procedure should include covariates that are more specific to the technological improvements. Such project should require full cooperation from the fishing companies.

5. Conclusion

The different spatio-temporal scales of logbook data and environmental variables make difficult to show the effects of the environment on tuna abundance, especially in the last years, where the accessibility of the resources could have been increased due to favourable oceanographic conditions. This makes necessary to investigate furtherhow relating fishing data to environmental data. Including economic factors of annual investment in non fungible equipment of the fleet should be desirable to estimate a proxy of the increase in catchability of the EU purse seine fleet. These two factors are not well reflected in the GLM indices and consequently, the indices tend to overestimate the real abundance in the last years.

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Table I. Data and covariate selection used for the different generalized linear models (GLMs) considered for standardizing yellowfin and skipjack tunas catch per unit of effort (CPUE) of the European purse-seine fishery in the Western Indian Ocean (WIO). NEQ = North Equatorial area (0°-10°N / 40°E-80°E), SEQ = South Equatorial area (0°-10°S / 40°E-80°E), FAD = fishing aggregating device, FSC = free school, YR = year, MO = month, ZONE = ET area, VESSEL = flag*category, NSET = total number of fishing sets, DNS = % of days with no set, PROPFSC = % catch in free schools, PROPFAD = % catch in FAD-associated schools, SST = sea surface temperature, D20 = depth of isotherm 20°C, CHL = sea surface chlorophyll concentration

Area	Season	Years	Species	Fishing effort	Fishing mode	Observations	Covariates
NEQ	Jul-Oct	1984-2007	Skipjack	Positive sets	FAD	logbook	YR, MO, VESSEL, NSET; D20
NEQ	Jul-Oct	1984-2007	Skipjack	Searching time	FAD	logbook	YR, MO, VESSEL, NSET; D20
NEQ	Jul-Oct	1984-2007	Yellowfin (< 10 kg)	Positive sets	FAD	logbook	YR, MO, VESSEL, D20
NEQ	Jul-Oct	1984-2007	Yellowfin (< 10 kg)	Searching time	FAD	logbook	YR, MO, VESSEL, D20
SEQ	Dec-Feb	1984-2007	Yellowfin (> 30 kg)	Searching time	FSC	logbook	YR, MO, VESSEL, D20
NEQ	Jul-Oct	1984-2007	Skipjack	Positive sets	FAD	Aggregated	YR, MO, DNS, PROPFSC, D20
NEQ	Jul-Oct	1984-2007	Yellowfin (< 10 kg)	Positive sets	FAD	Aggregated	YR, MO, DNS, PROPFSC, D20
SEQ	Dec-Feb	1984-2007	Yellowfin (> 30 kg)	Searching time	FSC	Aggregated	YR, MO, DNS, PROPFAD, D20
NEQ	Jul-Oct	1997-2007	Skipjack	Positive sets	FAD	Aggregated	YR, MO, DNS, PROPFSC, D20, CHL
NEQ	Jul-Oct	1997-2007	Yellowfin (< 10 kg)	Positive sets	FAD	Aggregated	YR, MO, DNS, PROPFSC, D20, CHL
SEQ	Dec-Feb	1997-2007	Yellowfin (> 30 kg)	Searching time	FSC	Aggregated	YR, MO, DNS, PROPFAD, D20, CHL

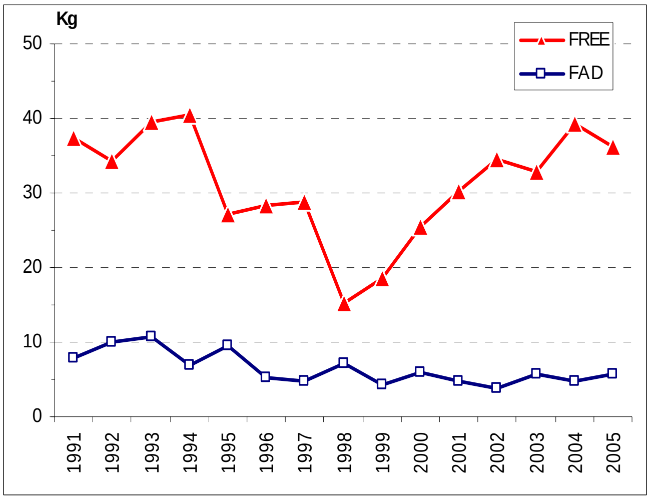

Figure 1 – Average weight of yellowfin taken on free schools (FSCs) and fishing aggregating devices-associated shools (FADs), 1991-2005

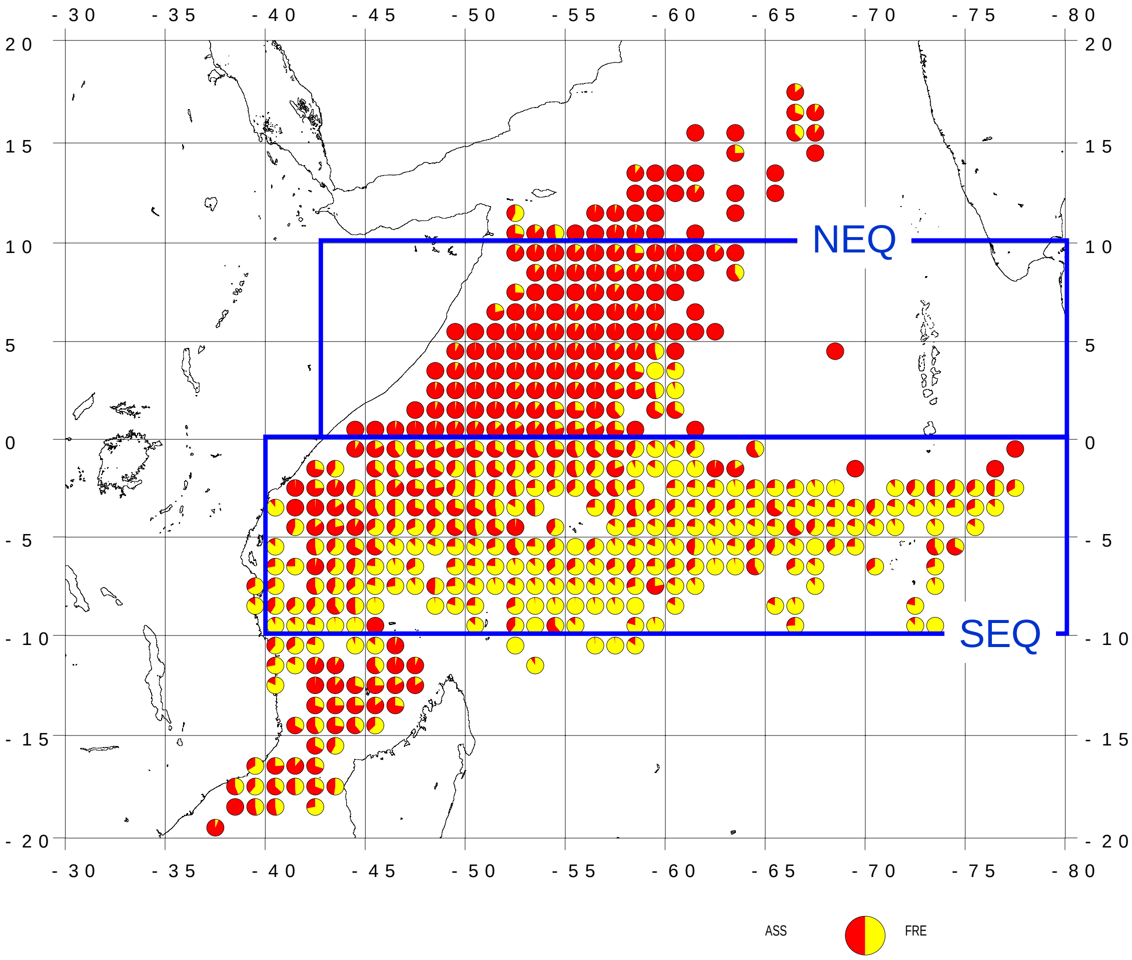

Figure 2 – Average proportion of major tropical tuna catch with regard to the fishing mode (ASS = fishing aggregating device associated, FRE = free school) for the European purse-seine fishery during 1984-2007. Statistical rectangles with catches < 500 t are not represented. The north equatorial (NEQ) and south equatorial (SEQ) areas considered in this paper are overlaid

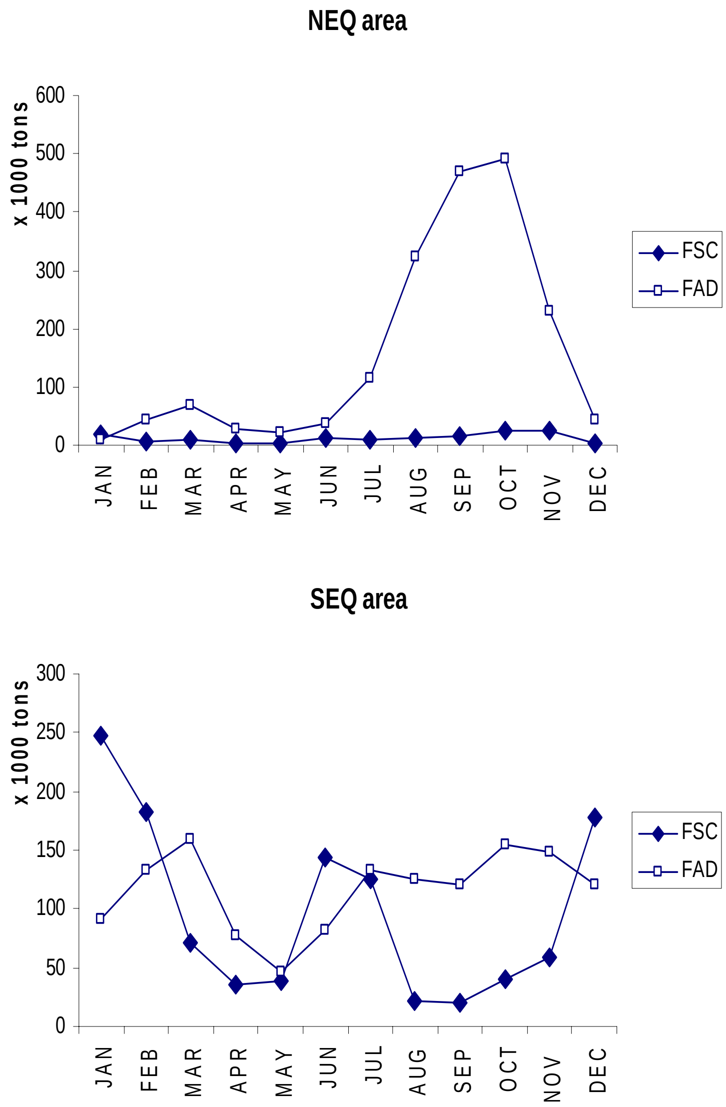

Figure 3 - Monthly catch by fishing mode (FSC = free schools ; FAD = fad-associated schools) cumulated over the period 1984-2007 in the two selected areas, NEQ (0°-10°N / 40°-80°E) and SEQ (0°-10°S / 40°E-80°E)

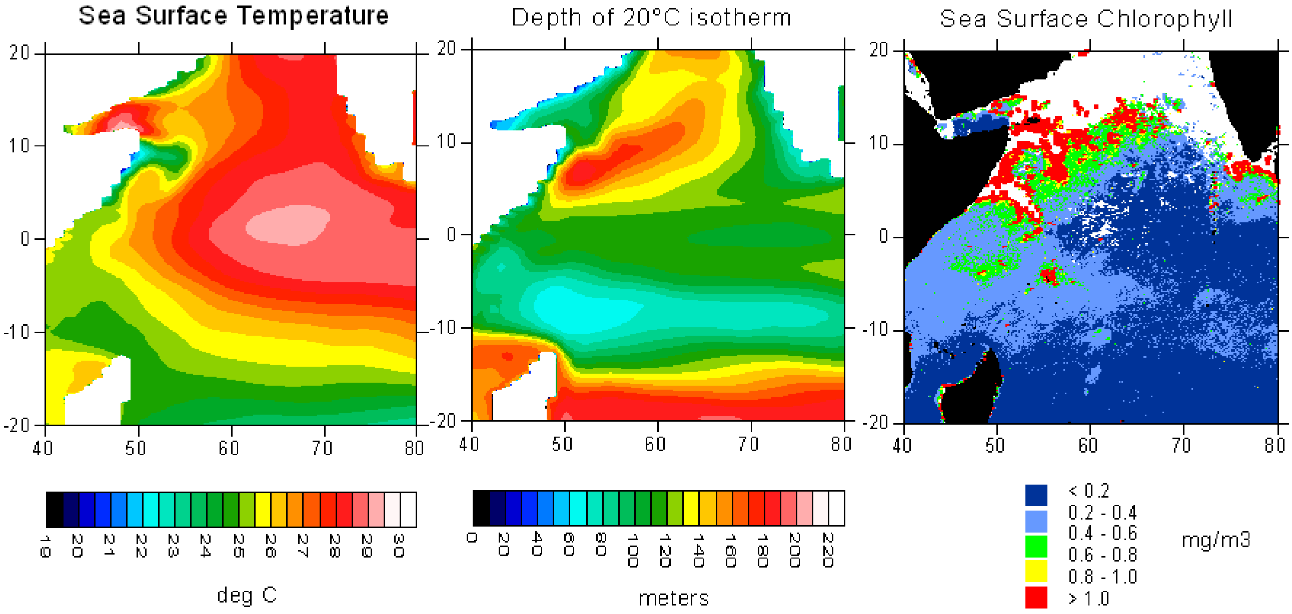

Figure 4 - Maps of sea surface temperature (SST) in July, average depth of the 20° isotherm (D20) in July, and sea surface chlorophyll (SSC) concentration in July 2004. The selected month reflect the oceanographic situation once the south-west monsoon is well established

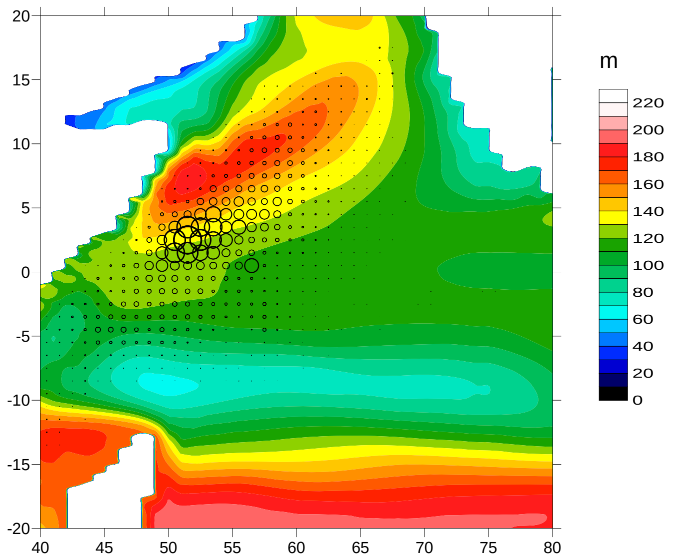

Figure 5 – Purse seine catch on FADs in July-October overlaid on the depth of the 20°C isotherm. Range in catch levels displayed is 0-2269 t

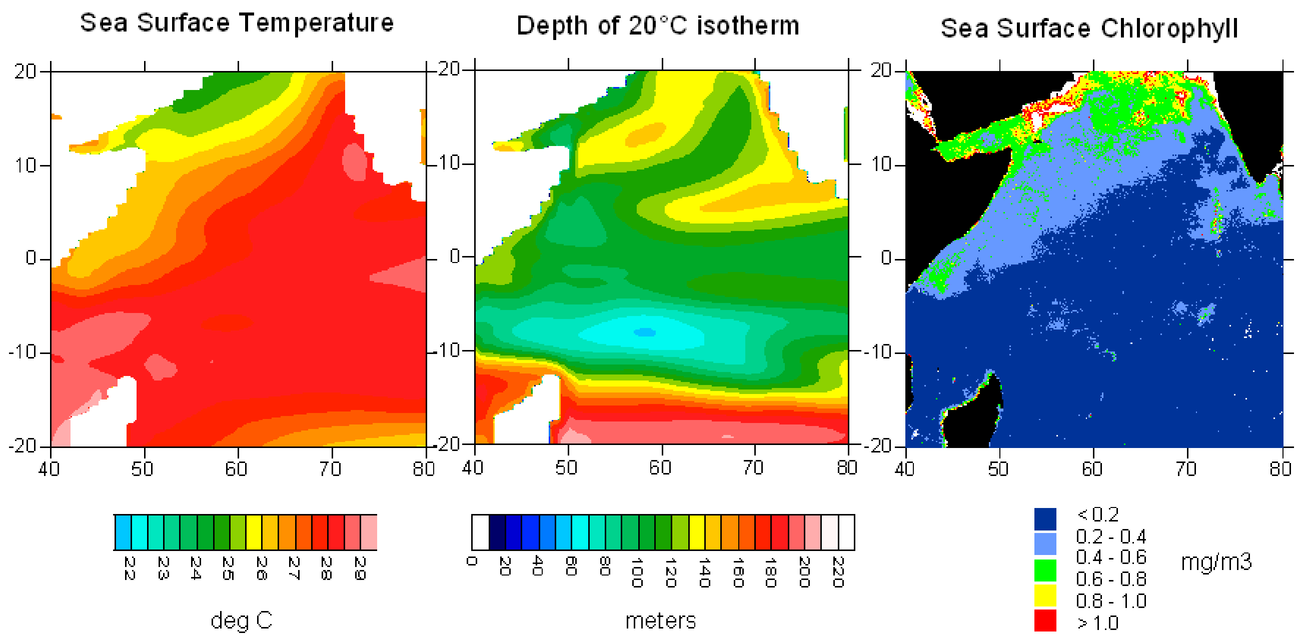

Figure 6 - Maps of sea surface temperature (SST) in January, average depth of the 20° isotherm (D20) in January, and sea surface chlorophyll (SSC) concentration in January 2000. The selected month reflect the oceanographic situation once the north-east monsoon is well established

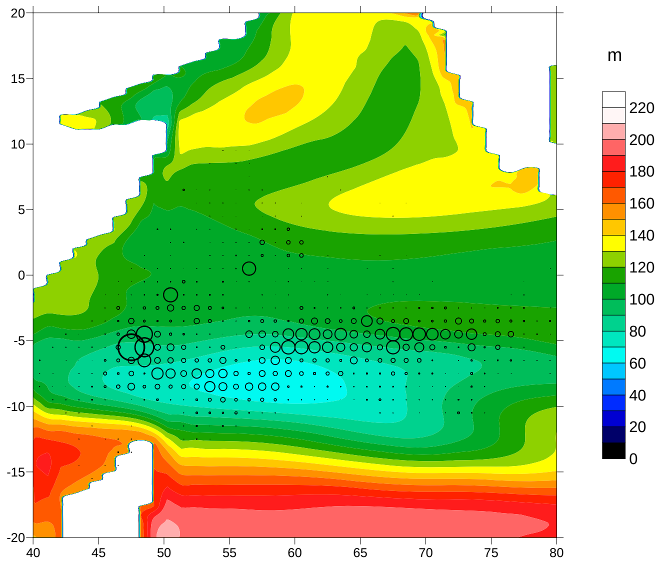

Figure 7 – Purse seine catch on free schools in December-February overlaid on the depth of the 20°C isotherm. Range in catch levels displayed is 0-1059 t

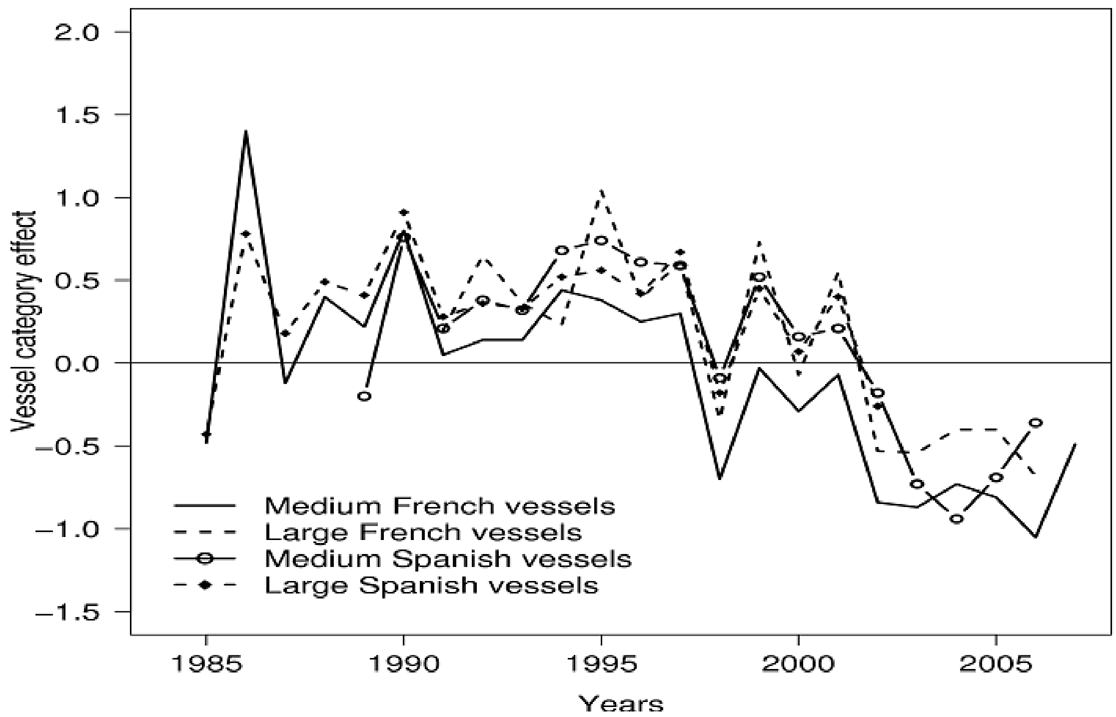

Figure 8 – Annual values of the 'category vessel' effect on skipjack catch per unit of effort (CPUE)

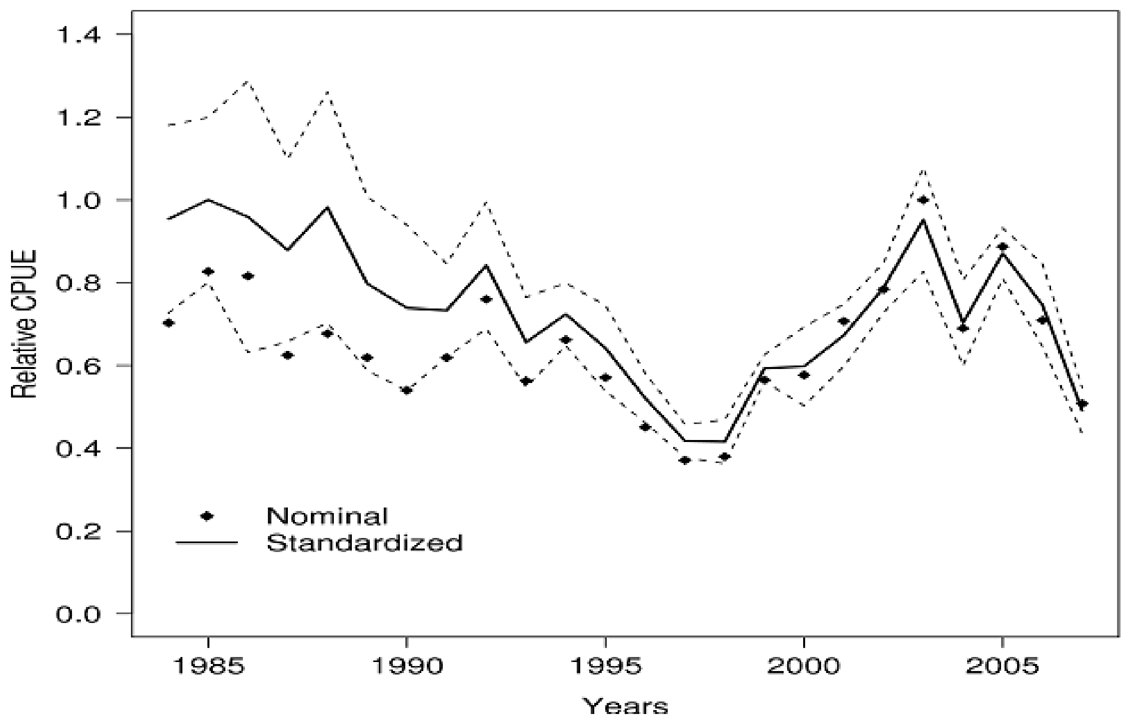

Figure 9 – Relative nominal and standardized skipjack catch per unit of effort (CPUE) with 95% confidence interval based on logbook data from the European purse seine fishery targeting tuna schools under fishing aggregating devices (FADs) in the North Equatorial area of the Western Indian Ocean. Absolute nominal CPUE were calculated based on fishing effort expressed in searching day

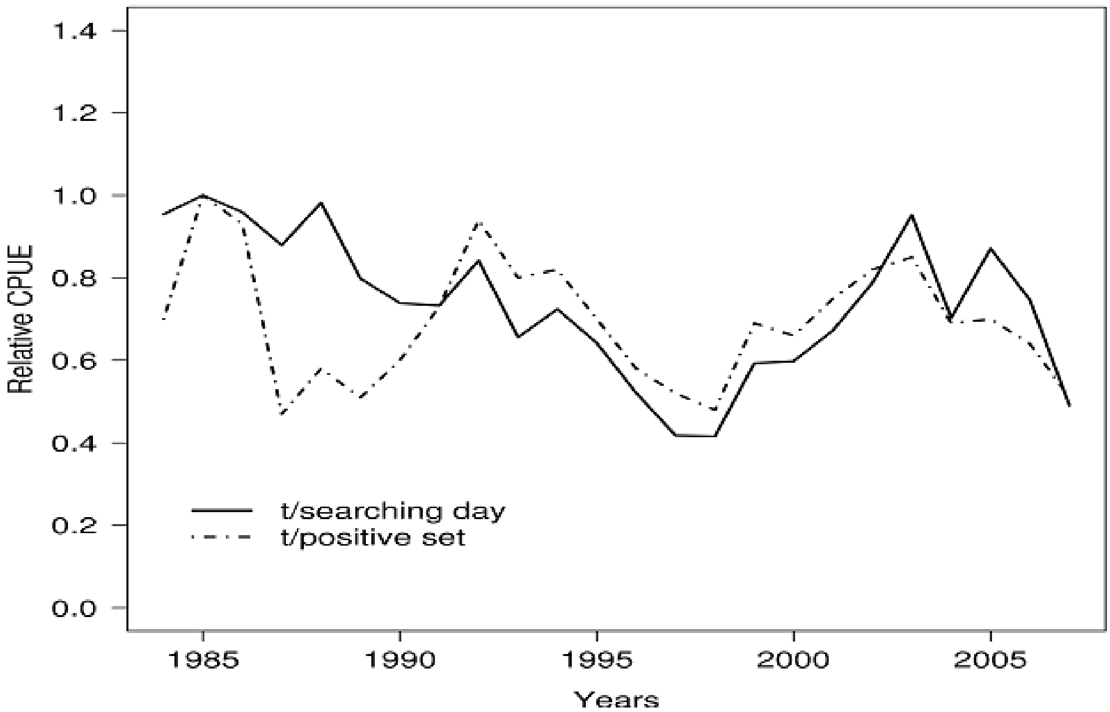

Figure 10 – Comparison between skipjack standardized catch per unit of effort (CPUE) estimated from nominal CPUEs calculated based on fishing effort expressed either in searching day or positive set

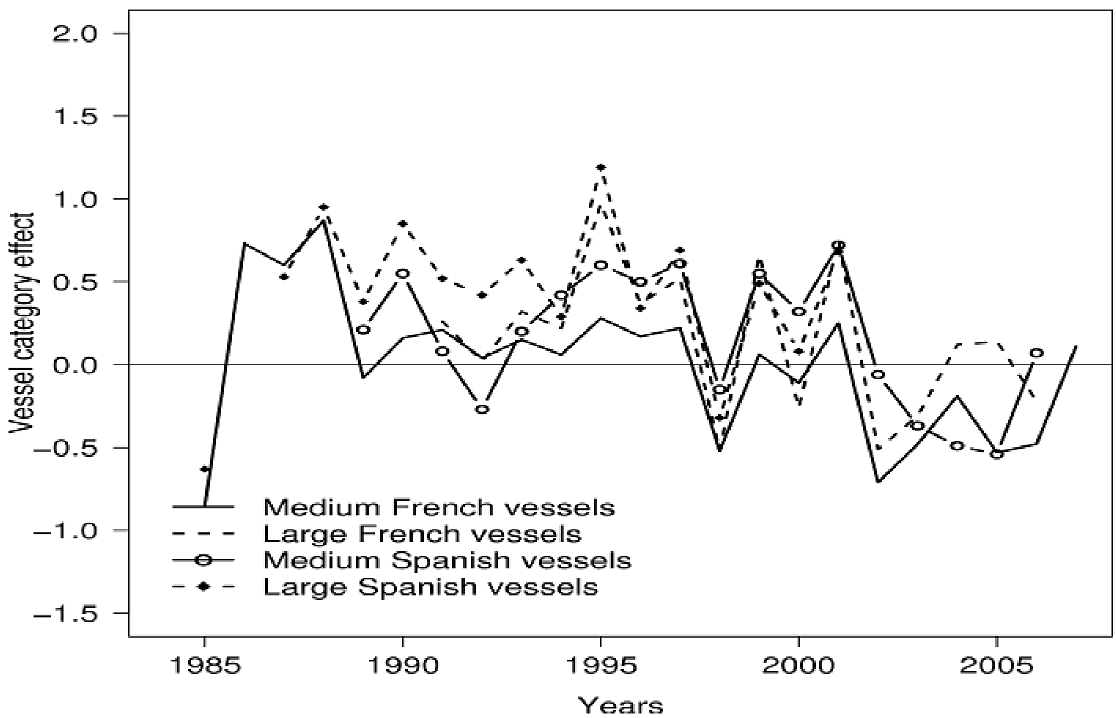

Figure 11 – Annual values of the 'category vessel' effect on small yellowfin catch per unit of effort (CPUE)

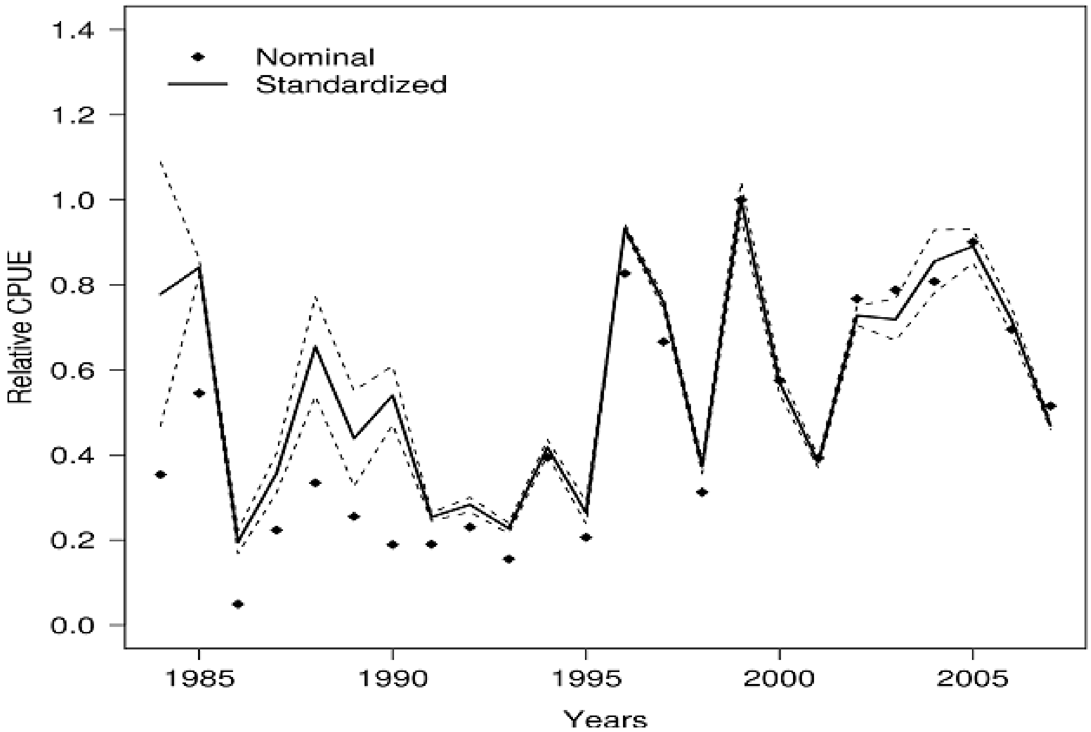

Figure 12 – Relative nominal and standardized small yellowfin catch per unit of effort (CPUE) with 95% confidence interval based on logbook data from the European purse seine fishery targeting tuna schools under fishing aggregating devices (FADs) in the North Equatorial area of the Western Indian Ocean. Absolute nominal CPUE were calculated based on fishing effort expressed in searching day

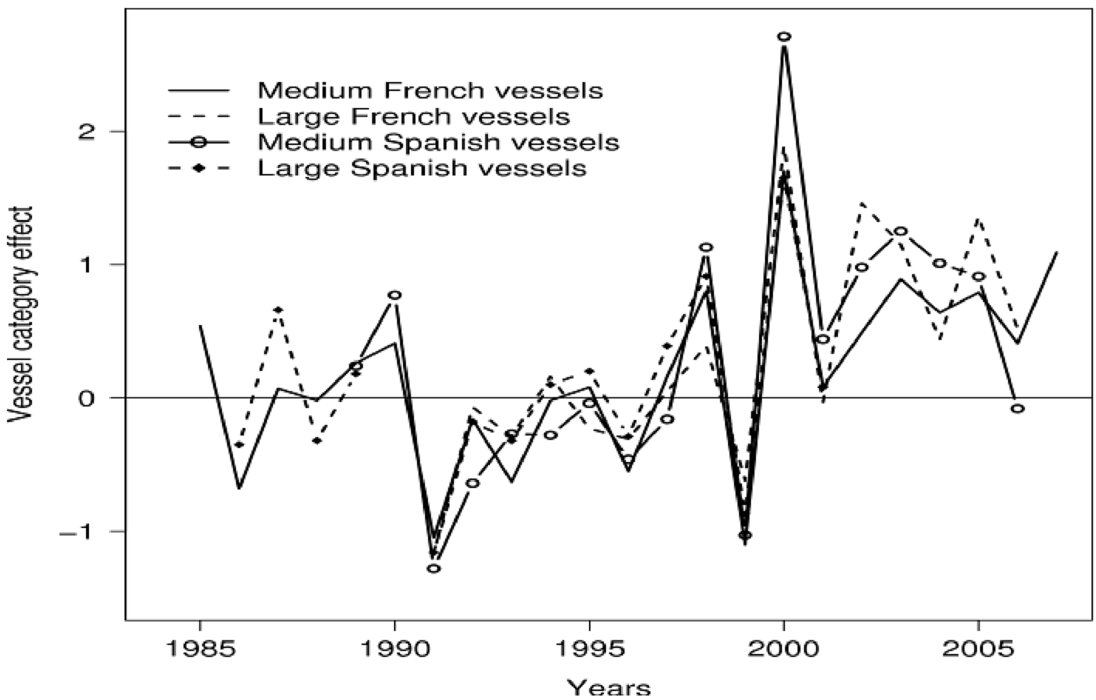

Figure 13 – Annual values of the 'category vessel' effect on large yellowfin catch per unit of effort (CPUE)

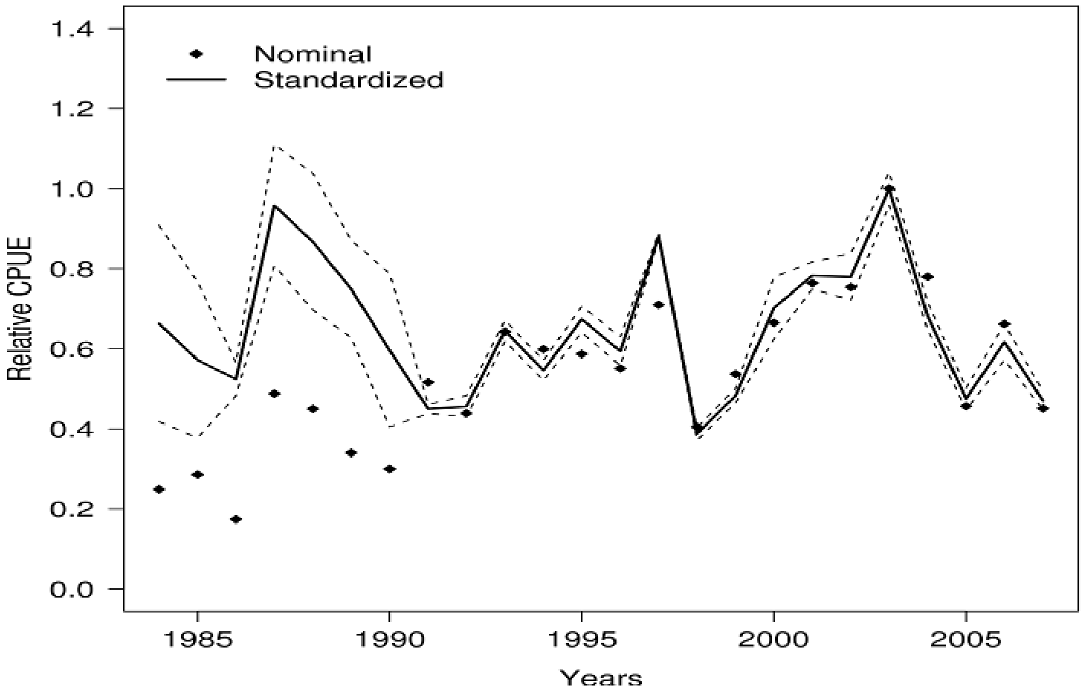

Figure 14 – Relative nominal and standardized big yellowfin catch per unit of effort (CPUE) with 95% confidence interval based on logbook data from the European purse seine fishery targeting tuna free schools in the South Equatorial area of the Western Indian Ocean. Absolute nominal CPUE were calculated based on fishing effort expressed in searching day

Appendix

Table II. Deviance table for the lognormal model and the proportion of catches of skipjack (SKJ). nset = number of sets; D20 = depth of the 20ºC isotherm; lgD20=log transformation of D20; Df = degrees of freedom. Explanatory factors are emboldened.

SKJ					
Model formulation	Df	Change in Deviance	Residual deviance	p-value	Percentage of total deviance
Positive CPUE					
1	1		18362.5		
Factor					
+year	23	834.9	17527.6	< 0.001	41.9%
+month	3	96.6	17430.9	< 0.001	4.9%
+vessel	4	188.3	17242.7	< 0.001	9.5%
+nset	1	171	17071.7	< 0.001	8.6%
+lgD20	1	59.6	17012	< 0.001	3.0%
Interaction					
+year:month	68	365.7	16646.4	< 0.001	18.4%
+year:vessel	75	213	16433.4	< 0.001	10.7%
+year:lgD20	23	61.3	16372.1	0.0012	3.1%
Proportion of positive CPUE					
1			1984.3		
Factor					
+year	23	697.7	1286.6	< 0.001	48.6%
+month	3	3.7	1283	0.2986	0.3%
+vessel	4	302.3	980.6	< 0.001	21.1%
+nset	3	14.2	966.4	0.0026	1.0%
+D20	1	3.6	962.8	0.0568	0.3%
Interaction					
+year:month	68	139.8	823	< 0.001	9.7%
+year:vessel	75	240	583	< 0.001	16.7%
+year:D20	22	34.9	548.2	0.04	2.4%

Table III. Deviance table for the lognormal model and the proportion of catches of small yellowfin (YFT). nset = number of sets; D20 = depth of the 20ºC isotherm; lgD20 = log transformation of D20; Df = degrees of freedom. Explanatory factors are emboldened

YFT < 10 kg					
Model formulation	Df	Change in Deviance	Residual deviance	p-value	Percentage of total deviance
Positive CPUE					
1			18057.8		
Factor					
+year	23	2299.1	15758.7	< 0.001	65.3%
+month	3	196.7	15562.1	< 0.001	5.6%
+vessel	4	166.9	15395.2	< 0.001	4.7%
+nset	1	126	15269.2	< 0.001	3.6%
+lgD20	1	24.1	15245.1	< 0.001	0.7%
Interaction					
+year:month	66	493.4	14751.7	< 0.001	14.0%
+year:vessel	73	214.7	14537	< 0.001	6.1%
Proportion of positive CPUE					
1			4086.4		
Factor					
+year	23	2763	1323.4	< 0.001	85.6%
+month	3	9.6	1313.7	0.0220	0.3%
+vessel	4	212.9	1100.8	< 0.001	6.6%
+D20	1	8.5	1092.3	0.0035	0.3%
+nset	3	46.7	1045.6	< 0.001	1.4%
Interaction					
+year:vessel	75	188.1	857.5	< 0.001	5.8%

Table IV. Deviance table for the lognormal model and the proportion of catches of large yellowfin (YFT). nset = number of sets; D20 = depth of the 20ºC isotherm; lgD20 = log transformation of D20; Df = degrees of freedom. Explanatory factors are emboldened

YFT > 30 kg					
Model formulation	Df	Change in Deviance	Residual deviance	p-value	Percentage of total deviance
Positive CPUE					
1			6436.4		
Factor					
+year	23	342.0	6094.4	< 0.001	38%
+month	2	72.5	6021.9	< 0.001	8%
+vessel	4	17.4	6004.5	0.0068	2%
+nset	1	98.6	5905.8	< 0.001	11%
+lgD20	1	0.0	5905.8	0.8754	0%
Interaction					
+year:month	46	225.8	5680.1	< 0.001	25%
+year:vessel	72	145.2	5534.9	< 0.001	16%
Proportion of positive CPUE					
1			1865.7		
Factor					
+year	23	1103.5	762.2	< 0.001	79%
+month	2	7.8	754.4	0.0205	1%
+vessel	4	123.6	630.8	< 0.001	9%
+D20	1	0.3	630.5	0.6170	0%
+nset	3	3.6	626.9	0.3056	0%
Interaction					
+year:vessel	75	161.9	465.0	< 0.001	12%