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Reference fleets identification by LPUE data filtering applied to the striped red mullet (*Mullus surmulletus*) in the Bay of Biscay

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1 Introduction

The striped red mullet (*Mullus surmuletus*) is a species for which ICES advances individualization of stocks in Western Europe. One of them concerns the Bay of Biscay, the waters bordering the Iberian Peninsula as well as the Celtic Sea, namely striped red mullet in Subareas and Divisions 6, 7a-c, e-k, 8, and 9a (Mur. 27.67a it-k89a).

This stock is part of the Data Limited Stocks (DLS) and is currently classified in Category 5 (ICES, 2016); it is a stock for which only landings data are available. Such knowledge is insufficient to apply the ICES MSY approach and the advice rule on fishing possibilities is therefore based on the precautionary approach.

For this stock, this approach is applied since 2012. For 2013 and 2014, ICES has recommended reducing landings by 20% compared to 2009-2011. In the absence of new information on stock biomass or exploitation level, the precautionary approach was applied again in 2017 (ICES, 2017). It led to a landing advice of a maximum of 1600 tonnes in 2018, 2019, and 2020.

It is in this context that the ROMELIGO project (Improvement of the fishery knowledge of striped red mullet, whiting and pollack of the Bay of Biscay) was conducted. A first step consisted of an update of the bibliographic review on the biology of the species and analyse the catches and the activity of the French professional fishery (composition and evolution of catches, seasonality, spatial distribution, gear used and discards). This work was the subject of a first WD transmitted and used by WGWIDE in 2017 (Caill-Milly et al, 2017).

This second WD concerned the Landings Per Unit of Effort (LPUE) of French vessels and proposes a data filtering method to identify vessels of interest (reference fleet) whose LPUEs can be considered as proxies of abundance indices of this resource. According to the landing distribution per “grouped gears” from 2000 to 2015 (Caill-Milly et al, 2017), five fleets are identified as potentially interesting: fleets using OTB (otter bottom trawls); OTT (otter twin trawls); GNS (set gillnets); GTR (trammel nets) and SDN (Danish seines).

The final objective is to strengthen expertise on this stock by providing data for the abundance and if possible move away from category 5 in the future.

2 Material and methods

2.1 Origin of data

Data on catches (landings and discards) by commercial fishing are of two types:

Landings data: these are validated, consolidated and qualified sets of production and effort data. They come from a work of reconciliation, verification, checks of coherences of different flows of data (fishing trips, sales, vessel monitoring etc...) within the framework of a project Ifremer / DPMA (Sacrois), but no correction on the data is done (Demanèche et al., 2013). Sacrois data are considered as the most comprehensive for reporting vessel activity and their inputs. They are available since 2000.

Discards data: Ifremer's "Observation on board fishing vessels" (OBSMER) action is the collection of catch data on board. The boarding allows the observation, on fishing area, of the parts kept on board (catches) and the parts not retained on board (discards) as well as the gear used. The fraction not retained aboard (discards) concerns not only undersized individuals, but may also include (commercial sized) fishes that the fisherman decides not to keep for various reasons such as conservation status, over-quota or lack of market. OBSMER data are available since 2003.

2.2 Extraction of data and definition of the studied population

SACROIS data were extracted over the period 2000 - 2015; the OBSMER data were for the period 2003 - 2015. The study population was defined by activity criteria applied to the vessels and by the spatial extent of the inputs.

2.2.1. Vessel activity criteria

We considered that a vessel was retained if it had an activity equivalent to a mean of two fishing sequences[1] per month per year (all gear combined) with the presence of striped red mullet (whatever the distribution of these fishing sequences in the year, at first). For a given year, the vessels selected are therefore those having made, at least, 24 fishing trips per year. A vessel can therefore be selected one year and not another over the period studied.

2.2.2. Fishing area of catches

Two criteria have been applied concerning the spatial extent of the inputs: the first is related to the strategies operating by the vessels; the second to the biology of the species studied.

Within the geographical area defined for the Mur.27.67a-ce-k89a stock, vessels from harbours of the Bay of Biscay and those outside and catching red mullet develop different fishing strategies (Caill-Milly et al., 2017). To overcome a bias in the calculation of the LPUE that would be related to these differences in fishing strategies, it was decided to focus the analysis on the main input area that presents consistent techniques, namely the divisions "27.8.a", "27.8.b", "27.8.c", "27.8.d", and "27.8.e".

A spatial selection was also made to retain only the statistical rectangles consistent with the bathymetric distribution of striped red mullet that is less than or equal to 300 m (Mahé et al., 2005, Desbrosses, 1935, in Suquet & Person-Le Ruyet, 2001).

2.3 Extent of the time series

Regulatory changes may affect the indicators of catches per unit of effort. It is therefore important to identify them and limit their effects because the aim is to work on landings per unit of effort to take into account the abundance of the species studied. In the case of striped red mullet, a preliminary graphical analysis of landings by fishing sequence and statistical rectangle between 2000 and 2015 (see Appendix 1) showed clear changes in trend in 2005 for trawlers and gillnetters. Discussions at the Working Group of the project associating

[1] A fishing sequence is defined by a day, a gear, a gear mesh size and a statistical rectangle.

professionals and scientists allowed linking this observation to the implementation of a selectivity device confirmed later by the Council Regulation (EC) (No 1288/2009). To overcome this regulatory bias, it was decided to conduct the various analyses over the period 2005-2015.

2.4 "Cleaning" and preparation of data

- "Cleaning" data

The "cleaning" concerned only the landings data.

The rows describing fishing trips whose occurrence per month was less than 2 were suppressed because of the error they cause in the calculation of the coefficient of variation.

Rows with atypical values (expert thought) of landings were removed from the analysis because of their suspect feature to avoid disturbing the analysis (7 rows in 137210 for trawlers and zero for gillnetters and Danish seine).

Rows with gear mesh sizes less than 20 mm and greater than 320 mm were considered transcription errors. The sequences associated with these gear mesh sizes have been deleted.

Fishing sequences without statistical rectangles information were also removed.

Vessels with zero fishing time were deleted because the data was considered suspicious.

- Prepared data

For Sacrois and OBSMER, the single data is the fishing sequence that is defined by a day, a gear, a gear mesh size and a statistical rectangle. To conduct the analyses, the landing data were aggregated by year, rectangle, month, gear, vessel length, vessel engine power, gauge, registration number, gear mesh size (grouped in mesh class). The discards data were by year, rectangle, month, gear. For the latter, the level of aggregation is less fine because it is based on a limited number of observations related to sampling. These aggregations constitute rows statistical units.

For landings, level indicator (mean, median) and dispersal (interquartile range IQR, variance Var, standard deviation StD, and coefficient of variation CV) associated with landings were calculated and are the variables for the landings columns. For releases, the calculated column variables are the level indicator (mean, median) and dispersion (standard deviation StD) associated with catches and discards.

The total number of fishing sequences and the number of sequences only with striped red mullet were calculated, as well as the total weight of the fishing sequence.

2.5 Preliminary analysis of discards data

The effort data available as a potential proxy of abundance are derived from landings data and are therefore not catch related. To be able to consider them thereafter as indicators of abundance, it is therefore essential to ensure, in advance, that the discards do not disturb the variables studied. For this, a discard analysis was conducted for each of the 5 identified fleets (OTB, OTT, GNS, GTR and SDN). To evaluate the proportion of discards and their characteristics, different criteria were apprehended simultaneously:

- The availability of a sufficient number of observations;
- The proportion of discards mean by month and by year from the number of total sequences carried out;
- The stability of this level over time;
- The size composition of the discards.

There is no minimum catch size for striped red mullet but a minimal commercial landing weight (EC Regulation No. 2406/96). This weight is 40 grams that amounts to a total length of about 18 cm.

This preliminary work allow retaining the gear that could be used to define the reference fleets.

2.6 Approach and analysis of landings data

The approach followed to select the interest fleet (s) is based on four steps.

Step 1: Identify the factors influencing the level and variability of the LPUE

This first step focuses on evaluating and prioritizing the different sources of variability of the LPUEs. It is based on an analysis of links between the variables of interest characterizing the LPUEs, the characteristics of the vessels and their activity (the technical characteristics of the vessel and the gears), and the spatiotemporal factors (year, month, statistical rectangles). It is also a question of prioritizing the effect of these characteristics on the variables of interest. To this aim, two statistical approaches were conducted.

First approach: the research for linear links

A Normalized Principal Components Analysis (NPCA) was conducted on the following data:

- In rows (individuals) = vessels, years, months, statistical rectangles and gear mesh size;

- In columns (quantitative variables) = level indicators (mean and median) and heterogeneity of landings (Var, Std, IQR, CV), technical characteristics, landings characteristics and fishing sequences.

The setting was as follows:

- Active variables: level indicators (mean and median) and heterogeneity of landings (Var, StD, IQR, CV);

- Additional variables: technical characteristics, landing characteristics and fishing sequences, months, years, statistical rectangles and gear mesh classes;

- Active individuals: all.

In addition to the NPCA, the discriminating power of the spatiotemporal variables and the gear mesh classes was evaluated for each of these variables using a Kruskal and Wallis test on the coordinates of the axis 1 of the NPCA. An Agglomerative Hierarchical Clustering (AHC) (Ward aggregation criterion and Euclidean distance) on the 5 coordinates resulting from the NPCA of the additional variables taken one by one led to a typology of years, months, rectangles and gear mesh classes.

Second approach: the research for other links and interaction between explanatory variables

A data-mining method, through the analysis of “regression trees”, was then applied to search for non-linear links between the variables and to investigate the possible interactions between the explanatory variables.

This analysis allows finding rules fixing the values of a target variable from a set of explanatory variables. It has the advantage of not requiring any binding assumption on the variables distribution, except that the target variable, if qualitative, does not contain rare outcomes. The obtained rules which take into account interaction between the variables can be displayed graphically using a binary tree. We chose the type conditional regression tree that performs a statistical test at each node.

The data used are the same as those used for NPCA.

The setting of the trees was as follows:

- Target variable: LogMoy; the “mean” variable has been transformed into Logarithm 10 which allows to “normalize” and thus to reduce the amplitude of these values;

- Model parameters: Min division: 20; Compartment min: 7; Max depth: 4; Complexity: 0.0100.

This first step allows knowing if the variability of the LPUE is primarily concomitant of space-time considerations or not.

Step 2: Vessels typology according to their technical characteristics

After analysing the variability of landings with regard to the different explanatory variables, it is essential to return to the “vessel level” which is the constituent element of the fleet. The objective of this second step was to have a typology of vessels with the most homogeneous technical characteristics possible within the same group (cluster) and the most heterogeneous possible from one cluster to another.

To do this, the analysed data are:

- In rows, vessels registration numbers;

- In columns the technical characteristics (length, engine power, gauge, age of the vessel).

The method used is the Agglomerative Hierarchical Clustering. The setting is:

- Ward aggregation criterion and Euclidean distance.

Step 3: Study the LPUE mean for each cluster

For each cluster, the monthly LPUE means were calculated. In order to select the most interesting clusters to constitute a reference fleet, i.e. whose representativeness in the activity and the contribution to landings are not too low, a list of mandatory and optional conditions allowing identifying the relevance of the cluster (s) has been established according to experts thought including professional knowledge. These conditions concern the number of vessels, the characteristics of the time series of the LPUE data, and the location of the LPUEs.

The mandatory and the optional conditions are detailed in the table 1. For the optional conditions, a points system was established. The points were assigned from the graphical analysis of the LPUE time series by cluster and on a scale of 3 (1 - low or zero, 2 - medium, 3 - strong).

Table 1: Mandatory and optional conditions used to select clusters of interest

Type of conditions	Object	Condition
Mandatory	Number of vessels constituting the cluster	Set at 30 minimum
	Length of the LPUE time series in the Bay of Biscay	Greater than the maximum longevity known for the considered species. The latter would be 11 years for striped red mullet (Quéro & Vayne 1997, ICES 2012)
	Minimum level of LPUE	Based on the mean value of the LPUEs, it was considered that the monthly mean value of the LPUE must be at least 5 kg

Optional	Seasonal signal	Stable in amplitude and periodicity over the period
	Spatial availability of the LPUEs	Activity available in the North and in the South of the Bay of Biscay to take into account as much as possible the entire range of striped red mullet in this area
	Seasonal variability	Moderate

The requirement of the mandatory conditions and the classification obtained for the optional conditions allow to preselect or not, one or more clusters of interest for each of the gears.

Step 4: Considering the gear mesh classes and seasonal variations

Following this pre-selection, the gear meshes and / or the months were considered if these variables were revealed during step 1. For the gear meshes, the analysis relates to the following criteria: their representativeness of the landing levels of the whole cluster, the continuity of use and a sufficient number of uses.

Seasonal variations were also studied by looking at monthly means and their confidence intervals in order to possibly identify more relevant periods than others depending on the gear. Filtering over the fishing season avoids a bias related to the seasonal variability of the fishery (Laurec and Le Gall, 1975 in Girard et al., 2000).

The whole approach is presented in figure 1. For the interest fleets identified with this approach, the evolution trend of the monthly LPUEs is considered as a proxy of the abundance of the species and is discussed.

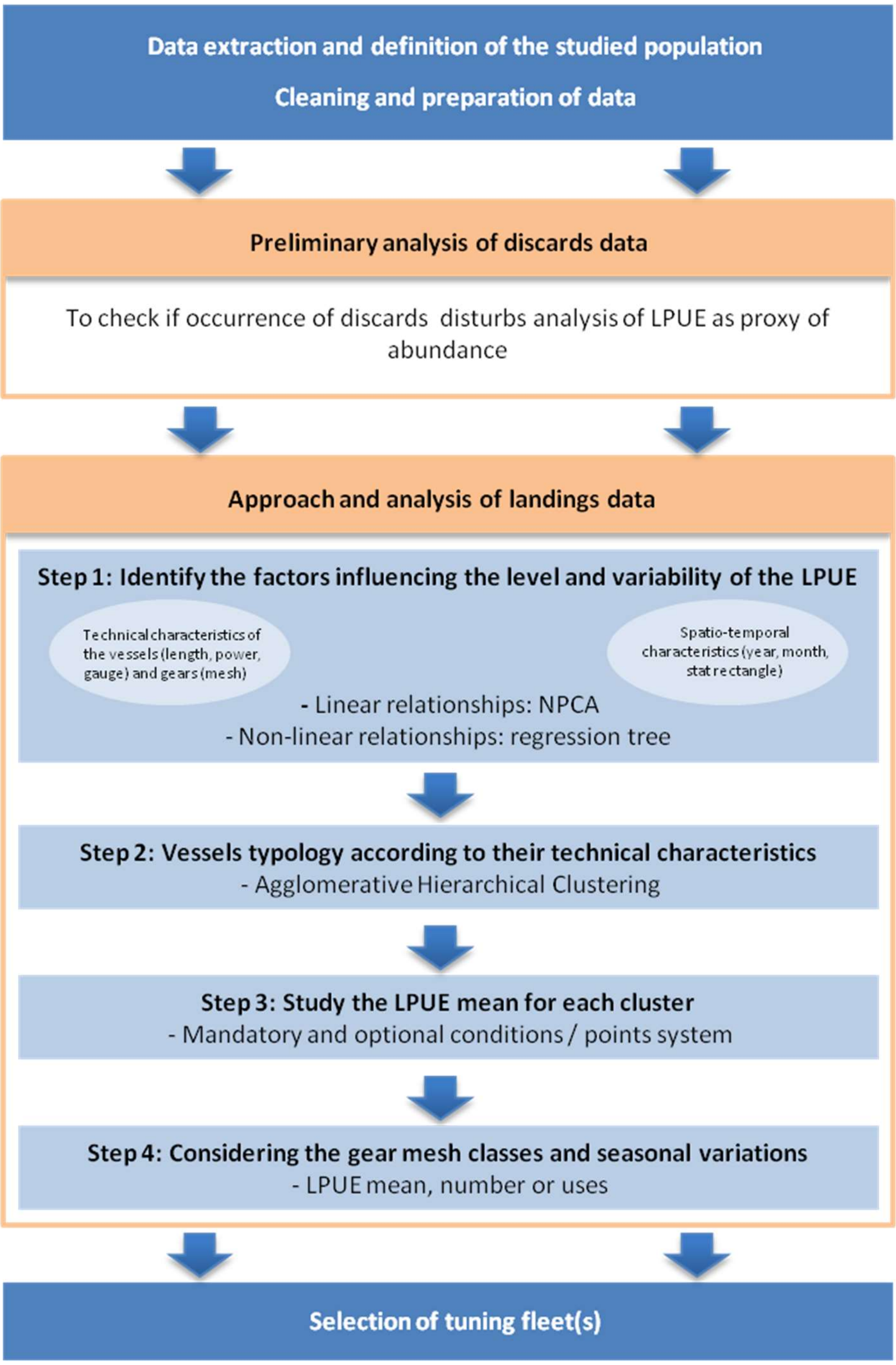


Figure 1: Retained approach for the identification of reference fleets from the study of the LPUE.

Calculations were carried out under R Software. The following packages were used: FactoMineR for simple descriptive statistics, rpart for classification trees.

3 Results

3.1 Discards analyses

For the five selected gears *a priori* (OTB, OTT, GNS, GTR and SDN), we have enough discards data to decide on the importance of the discards (Appendix 2).

For the trawlers, the number of observations is high and these are well distributed over the year especially since 2008-2009. For gillnets, the number of observations is lower with observations distributed over the year from 2009-2010 even if the first quarter is less observed. For the Danish seines, observations start in 2012. This short series does not allow the consideration of this gear that moreover appeared only since 2010.

Although data are available for the period 2003-2015, the review of the observations distribution leads to a better analysis over the period 2009-2015 for the four remaining gears (Appendix 3):

- Otter bottom trawls (OTB) show discards of fishes, above the commercial weight, stable and very low (less than 3% on average except in December when this rate reaches 11% on average). Confidence intervals are restricted around the mean, only December presents a slightly larger interval;

- Otter twin trawls (OTT) display releases of fishes above the commercial weight extremely low (less than 1%), very stable over the time period and with very limited confidence intervals;

- Set gillnets (GNS) exhibit low releases of fishes above the mean commercial weight and along the time series (less than 5%). The average over the months is characterized by higher values for January and November. The confidence intervals are also extended for January, February, April, August and November;

- Trammel nets (GTR) show discards of fishes above the commercial weight, regularly higher than 15% (whether for years or for months) with a peak in March (40% on average). In addition, the range of confidence intervals is very important for this gear.

Regarding these results, it is therefore proposed to retain the otter bottom trawls (OTB), the otter twin trawls (OTT) and set gillnets (GNS) for further analysis. They potentially allow the approach of LPUEs as indicators of abundance, but only for fishes above the commercial weight - 40 gr.). In the case of gillnets, January and November should be avoided later in the analysis of the LPUEs.

3.2 Results for otter bottom trawls (OTB)

3.2.1. Factors influencing the level and variability of LPUEs

3.2.1.1. Regarding for linear links

The correlation circle of the NPCA shows the linear relationships that exist between the different variables. There is no linear relationship between the levels of LPUEs, the variability indicators and the technical characteristics of the vessels (Figure 2).

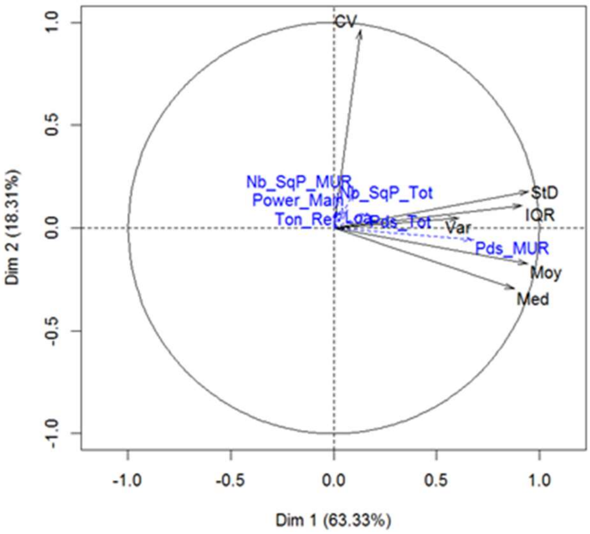


Figure 2: Correlation circle for OTB

The Kruskal-Wallis tests allow retaining statistical rectangle, month, year and gear mesh classes as discriminant variables.

The years 2013, 2014 and 2015 display similarities because of their low LPUEs, whereas the years 2006, 2009 and 2011 are characterized by strong LPUEs (Figure 3).

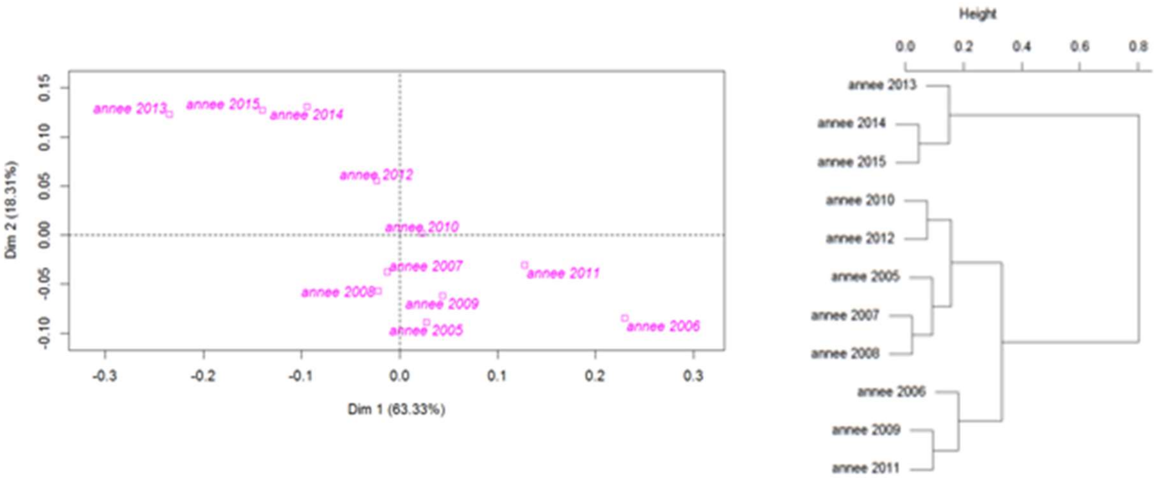


Figure 3: Year barycentre clouds in the principal factorial plane of the NPCA and associated AHC

January, February and March are characterized by low LPUEs, while May and October are characterized by strong LPUEs (Figure 4).

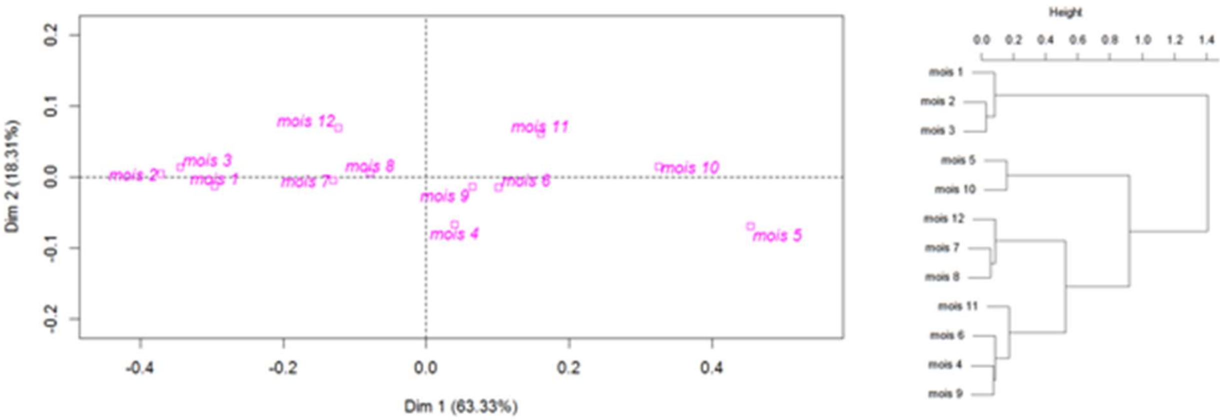


Figure 4: Month barycentre clouds in the principal factorial plane of the NPCA and associated AHC

The statistical rectangles 21E5, 21E6, 22E6, 22E8, 23E3, 23E4, 23E5, 24E2, 24E3, 24E4, and 24E5 form a group with the common characteristics of small LPUEs (Figure 5). The cluster including the statistical rectangles 16E7, 17E7, 17E8, 18E7, 18E8, 19E6, 19E8 and 22E4 is characterized by strong LPUEs (Figure 5).

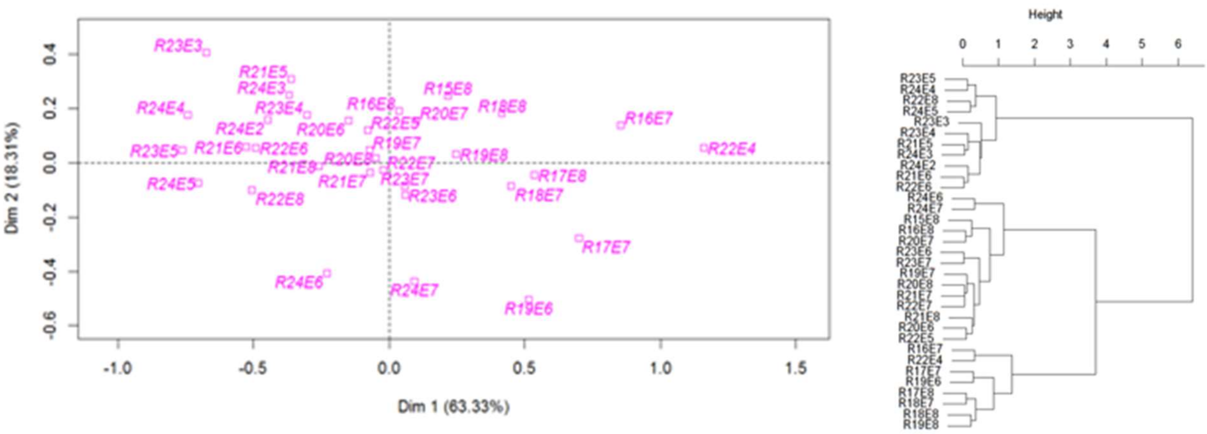


Figure 5: Statistical rectangle barycentre clouds in the principal factorial plane of the NPCA and associated AHC

Finally, gear mesh sizes greater than 90 mm are associated with lower LPUEs (Figure 6).

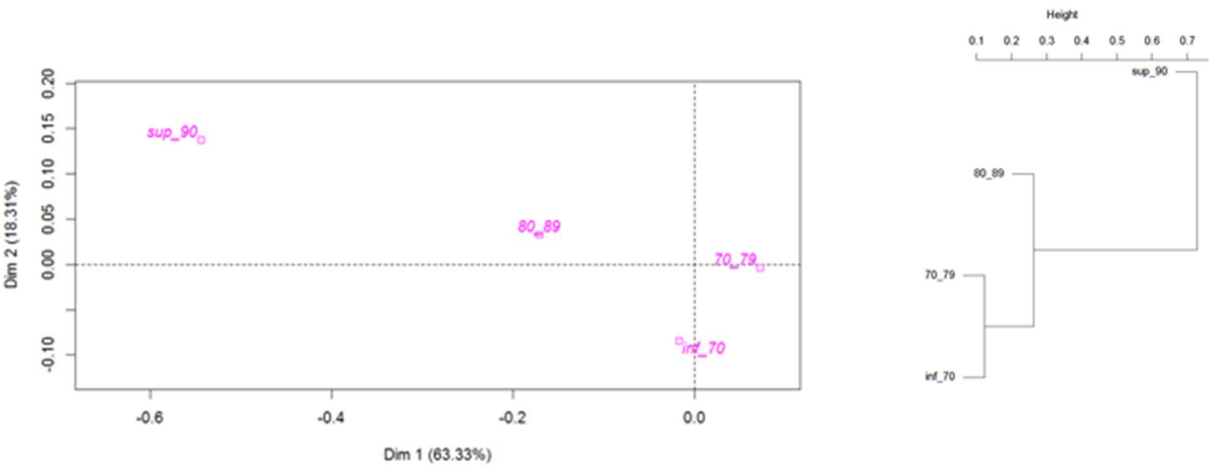


Figure 6: Barycentre clouds of gear mesh classes in the principal factorial plane of the NPCA and associated AHC

Gear meshes greater than 90 mm are sparingly used for OTB (Figure 7) while the 70-79 mm class is widely used.

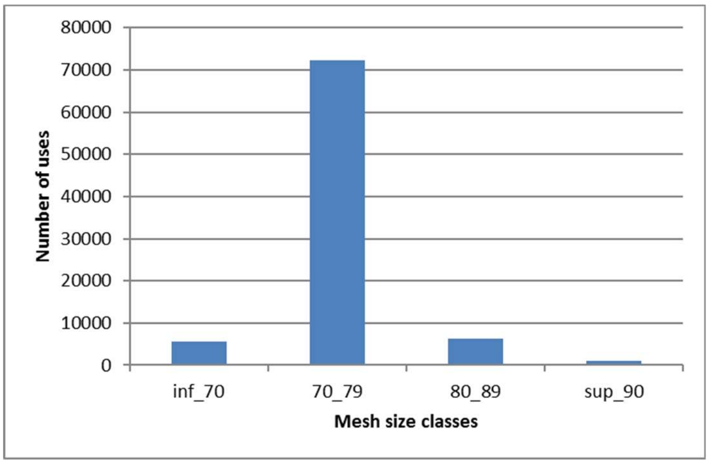


Figure 7: Number of uses of the different gear mesh classes over the period 2003 to 2015

Review:

The sum of the two dimensions of the NPCA is equal to 81%, thus clearly accounting for the dispersion of the LPUEs and their associated indicators of variability. However, it does not highlight linear relationships between the LPUE levels, their variability indicators and the technical characteristics of the vessels.

It is interesting to note a north / south effect of the Bay of Biscay, the south being characterized by higher LPUEs, as well as a clear temporal effect: January, February and March are associated with low LPUEs.

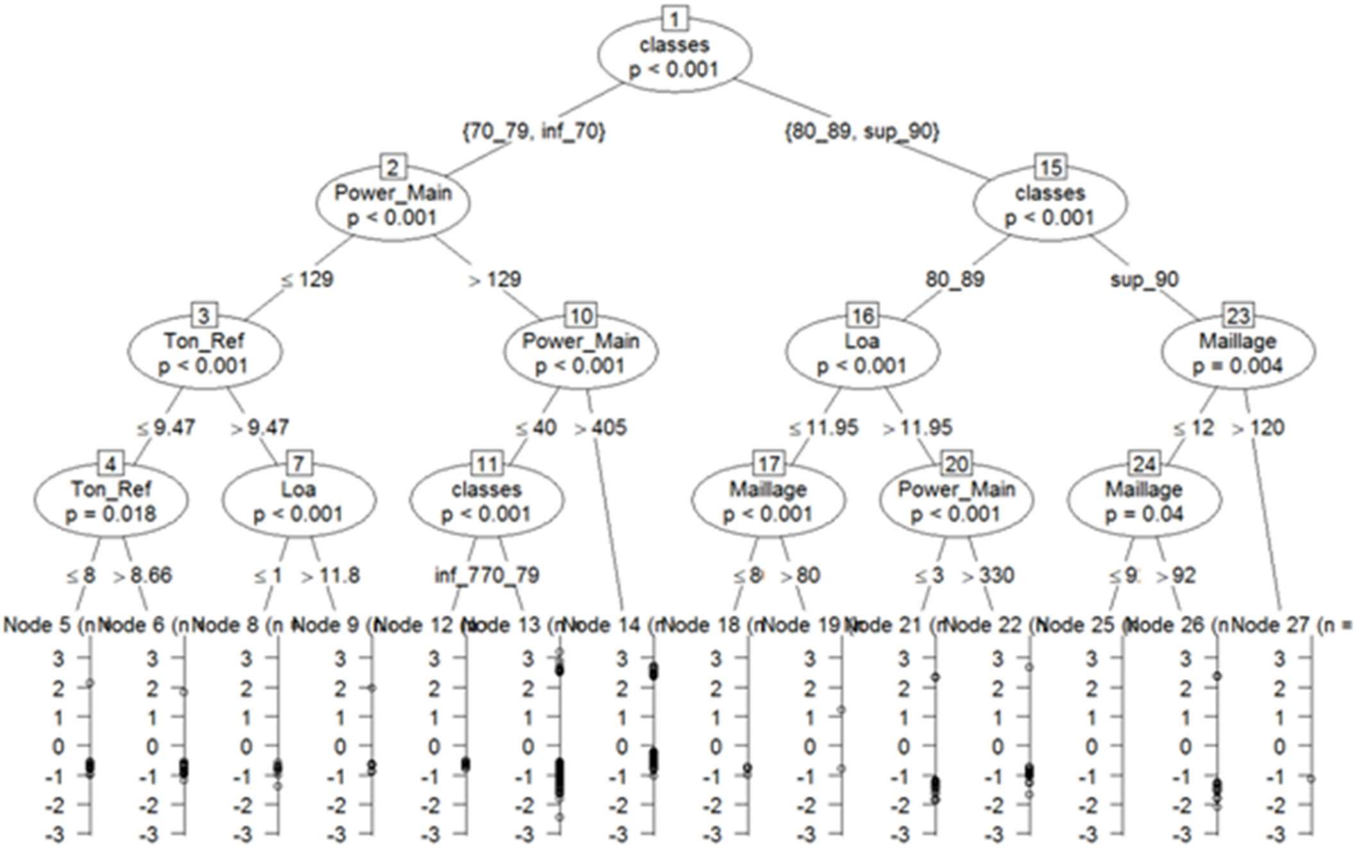
The linear relationship analysis does not allow selection and determination of an OTB reference fleet, depending on the technical characteristics of the vessels.

3.2.1.2. Regarding other types of link

First, all variables were considered as input variables, that is, participating in the construction of the regression tree. The first constructed tree (not shown here) highlights a great influence of the spatiotemporal variables on the variations of LPUEs; they could mask an influence of the technical characteristics. The choice was made to remove those spatiotemporal variables from the analysis in a second step (Figure 8).

The highest LPUEs (bold values in the table in figure 8) are associated with vessels of which:

- The engine power is greater than 405 kW when associated with a gear whose mesh is less than 79 mm;
- The engine power is between 129 and 405 kW, and gear has a mesh less than 70 mm;
- The vessel length is less than or equal to 11.95 m and the gear associated with a gear mesh equal to or less than 80 mm.



Moy	11,01	6,81	14,27	7,30	18,99	17,58	21,16	21,42	2,46	8,40	18,19	7,34	7,35	22,00
Med	6	3,98	8,24	4,42	**11,20**	9,36	**11,43**	**11,12**	1,07	3,44	9,20	5,12	3,52	9,46
N	1853	1013	2983	517	1533	24994	2356	865	10	2248	844	166	2485	38

Figure 8: Conditional regression tree on log10Moy (standardized LPUE) with technical characteristics

Review:

Spatiotemporal factors have more weight than technical characteristics to account for the variability of the LPUE. After removing these factors, the technical characteristics of the gear and the vessels are highlighted. Vessels with a engine power of more than 405 kW and a gear mesh less than 79 mm are associated with very LPUEs and have a large number.

3.2.2 Vessel typology according to their technical characteristics

AHC allows forming 3 distinct clusters (groups) according to the technical characteristics of the closer vessels (Figure 9).

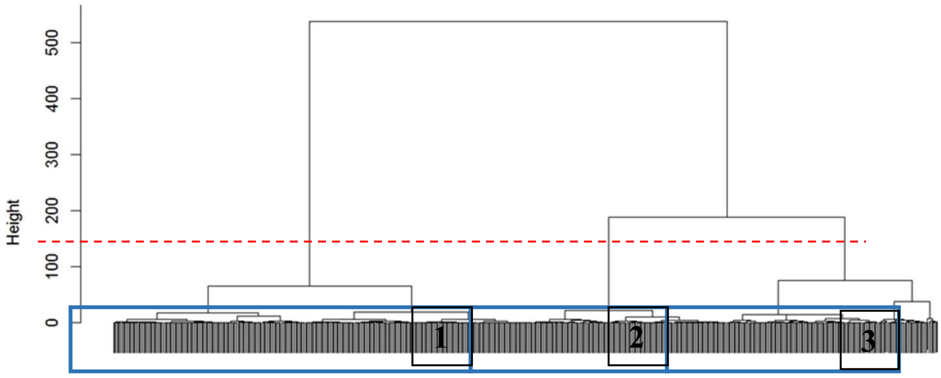


Figure 9: AHC of vessels according to their technical characteristics (standardized)

Table 2 presents the 3 selected clusters:

- Cluster 1 is defined by small vessels (between 7.9 and 15.8 m) with a small gauge between 2 and 43.9 grt, and an engine power between 44 and 256 kW;
- Cluster 2 is characterized by large vessels (between 16.5 and 37.2 m), with a gauge between 58 and 361 grt and an engine power between 261 and 1080 kW;
- Cluster 3 is characterized by medium-sized vessels (between 14.1 and 20.3 m), with a gauge between 29.5 and 115.8 grt and an engine power between 200 and 351 kW.

Table 2: Per cluster values of technical characteristics

Cluster		Vessel length (m)			Gauge (grt)			Engine power (kW)		
Code	Number	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	299	7.9	11.3	15.8	2	15.9	43.9	44	140.9	256
2	151	16.5	21.0	37.2	58	114.5	361	261	398.7	1080
3	138	14.1	15.9	20.3	29.5	48.6	115.8	200	275.4	351
Total	588									

3.2.3 Study of average LPUE per cluster for the identification of interest fleets

For each cluster, changes in landing average calculated by month and by year are shown in Figure 10. Cluster 2 presents a high variability at the end of the period. For clusters 1 and cluster 3, the variability decreases during the period studied as well as the average landings of striped red mullet. At the end of the period, cluster 1 displays low variability and low average landings. Conversely, cluster 3, which has a higher landing average, maintains some cyclicality in the levels of the LPUEs.

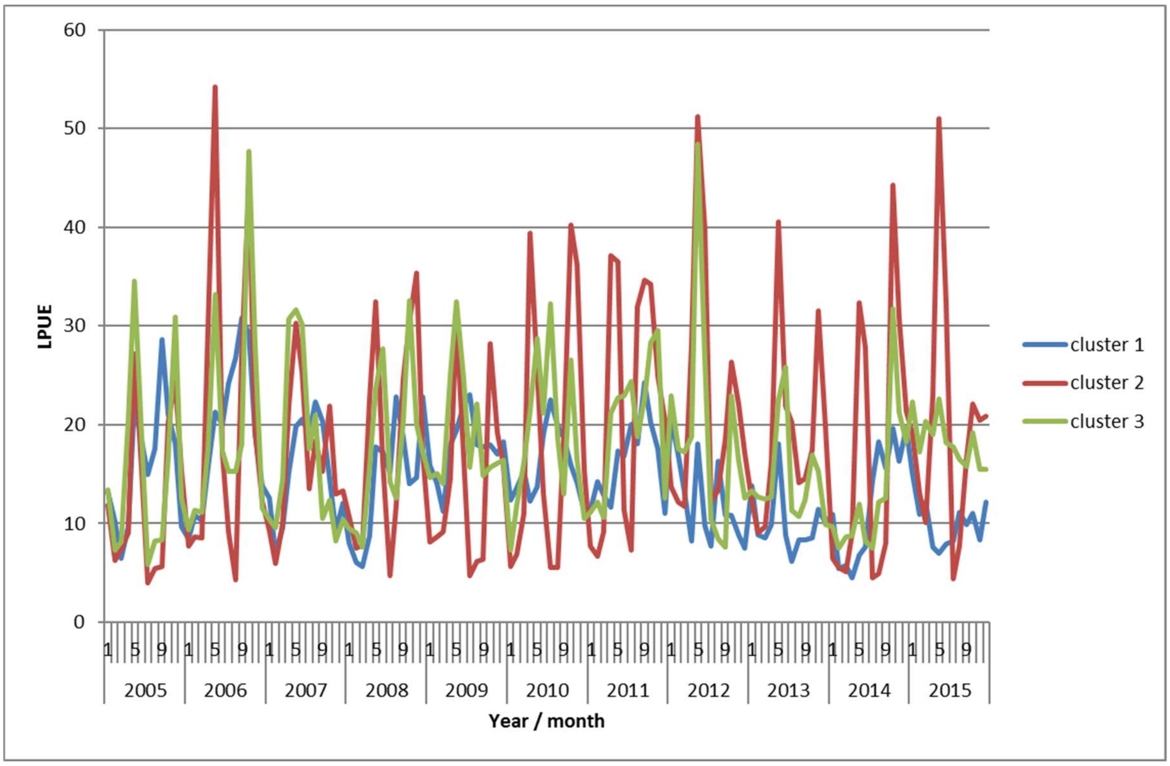


Figure 10: Average LPUEs per cluster for striped red mullet in the Bay of Biscay

In the northern Bay of Biscay (Figure 11), cluster 3 shows high variability at the beginning of the period, which seems to be decreasing at the end of the period. Cluster 2 has cyclical variability over several years with a peak at the end of 2014. Cluster 1 is characterized by a variability slightly decreasing over time. For this cluster, the LPUEs have an annual cycle except at the end of the period.

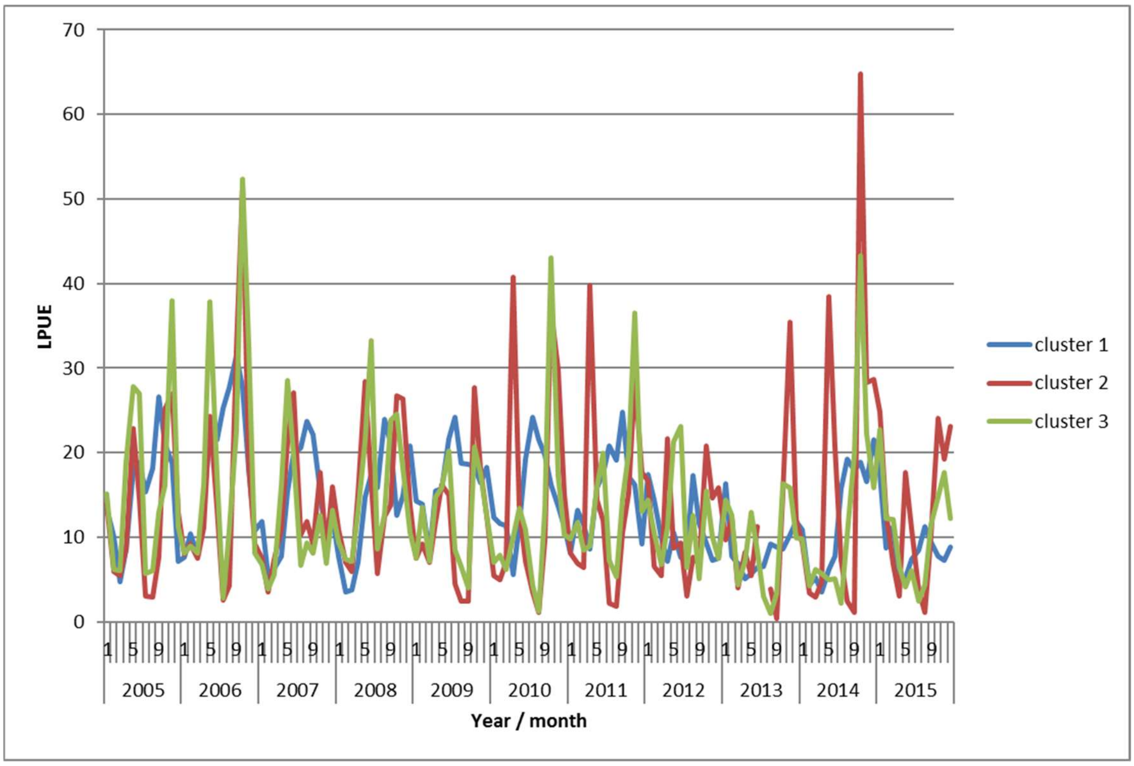


Figure 11: Average LPUEs per cluster for striped red mullet in the north of Bay of Biscay

In the southern Bay of Biscay (Figure 12), clusters 1 and 3 show a decrease in average landings along the series and a loss of cyclicity of the LPUE towards the end of the period. Cluster 2 has a large variability in average inputs; however, it remains cyclical throughout the period.

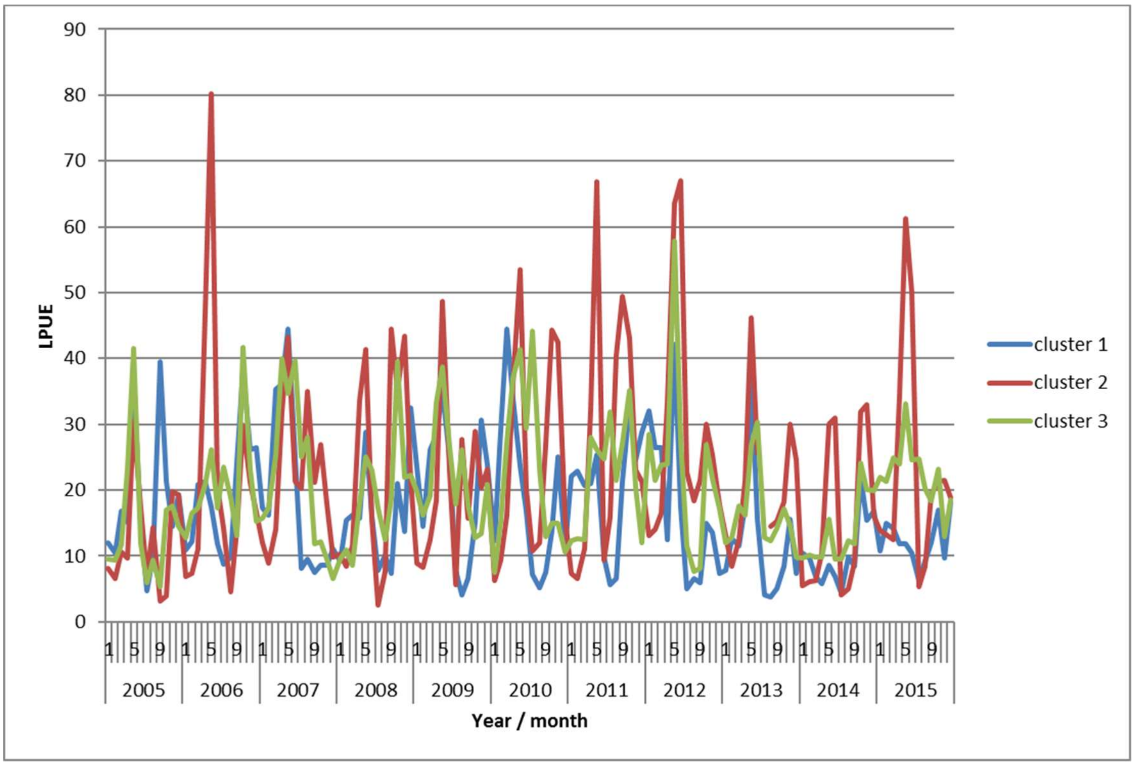


Figure 12 : Average LPUEs per cluster for striped red mullet in the south of Bay of Biscay

Table 3 summarizes the results following the application of the mandatory and optional conditions on the data series.

Table 3: Classification of clusters for OTB

Method		Gear : OTB		
Variability of LPUE				
Preliminary	According to the spatiotemporal and technical characteristics (vessels and gears)	1. Statistical rectangles 2. Months		
	According to the technical characteristics only (vessels and gears)	1. Mesh size classes 2. Engine power 3. Mesh size or length		
Multi-criteria selection method				
Level of obligation	Vessel typology (technical characteristics)	Cluster 1	Cluster 2	Cluster 3
Mandatory	Sufficient number of vessels (> 30)	X	X	X
	Long series (≥ 11 years)	X	X	X
	Medium to high CPUE level (> 5 kg/UE) over the period	X 14,6	X 16,4	X 16,6
Optional	Stable seasonal signal (both in amplitude and periodicity) during the series	1/3	1/3	1/3
	Activity present in N and S of the Bay of Biscay	3/3	2/3	3/3
	Moderate seasonal variability	3/3	2/3	2/3
Notation		7/9	5/9	6/9
Proposed ranking				
	Intra gear	1	3	2

Although the results are close, this point system allows proposing cluster 1 for OTB. The following analyses therefore concern only this cluster. Figure 13 shows average LPUEs above the minimum landing threshold (except one month in 2014) with no significant seasonality throughout the period.

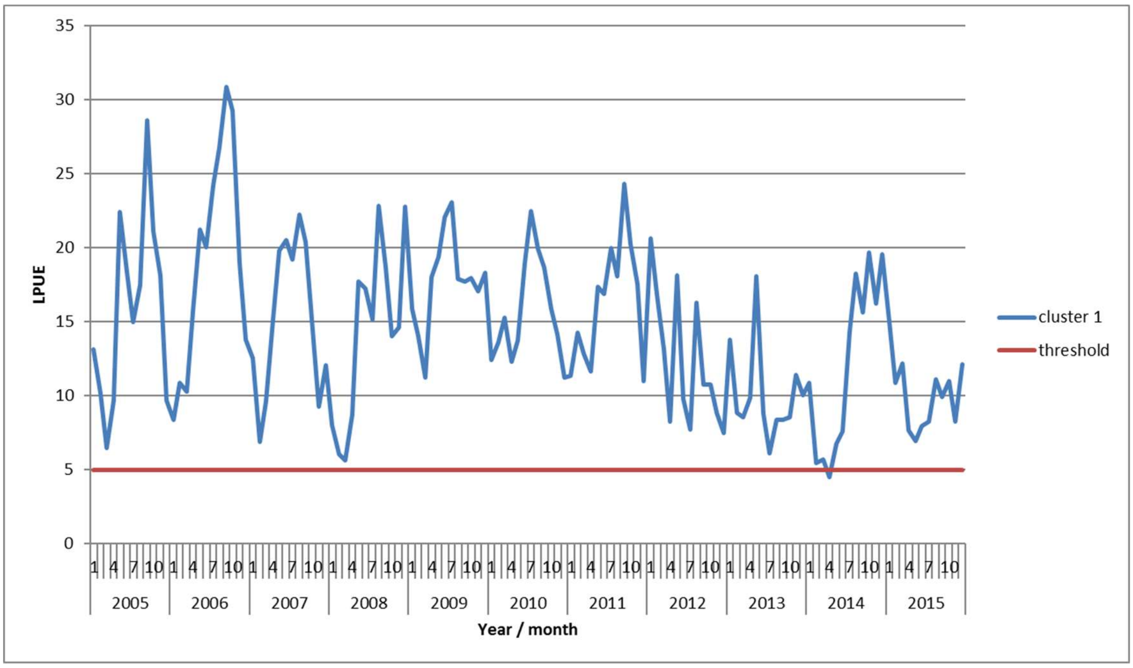


Figure 13: Average striped red mullet LPUE per month for cluster 1 OTB over 2005 - 2015

3.2.5. Considering gear mesh classes and seasonal variations

The monthly evolution of the LPUEs for each of the gear mesh classes used for cluster 1 - OTB is shown in appendix 4. The 70-79 mm mesh class is by far the most represented class for this cluster. We therefore focus, from now on, on the LPUE cluster 1 - OTB - mesh 70-79 mm (Figure 14).

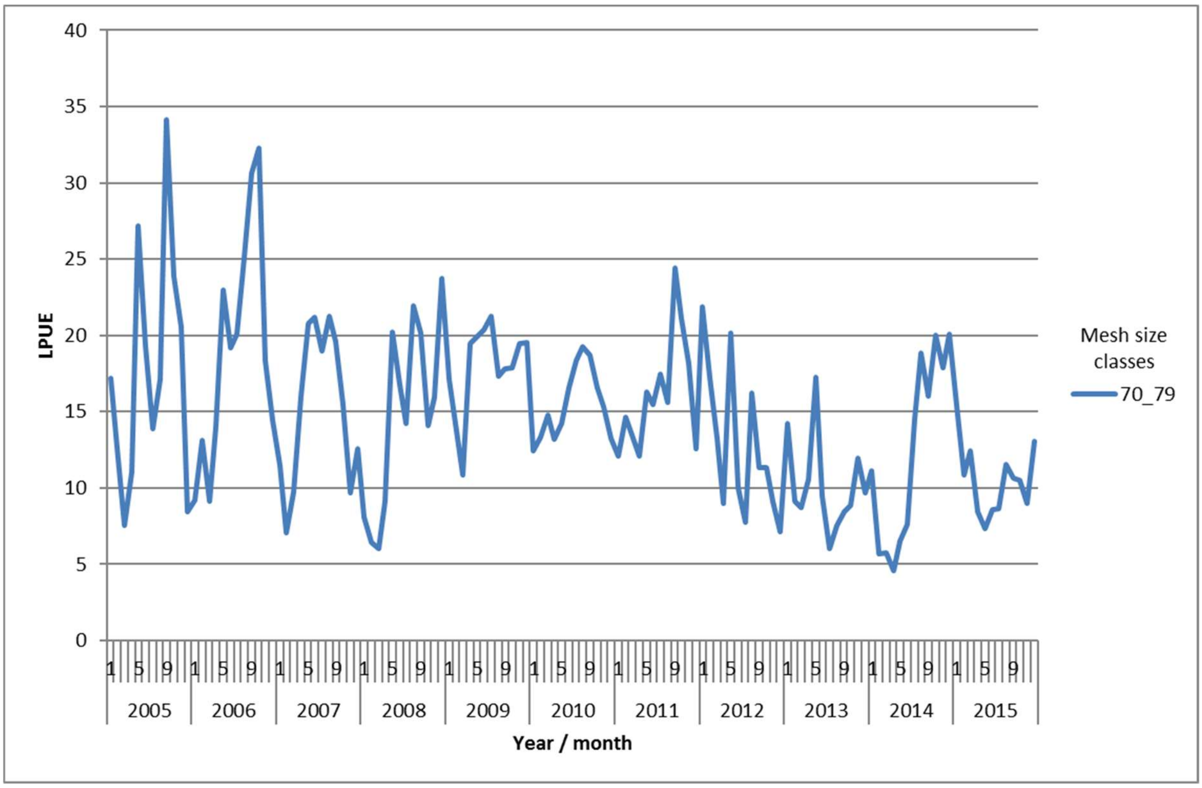


Figure 14 : Monthly evolution of the LPUEs for the 70-79 mm mesh size classes used for cluster 1 - OTB

For this gear mesh size of interest, the average LPUEs oscillate between 10 and 20 kg per unit of effort according to the months of the year. They are the strongest between May and October. The confidence interval is relatively constant (Figure 15).

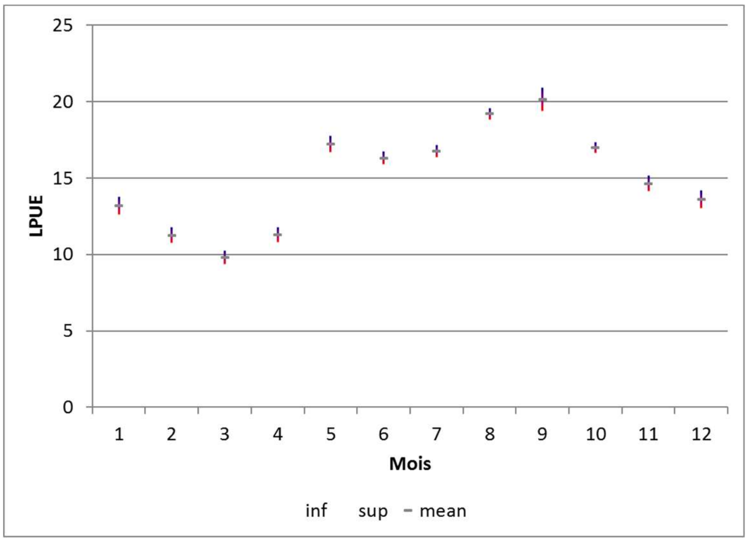


Figure 15: Average LPUEs per month over the period 2005 to 2015 for cluster 1 - OTB for mesh class 70 - 79 mm

Based on these characteristics, it is proposed to work throughout the year for this fleet.

For the cluster 1 - OTB with a 70 - 79 mm gear mesh size, the evolution of its use over time and of the LPUEs for the whole Bay of Biscay are considered.

The number of uses of the mesh 70 - 79 mm for OTB cluster 1 shows a decrease during the study period, however this decrease is not significant. Like use, LPUE decreases over the period of study but significantly in this case (Figure 16).

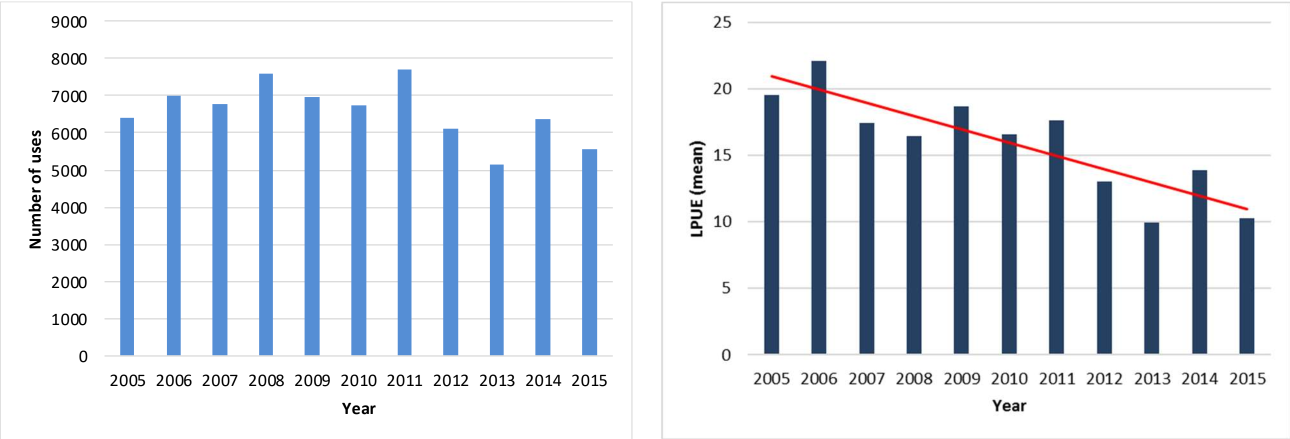


Figure 16: Number of uses and levels of associated LPUEs for the Bay of Biscay - OTB - cluster 1- mesh class 70 - 79 mm

3.3 Results for OTT

For this gear that was potentially of interest, the results are not presented because the LPUEs are below the set threshold value from 2012 onwards.

3.4 Results for GNS

3.4.1. Factors Influencing the Level and Variability of the LPUEs

3.4.1.1. Regarding linear links

The correlation circle of the NPCA shows the linear relationships that exists between the different variables. There is no linear relationship between the levels of the LPUE, the variability indicators and the technical characteristics of the vessels (Figure 17).

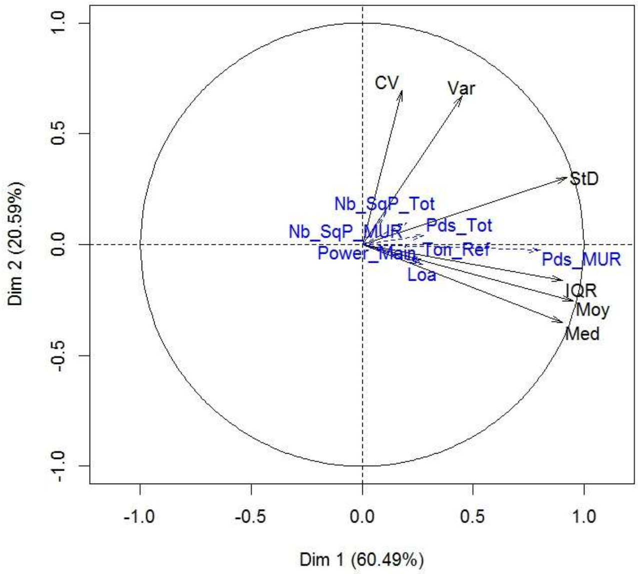


Figure 17: Correlation circle for the gear GNS

The Kruskal-Wallis tests allow retaining statistical rectangle, month, year and gear mesh class as discriminant variables.

The years 2014 and 2015 are characterized by low LPUEs (Figure 18).

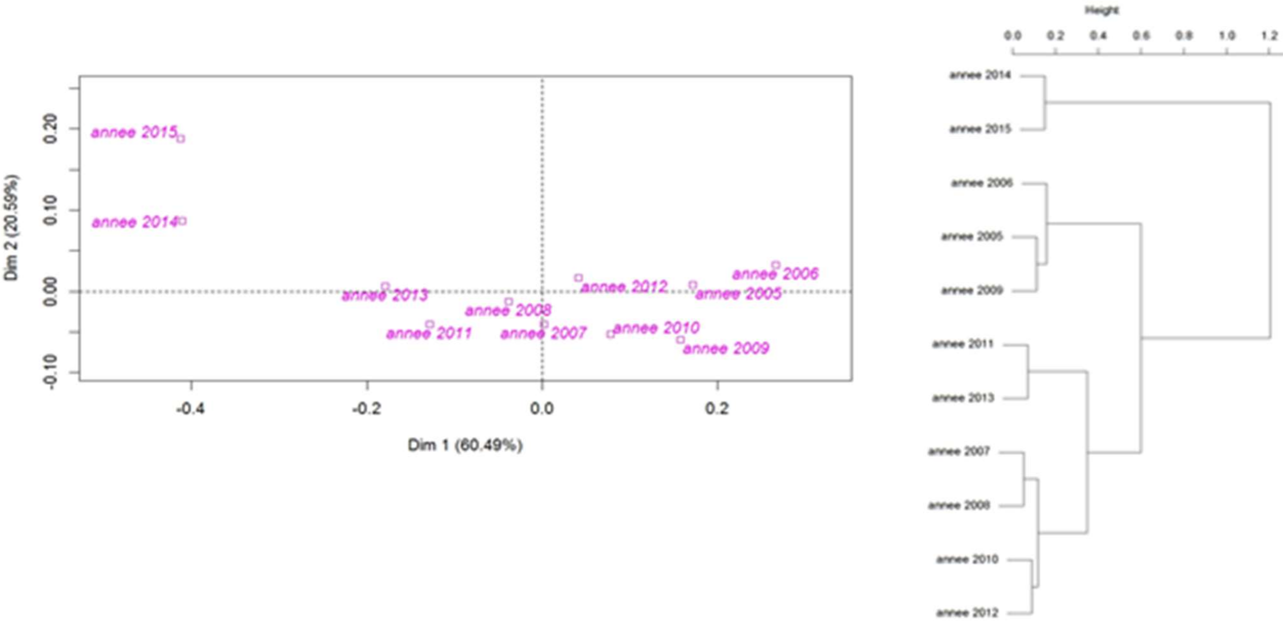


Figure 18 : Year barycentre clouds in the principal factorial plane of the NPCA and associated AHC

April, May and June display strong LPUEs (Figure 19).

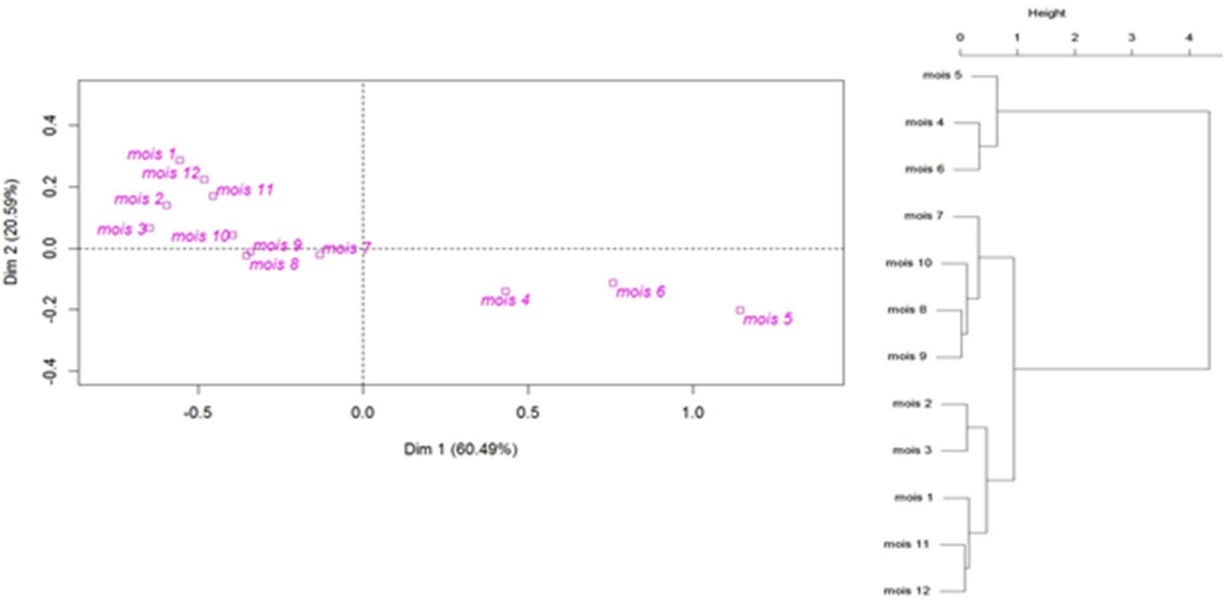


Figure 19: Month barycentre clouds in the principal factorial plane of the NPCA and associated AHC

The statistical rectangles 21E7, 22E6 and 22E7 are characterized by strong LPUEs. The statistical rectangles 15E8, 16E8, 18E8, 19E6, 19E8, 22E5, 24E3, and 24E4, 15E8, 16E8, 18E, 19E6, 19E8 and 22E5 are characterized by low LPUEs (Figure 20).

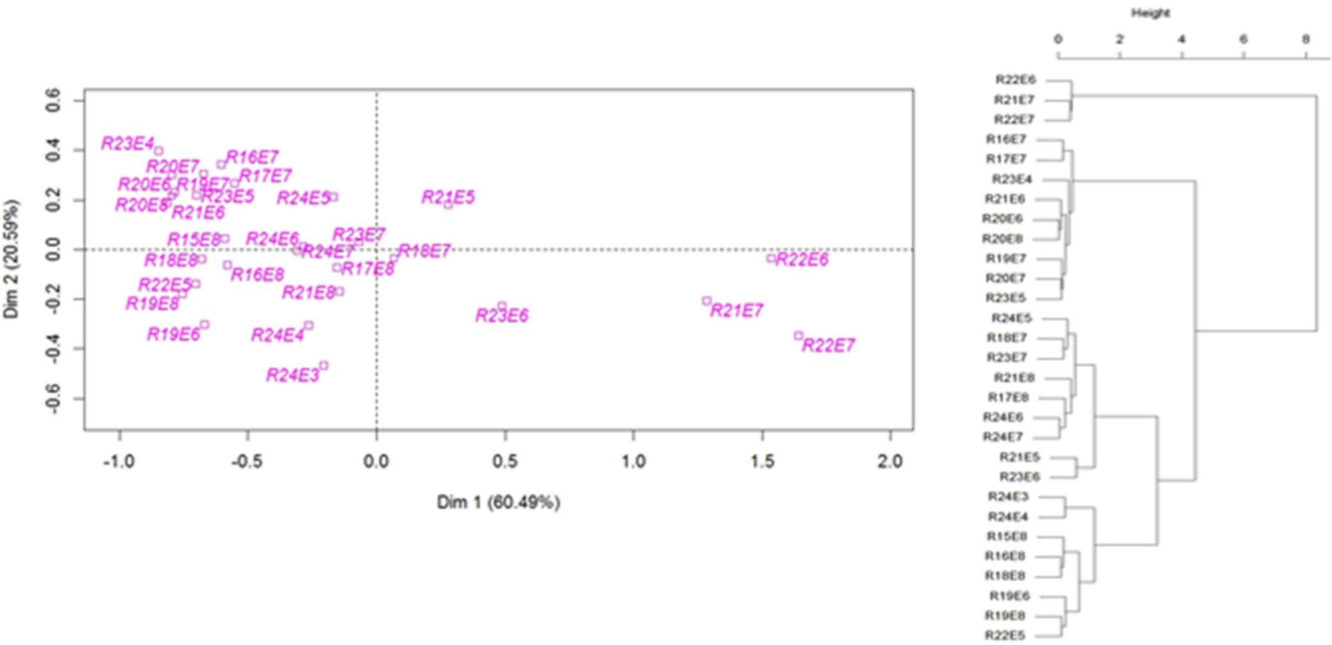


Figure 20: Statistical rectangle barycentre clouds in the principal factorial plane of the NPCA and associated AHC

Finally, the highest LPUEs are associated with gear meshes between 51 - 70 mm and 101 - 109 mm (Figure 21). The first grouping of gear meshes is part of those strongly implemented for this gear. The second grouping corresponds to meshes used rarely (Figure 22).

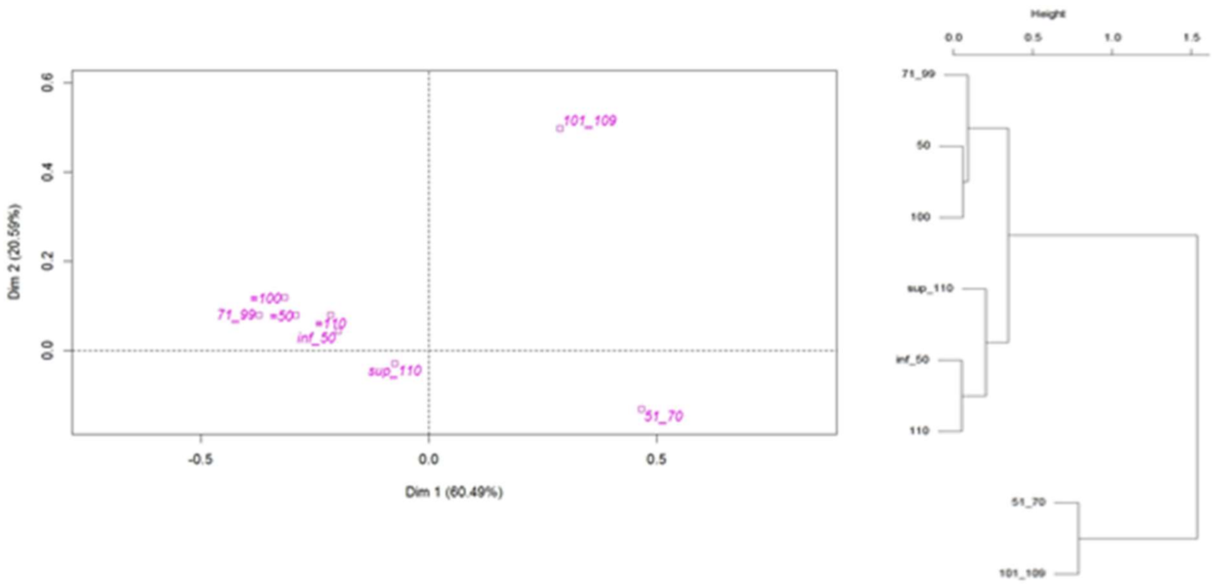


Figure 21: Barycentre clouds of gear mesh class in the principal factorial plane of the NPCA and associated AHC

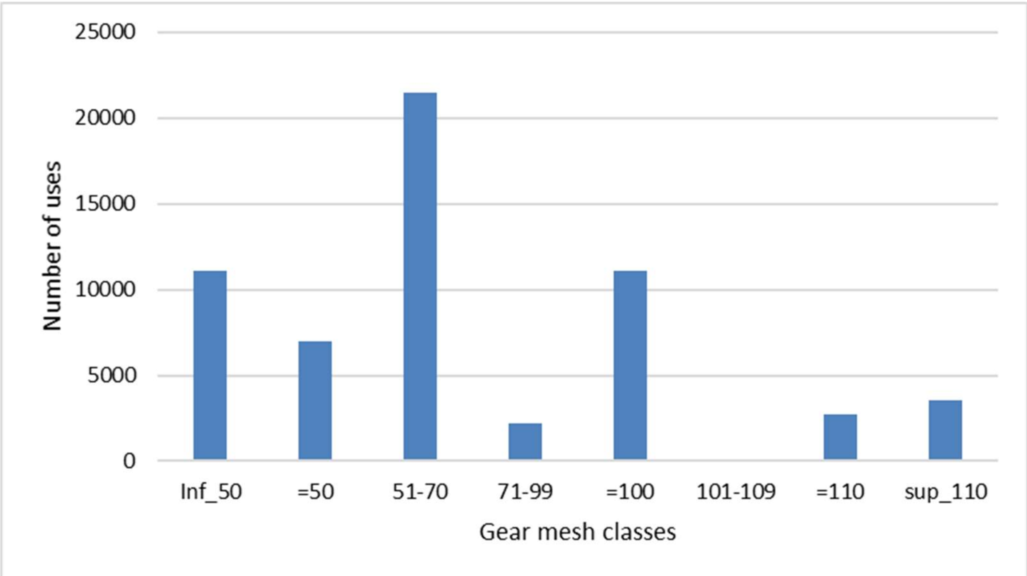


Figure 22: Number of uses of the different gear mesh classes over the period 2003 to 2015

Review:

The sum of the two dimensions of the NPCA is equal to 81%, thus clearly accounting for the dispersion of the LPUEs and their associated indicators of variability. However, it does not highlight linear relationships between the LPUE levels, their variability indicators and the technical characteristics of the vessels.

There is a significant time effect: April, May and June have the highest LPUEs. It is interesting to note also a spatial effect: rectangles 21E7, 22E6 and 22E7 are associated with strong LPUEs.

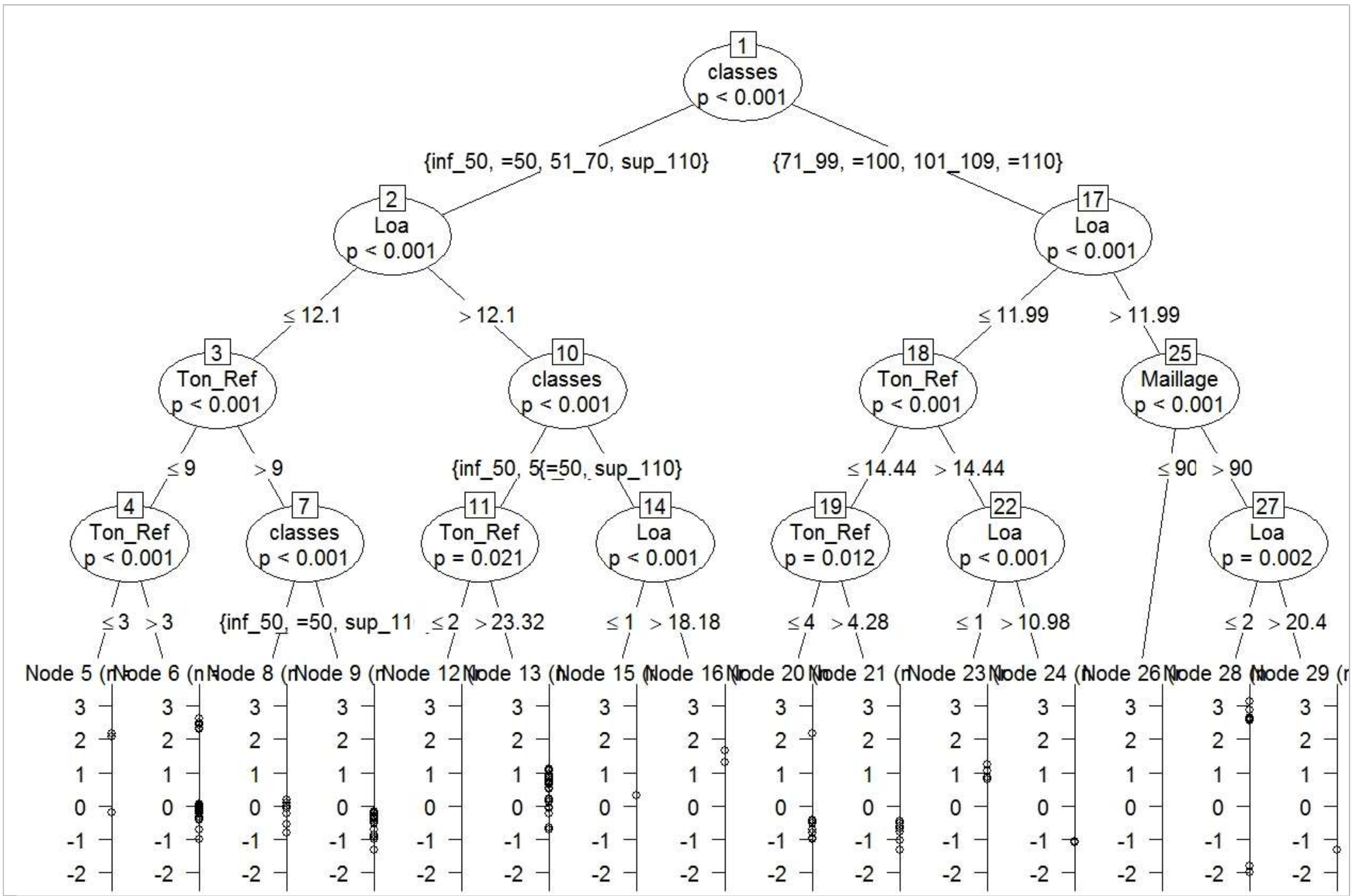
Linear relationships analysis does not allow selection and determination of a GNS reference fleet, depending on the technical characteristics of the vessels.

3.4.1.2. Regarding other types of link

Initially, all variables were considered as input variables, i.e., participating in the construction of the regression tree. The first constructed tree (not shown here) highlights a high influence of the spatiotemporal variables on the variations of LPUEs; they could hide an influence of the technical characteristics on the latter. The choice was made to remove those spatiotemporal variables from the analysis in a second step (Figure 23).

Strong LPUEs (bold values of the table in figure 23) are associated with vessels which:

- The length is higher than 12.1 m when combined with a gear mesh 60-79 mm, and less than 50 mm;
- The length less than or equal to 11.0 m, a gauge higher than 13.1 grt and whose gear has a mesh greater than 80 mm.



Moy	13,76	22,59	76,25	36,44	56,26	189,18	159,79	5,42	11,98	18,88	134,96	48,19	76,73	29,28
Med	10,59	15,48	39,01	20,94	44,44	**158,6**	**85,8**	1,18	7,76	11,02	**128,15**	18,43	24,96	3,2
N	1570	3448	678	535	19	426	43	15	886	1017	55	169	19	562

Figure 23: Conditional regression tree on log10Moy (standardized LPUE) with technical characteristics

Review:

Spatiotemporal factors have more weight than technical characteristics to account for the variability of the LPUEs. After removing these factors, the technical characteristics of the gear and the vessels are highlighted. The gear characteristics have bigger weight to account for the variability of LPUEs. Vessels longer than 12.1 m are associated with very high LPUEs when their gear mesh classes are 60 - 79 mm or lower than 50 mm.

3.4.2 Vessel typology according to their technical characteristics

AHC allows forming 3 distinct clusters (groups) according to the technical characteristics of the closer vessels (figure 24).

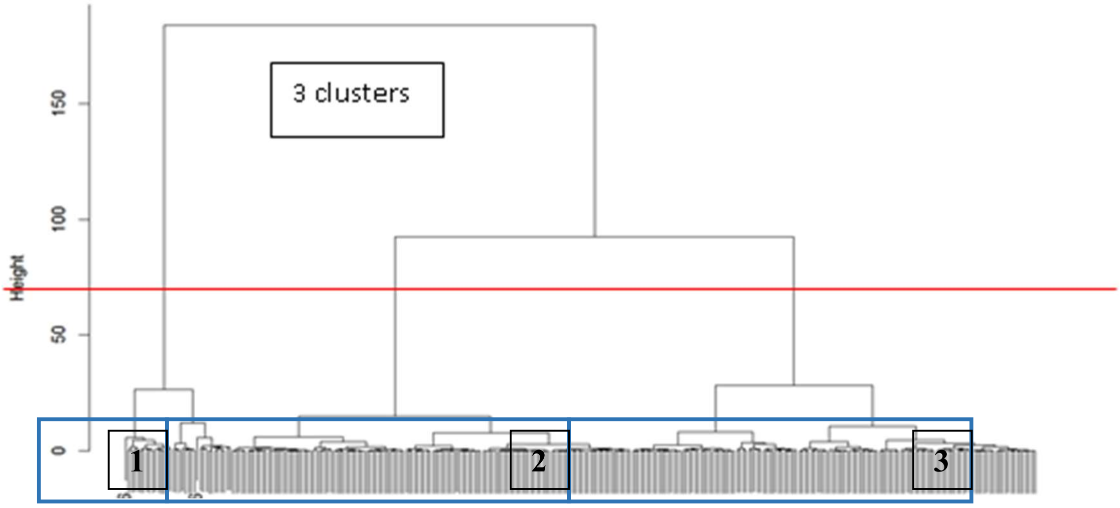


Figure 24 : AHC of vessels according to their technical characteristics (standardized)

- Cluster 1 is defined by small vessels (4.2 to 9.7 m), with a gauge between 0.6 and 39 grt and an engine power between 4 and 110 kW;
- Cluster 2 is characterized by medium-sized vessels (8.2 to 14, 8 m) with a gauge between 2 and 30.2 grt and an engine power between 70 and 331 kW;
- Cluster 3 is characterized by large vessels (12.0 and 30.3 m) with a gauge between 12 and 195 grt and an engine power between 152 and 558 kW.

Table 4 presents the 3 clusters retained:

- Cluster 1 is defined by small vessels (4.2 to 9.7 m), with a gauge between 0.6 and 39 grt and an engine power between 4 and 110 kW;
- Cluster 2 is characterized by medium-sized vessels (8.2 to 14, 8 m) with a gauge between 2 and 30.2 grt and an engine power between 70 and 331 kW;
- Cluster 3 is characterized by large vessels (12.0 and 30.3 m) with a gauge between 12 and 195 grt and an engine power between 152 and 558 kW.

Table 4: Per cluster values of technical characteristics.

Cluster		Vessel length (m)			Gauge (grt)			Engine power main (kW)		
Code	Number	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
1	136	4.2	7.7	9.7	0.6	4.0	39	4	62	110
2	137	8.2	10.8	14.8	2	11.8	30.2	70	147	331
3	37	12.0	19.2	30.3	12	105.4	195	152	321	558
Total	310									

3.4.3 Study of average LPUE per cluster for the identification of interest fleets

For each cluster, evolution in landing averages calculated by month and by year are shown. At the Bay of Biscay scale (Figure 25), the cluster 3 has regular inputs with a cyclic annually variation. However, this variation is lower at the end of the period studied. Cluster 1 displays a smoother profile and fewer variations than cluster 2. Cluster 1 has a regular profile with moderate variations of LPUEs.

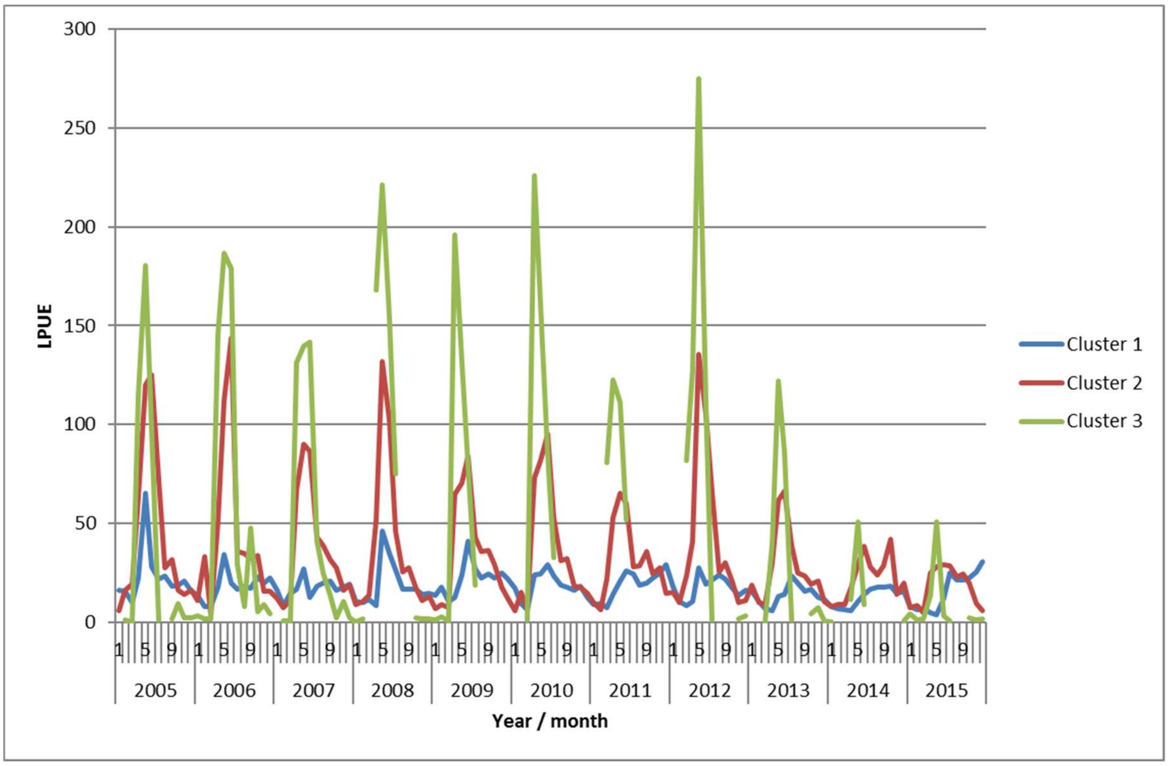


Figure 25: Average LPUEs per cluster for striped red mullet in the Bay of Biscay

In northern Bay of Biscay (Figure 26), cluster 2 shows regular landings of striped red mullet with cyclic variation annually. However, this variation is smaller from 2014. Cluster 1 presents more regular profile and its variations are more regular than cluster 2. Cluster 3 vessels do not have regular landings.

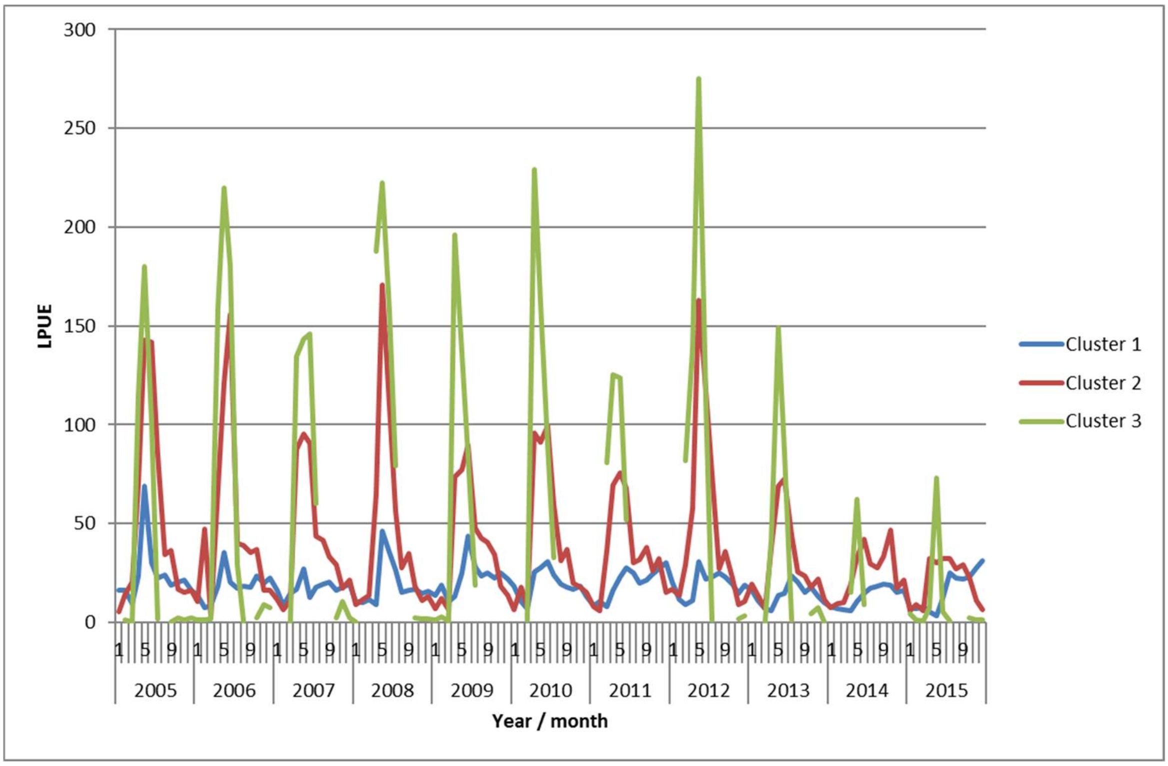


Figure 26: Average LPUEs per cluster for striped red mullet in northern Bay of Biscay

In southern Bay of Biscay (Figure 27), the clusters 1, 2 and 3 have no regular catches.

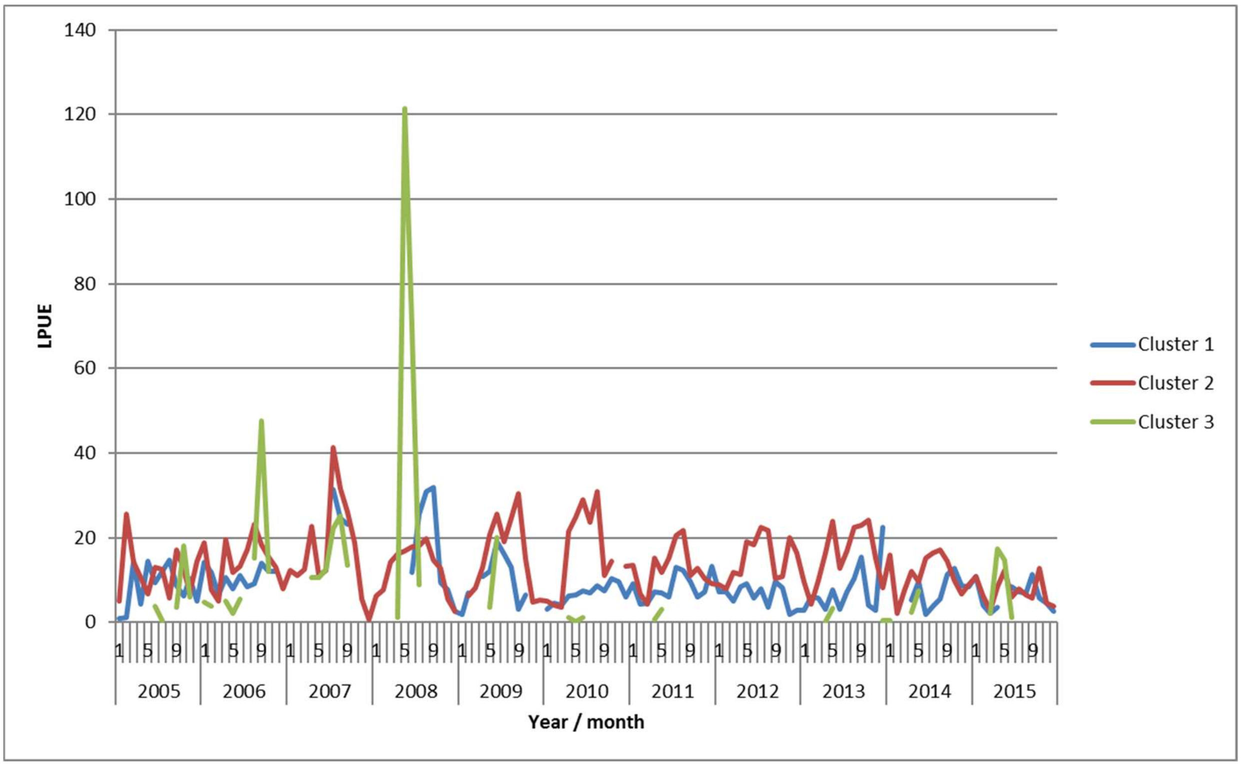


Figure 27 : Average LPUEs per cluster for striped red mullet in southern Bay of Biscay

The table 5 summarizes the results following the application of the mandatory and optional conditions on the data series.

Table 5: Ranking of cluster for GNS

Method		GNS		
Variability of CPUE				
Preliminary	According to the spatiotemporal and technical characteristics (vessels and gears)	1. Statistical Rectangles 2. Month 3. Gear mesh classes		
	According to the technical characteristics only (vessels and gears)	1. Gear mesh classes 2. Length 3. Gauge or gear mesh classes		
Multi-criteria selection method				
Level of obligation	Vessel typology (technical characteristics)	Cluster 1	Cluster 2	Cluster 3
Mandatory	Sufficient number of vessels (> 30)	x	x	x
	Long series (> 11 years)	x	x	
	Medium to high CPUE level (> 5 kg / EU) over the period	X 17,3	X 39,8	94,9
Optional	Stable seasonal signal (both in amplitude and periodicity) during the series	1/3	2/3	
	Activity present in N and S of the Bay of Biscay	2/3	3/3	
	Moderate seasonal variability	3/3	2/3	
Notation		6/9	7/9	
Proposed ranking				
	Intra gear	2	1	

Although the results are tight, this point system allows proposing cluster 2 for GNS. The following analyses therefore concern only this cluster. Figure 28 shows a high level of LPUEs and a marked seasonality throughout the series. Despite a decreased level of LPUEs in 2014 and 2015, LPUEs remain above the minimum landing threshold.

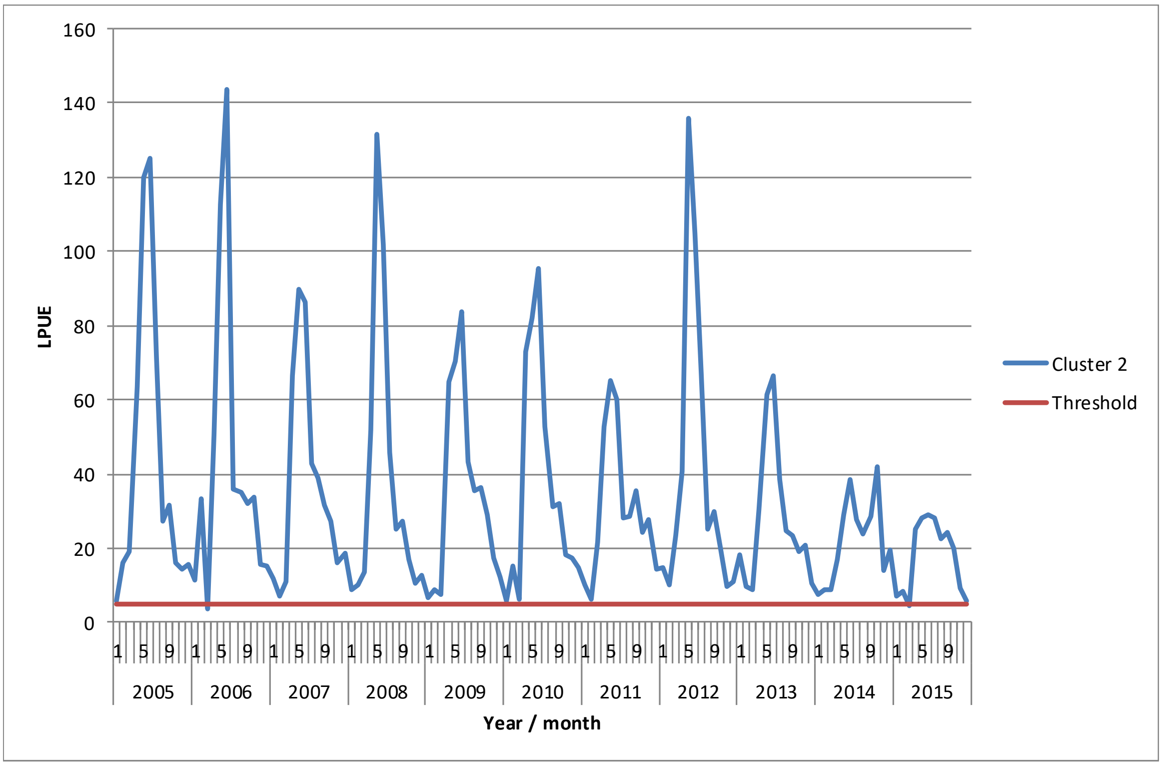


Figure 28: Average striped red mullet LPUEs per month for cluster 2 GNS over 2005 - 2015

3.4.5. Considering gear mesh classes and seasonal variations

The monthly evolution of the LPUEs for each gear mesh classes used for cluster 2 – GNS is shown in appendix 4. The 50 - 59 mm, 60 - 69 mm and higher than 90 mm mesh classes are the most used for this cluster (Figure 29). We therefore focus from now on these 3 classes to refine the characteristics of the reference fleet.

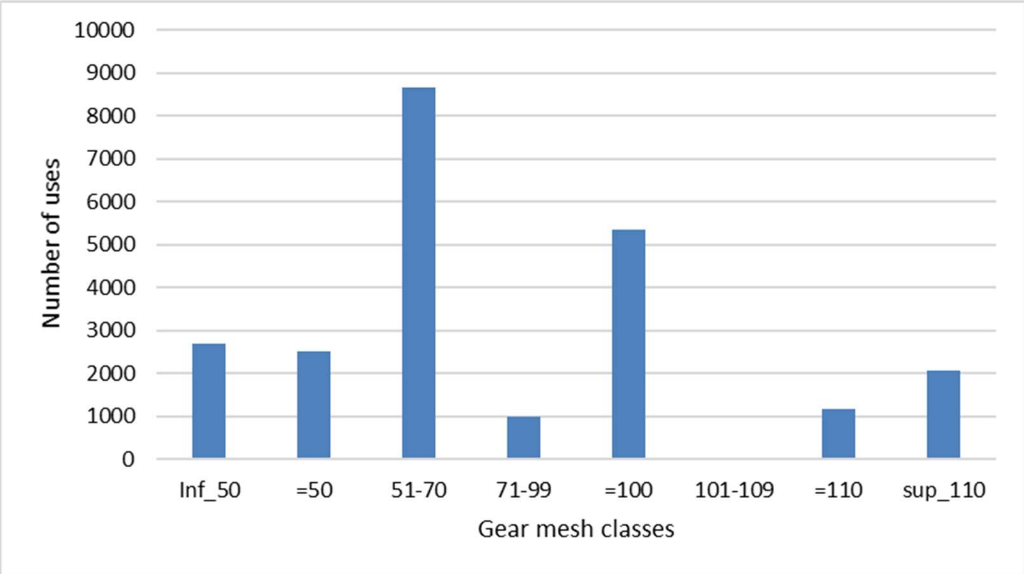


Figure 29: Number of uses of gear meshes between 2005 and 2015 for cluster 2 - GNS

figure 30The monthly evolution of the LPUEs for these three classes is shown in figure 30.

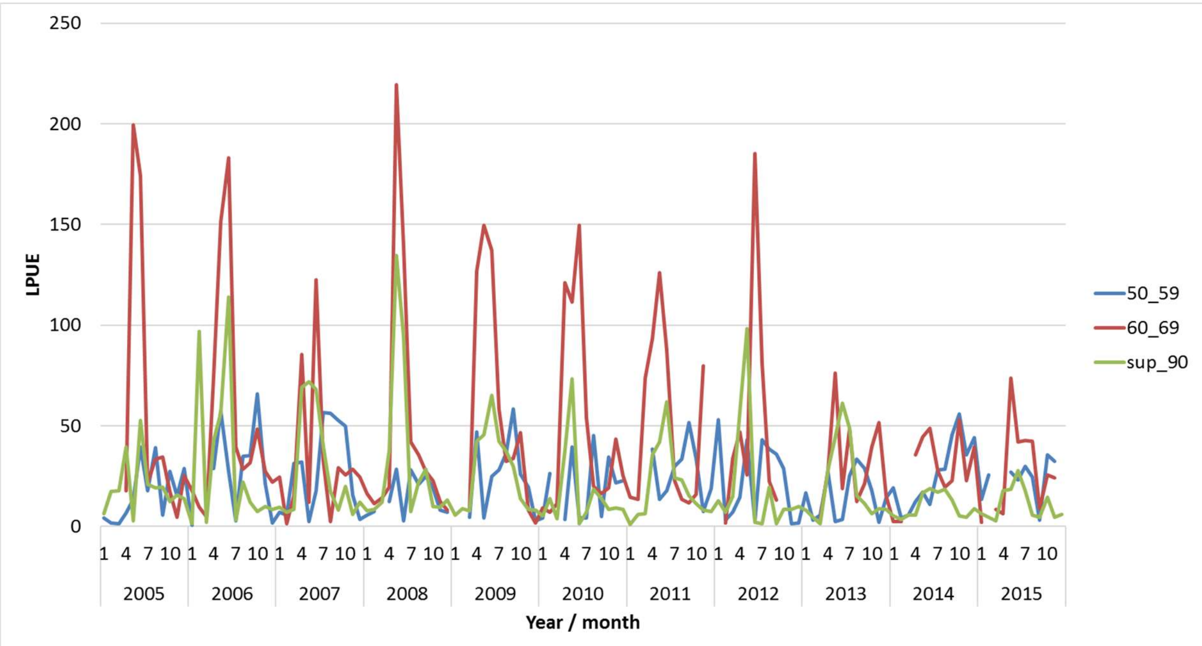


Figure 30: Monthly evolution of the LPUEs for the main gear mesh classes used for cluster 2 - GNS

Mesh classes are considered according to several criteria: their representativeness of the landing levels of the whole cluster, the continuity of use and a sufficient number of uses (Table 6). For those criteria, the three classes of gear mesh 50 - 59 mm, 60 - 69 mm and above 90 mm are considered as interesting for GNS.

Table 6: Results by gear mesh class for LPUEs criteria for cluster 2 - GNS

Selection of proposed gear mesh class			
Metier	GNS		
Cluster	2		
Gear mesh classes (mm)	50-59	60-69	Sup 90
Sufficient level of LPUE	X	X	X
Presence over a long period	X	X	X
Representativeness of the cluster	X	X	X
Many uses	X	X	X
Limited confidence interval			
Gear mesh retained	X	X	X
Quarterly split study	2-3	2	2

The 50 - 59 mm gear mesh has high LPUEs from April to September. March and, to a lesser extent May, are characterized by high confidence intervals (Figure 31).

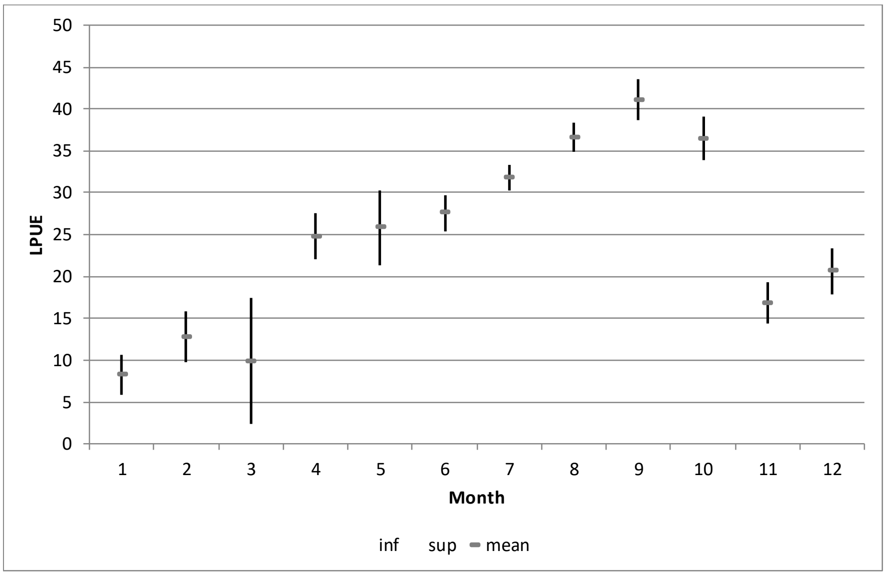


Figure 31: Average LPUEs per month over the series 2005 to 2015 for cluster 2 - GNS for gear mesh class 50 - 59 mm

The gear mesh 60 - 69 mm has high LPUEs in April, May and June. These months are also characterized by a high confidence interval around the mean (Figure 32).

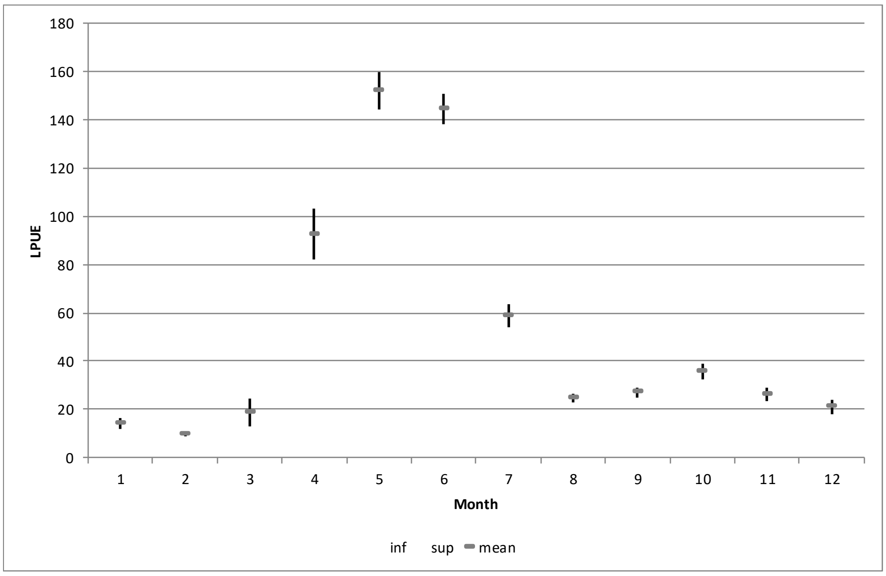


Figure 32: Average LPUEs per month over the series 2005 to 2015 for cluster 2 - GNS for gear mesh class 60 - 69 mm

Gear meshes higher than 90 mm have high LPUEs in April, May, June and July. These months and February are characterized by high confidence intervals around the mean (Figure 33).

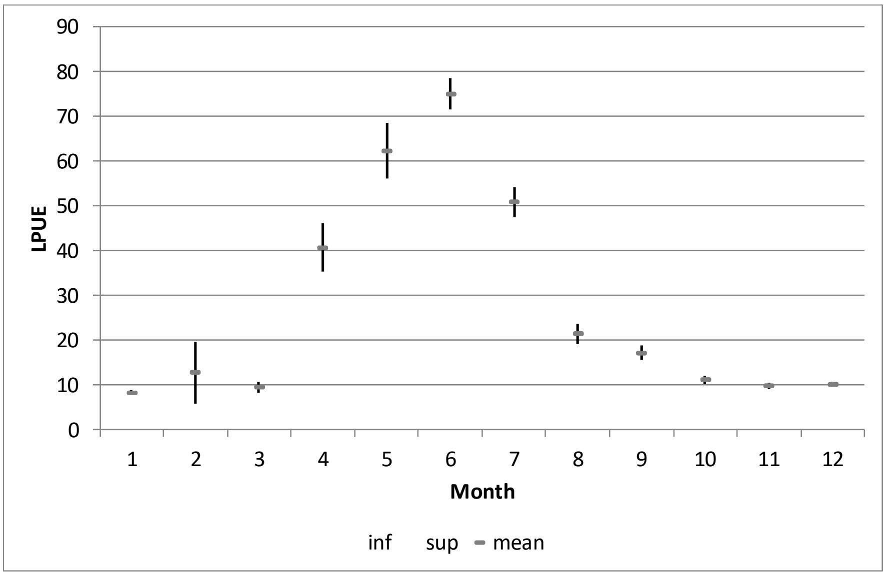


Figure 33: Average LPUEs per month over the series 2005 to 2015 for the cluster 2 - GNS for the gear mesh class greater than 90 mm

Thus, for GNS, a selection of quarters is necessary: quarters 2 and 3 for the gear mesh 50 - 59 mm; quarter 2 for meshes 60 - 69 mm and above 90 mm.

For each of these combinations mesh / quarter of cluster 2 - GNS, the evolution of their use over time and of their LPUEs for the entire Bay of Biscay is considered.

Gear meshes 50 - 59 mm and 60 - 69 mm have their use levels that decrease significantly for the second quarter. For the gear mesh 60 - 69 mm, this decrease is in conjunction with a significant decrease of the LPUEs over the period.

For the other couples of gear mesh classes / quarter, the numbers of uses and the LPUEs seem to decrease but it is not significant (Figure 34).

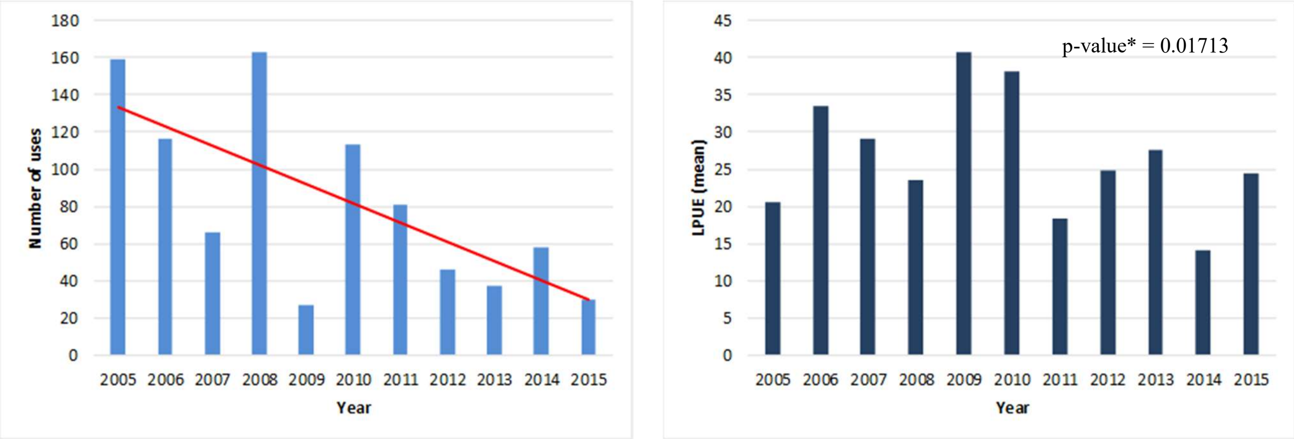


Figure 34: Number of uses and levels of associated mean LPUEs for the Bay of Biscay - 2nd quarter - GNS - cluster 2- gear mesh class 50 - 59 mm

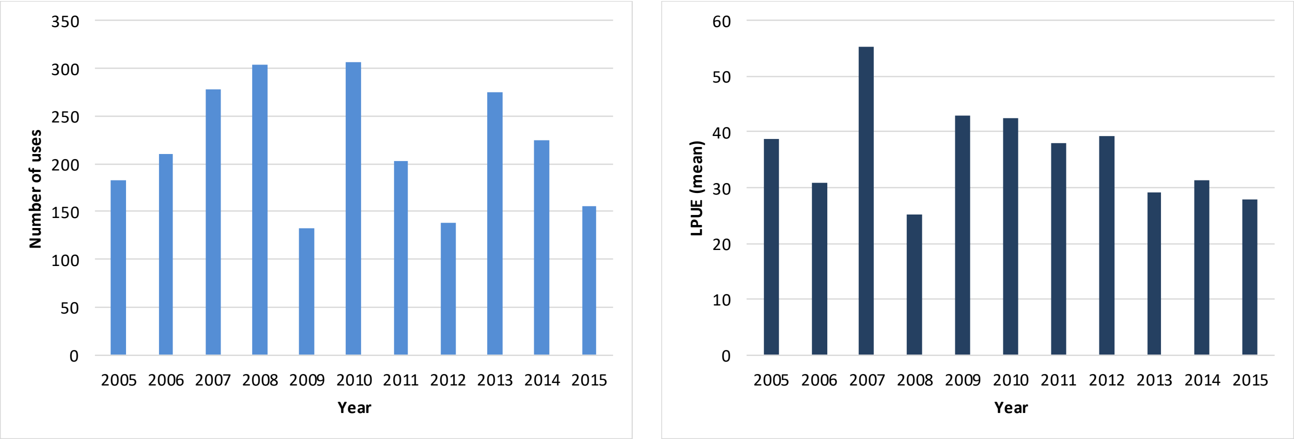


Figure 35: Number of uses and levels of associated mean LPUEs for the Bay of Biscay – 3rd quarter - GNS - cluster 2- gear mesh class 50 - 59 mm

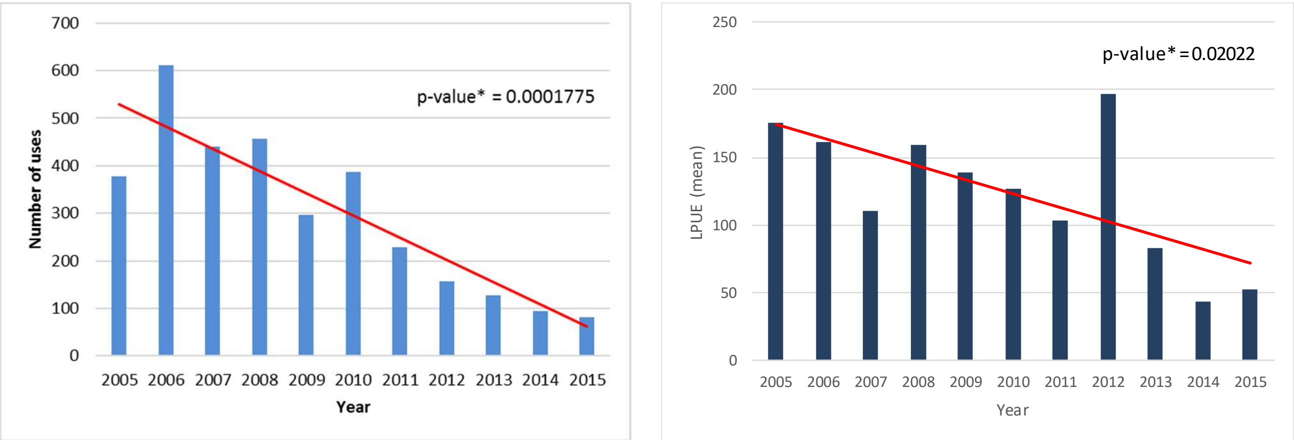


Figure 36: Number of uses and levels of associated mean LPUEs for the Bay of Biscay - 2nd quarter - GNS - cluster 2- gear mesh class 60 - 69 mm

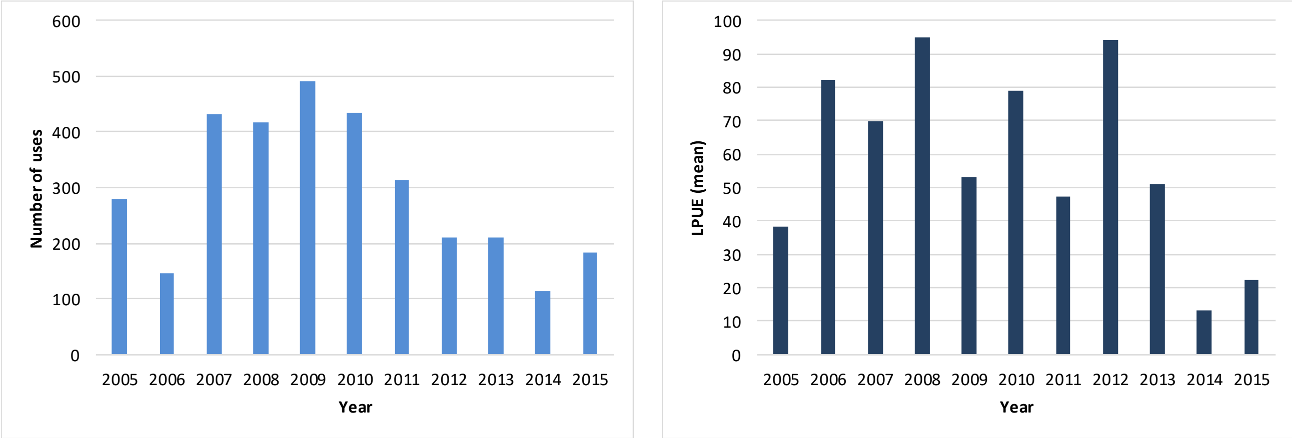


Figure 37: Number of uses and levels of associated mean LPUEs for the Bay of Biscay - 2nd quarter - GNS - cluster 2- gear mesh class higher than 90 mm

4 Conclusion / Review

This document proposes a method to identify reference fleets for the calculation of LPUEs, eliminating the sources of variation of those related to the technical characteristics of the vessels and / or gear, by understanding the spatial and temporal variations.

This identification work was carried out according to a scientific / fishermen collaborative approach carried out within the framework of the FFP ROMELIGO project thanks to the setting up of a specific working group on the issue of the LPUEs throughout the project. At the meetings of this group, the scientists presented the data used and prepared, as well as the analyses conducted. Discussions and exchanges were held with the professional fishermen on the selected criteria (meshes, targeted species, strategies of fishermen, etc...) and the choices made.

The originality of this work is also because the impact of discards on the calculated abundance indicator was considered. This consideration is not very widespread in the work on the LPUEs, whereas it seems important to us to consider in the beginning to any analysis of the landings in this optics.

This work leads to the identification of two reference fleets, namely:

- OTB: Small vessels (between 7.9 and 15.8 m) with a gauge between 2 and 43.9 grt, an engine power between 44 and 256 kW and using a gear equal to 70 mm;
- GNS: medium-sized vessels (8.2 to 14.8 m), with a gauge between 2 and 30.2 grt, with an engine power between 70 and 331 kW and using a gear mesh size at 50 - 59 mm (second and third quarter), or 60 - 69 mm (second quarter) or higher than 90 mm (second quarter).

For these fleets, the evolution of the LPUEs shows a decreasing trend, significant in two of four cases. They may reflect a deterioration in the status of the striped red mullet stock.

In a perspective of use of these clusters over time, it will be necessary to remain vigilant on the possible introduction of biases related to modifications of the regulation (example of the possible impact of the obligation to use a gear mesh of 80 mm since 2016 for trawlers over 12 m not holding a European Fishing Authority for common sole). One possibility to remedy this would be to restrict the calculation of the LPUEs to a fish size considered unaffected by the regulatory change (using the “commercial category” information).

5 Acknowledgments

This work is part of the ROMELIGO project that has been funded by FFP (France Filière Pêche) on the thematic focus - acquisition of knowledge on the fishery resources.

6 Bibliography

Caill-Milly, N., Lissardy, M. Léauté, J.-P., 2017. Improvement of the fishery knowledge of striped red mullet of the Bay of Biscay. Working Document for the Working Group on Widely Distributed Stocks (WGWIDE), 30 August - 5 September 2017, Copenhagen (Denmark), 30 p.

Demanèche,S., Bégot, E., Gouëllo, A., Campéas, A., Habasque, J., Merrien, C., Leblond, E., Berthou, P., Harscoat, V., Fritsch, M., Leneveu, C., Laurans, M., 2013. PROJET SACROIS « IFREMER / DPMA » V 3.2.5 - 11/2013. 43 p.

Desbrosses, P., 1935. Contribution à la connaissance de la biologie du Rouget-Barbet en Atlantique Nord, 1ère et 2ème partie. Rev. Trav. Office des Pêches, VIII.

Girard, M., Lorance, P., Biseau, A., 2000. Catch Per Unit Effort of deep-sea species off the continental slope to the west of British Isles. Cybium. 24(3), 97-104.

ICES, 2012. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK), 27 April - 03 May 2012, ICES Headquarters, Copenhagen. ICES CM 2012/ACON:13. 1346 p.

ICES. 2016. Advice basis. In Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.2.

ICES, 2017. Advice on fishing opportunities, catch, and effort Bay of Biscay and the Iberian Coast, Celtic Seas. Greater North Sea, and Oceanic Northeast Atlantic Ecoregions. DOI: 10.17895/ices.pub.3032 mur.27.67a-ce-k89a, 5 pp.

Laurec, A., Le Gall, J.-Y., 1975. De-seasonalizing of the abundance index of species. Application to the albacore (*Thunnus alalunga*) monthly catch per unit of effort (C.P.U.E.) by the Atlantic Japanese longline fishery. Bull. Far. Seas Fish. Res. 12, 145-169.

Mahé, K., Destombes, A., Coppin, F., Koubbi, P., Vaz, S., Le Roy, D., Carpentier, A., 2005. Le rouget barbet de roche *Mullus surmuletus* (L. 1758) en Manche orientale et mer du Nord. Rapport de Contrat IFREMER/CRPMEM Nord-Pas-de-Calais, 187p.

Quéro, J.C. and Vayne, J.J. 1997. Les poissons de mer des pêches françaises. Ifremer, Ed. Delachaux & Niestlé, 304 pp.

Suquet, M., Person-Le Ruyet, J., 2001. Les rougets barbets (*Mullus barbatus*, *Mullus surmuletus*). Biologie, pêche, marché et potentiel aquacole. Ifremer eds., 47 pp.

Appendix 1 - Landings by fishing sequence and statistical rectangle

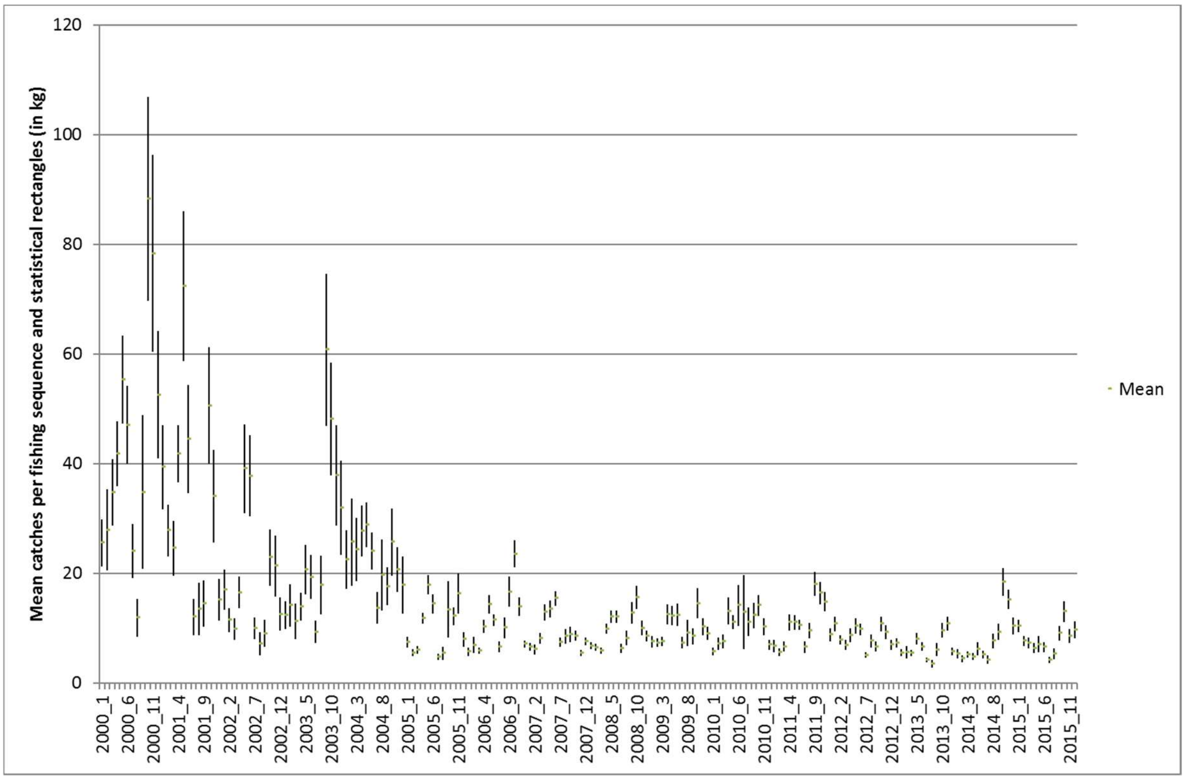


Figure 38: Landings by fishing sequence and statistical rectangle (2000 - 2015) for Trawlers

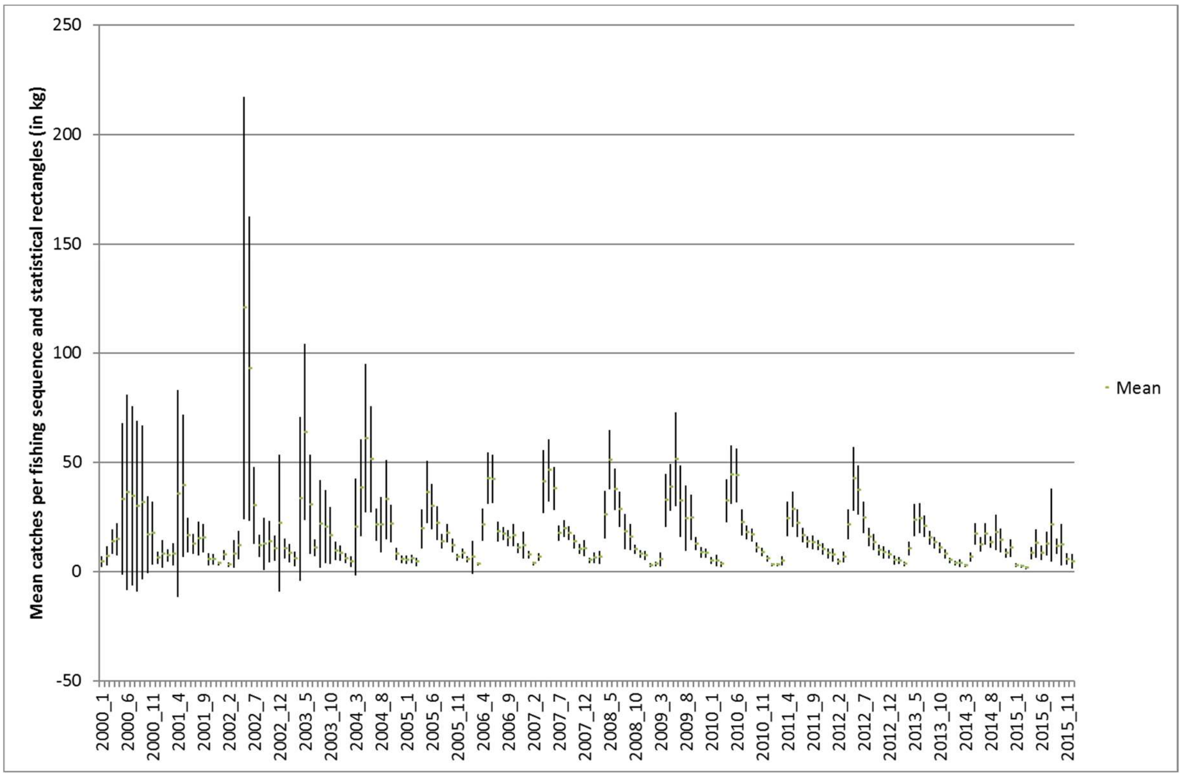


Figure 39: Landings by fishing sequence and statistical rectangle (2000 - 2015) for Gillnetters

Appendix 2 - Analysis of the LPUEs and identification of reference fleets for striped red mullet.

Summary of the number of Discards fishing sequences for the 4 selected gears

Table 7 : Number of fishing sequences per month and year for OTB

Years	01	02	03	04	05	06	07	08	09	10	11	12	Total
2004							3		5				8
2005				1	2	7					5	10	25
2006			1	1		1						6	9
2007									1	7	3		11
2008									2	8	5		15
2009					5	4	4	3	4	1		2	23
2010	2		1	2	5	2	5	10	10	10	4	1	52
2011	13	3		2	9	7	7	9	11	12	3		76
2012	2	1			4	3		6	13	4	4	3	40
2013		2		1	6	6	3	7	6	1	3	2	37
2014	2	1		1	3	10	3	7	7		5	5	44
2015	4	2	3	2	2	5	7	1	3	3	4		36

Table 8: Number of fishing sequences per month and year for OTT

Years	01	02	03	04	05	06	07	08	09	10	11	12	Total
2004	1	2	1	2								3	9
2005	1	1		1	1	7	9	1	6	5	19	4	55
2006	1	1	3	2	3	12	3		7	8	5		45
2007		1	5		1	6	10		11	8		13	55
2008	5		1	1	1	1	2			3		2	16
2009				6	12	3	4			1	2	9	37
2010	6	10	6	4	14	8	7	5	1	4		6	71
2011	3	2	3	1	4	3	7		1		3	3	30
2012	2			3	2	7	7			7	3	5	36
2013	11	2	6	1	6	18	7	2	1	4	3	6	67
2014	6	1	2	2	12	6	6	1		3		4	43
2015	6	5	5	14	16	14		5		1		6	72

Table 9: Number of fishing sequences per month and year for GNS

Years	01	02	03	04	05	06	07	08	09	10	11	12	Total
2004							1			1	2		4
2005						2				1			3
2007				2	4	5			1		1		13
2008					5	6		1	1	4	5		22
2009				3	7	7		3		1			21
2010	5	3	12	2	2	12	4		4	6	4	3	57
2011		2		2		3	3	3		2	4	3	22
2012	1	3	2		2	3	6	1	2	4	2		26
2013		3		1	4	3		2	2	8	6	1	30
2014	1		3			2	3	4	8	8		2	31
2015	1		1	3	2	3	4	7	15	4	5	3	48

Table 10: Number of fishing sequences per month and year for GTR

Years	01	02	03	04	05	06	07	08	09	10	11	12	Total
2004							2				4		6
2005						1							1
2006									1	1			2
2007			2						6				8
2008		3	1	4	6				3	6	5	5	33
2009	2	7	2	3	3	4	2			2	2		27
2010	3	2	2	1	6	5	1		12	15	2	2	51
2011	1	4	3	4	2	1	2	2	1	4	1		25
2012	3			2	3		1		2	2	1	1	15
2013		10			2	1	1		1	1			16
2014					6		5	6	6	8	14		45
2015	2	1	1	4	3			4	3	4	8	2	32

Appendix 3 – Discards analyses

OTB

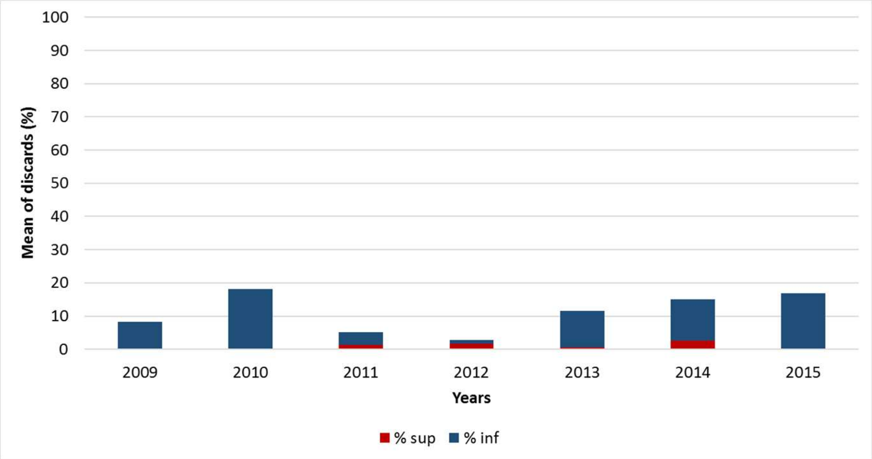


Figure 40: Mean of discards for all the series for OTB (2009-2015) – by years in %

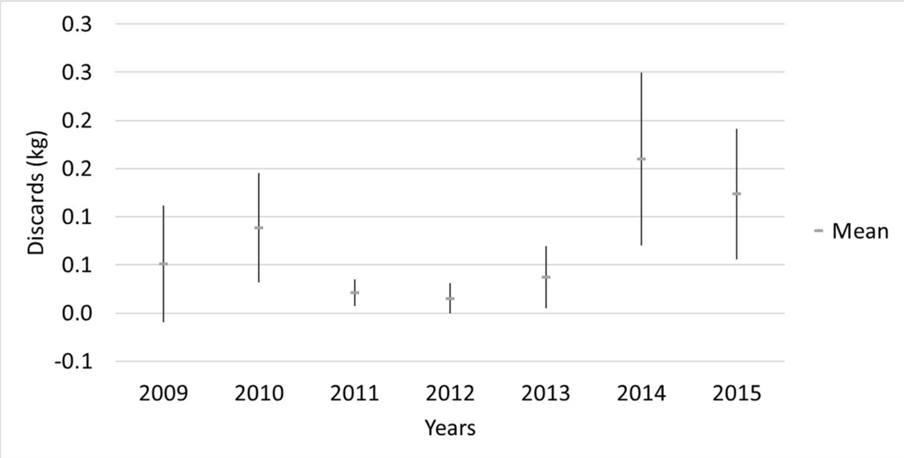


Figure 41: Mean of discards for all the series for OTB (2009-2015) – by years in kg

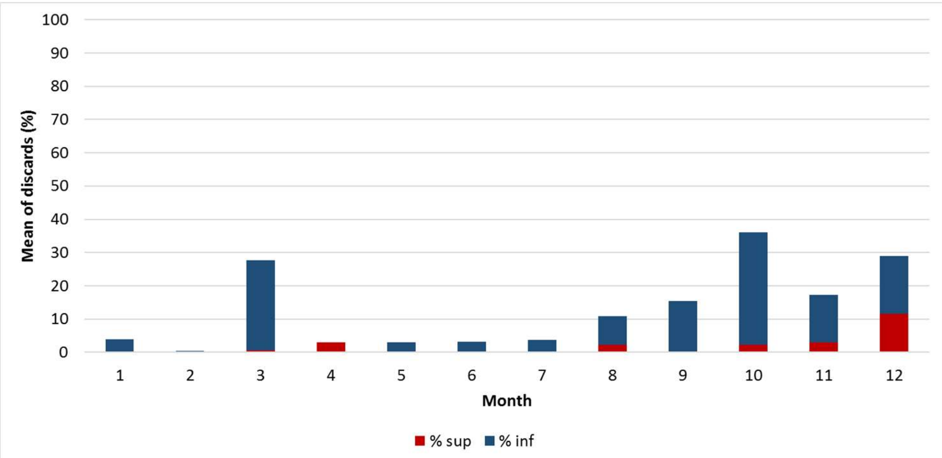


Figure 42 : Mean of discards for all the series for OTB (2009-2015) – by month in %

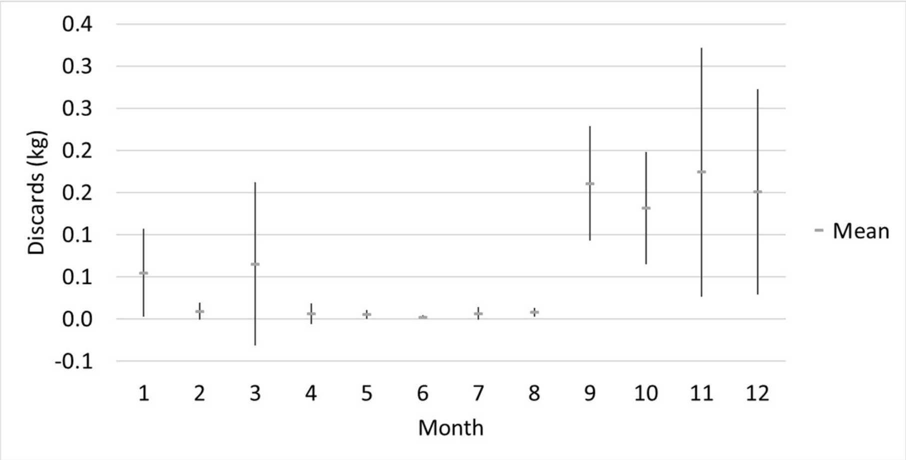


Figure 43: Mean of discards for all the series for OTB (2009-2015) – by month in kg

OTT

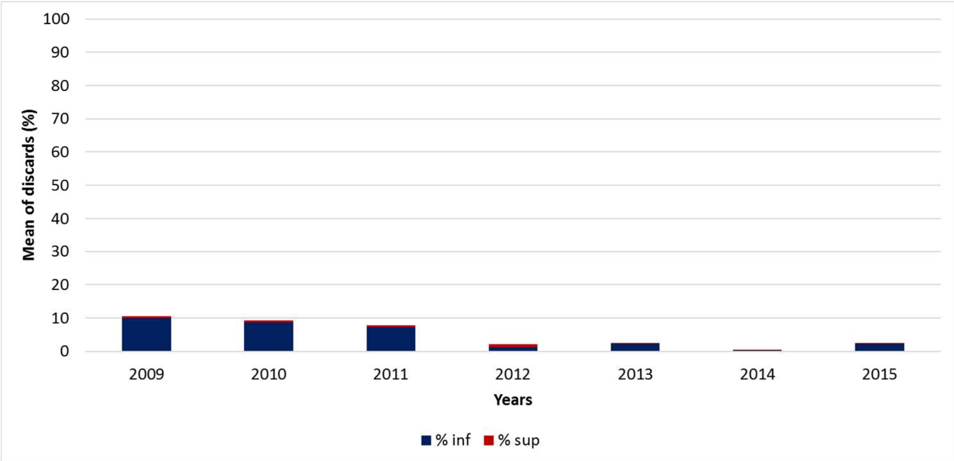


Figure 44: Mean of discards for all the series for OTT (2009-2015) – by years in %

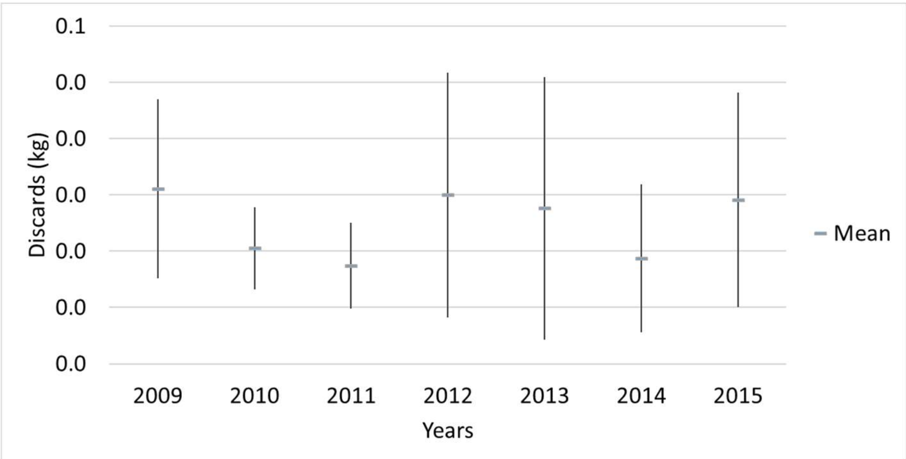


Figure 45: Mean of discards for all the series for OTT (2009-2015) – by years in kg

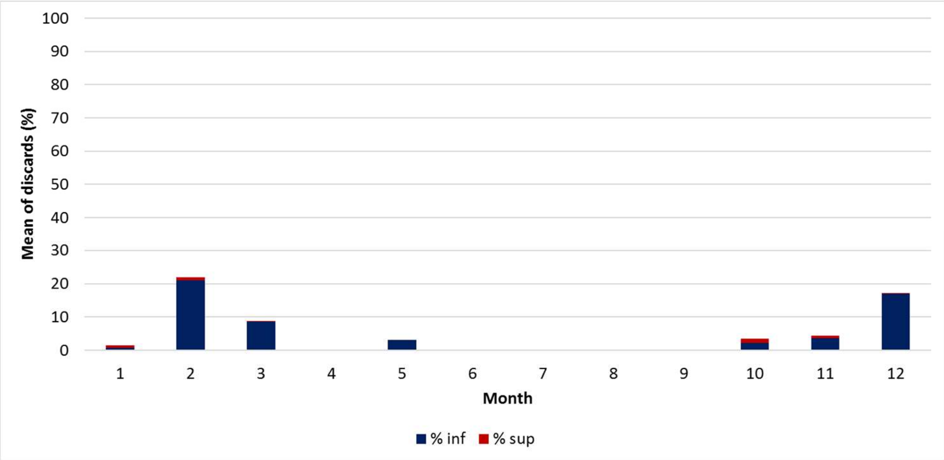


Figure 46: Mean of discards for all the series for OTT (2009-2015) – by months in %

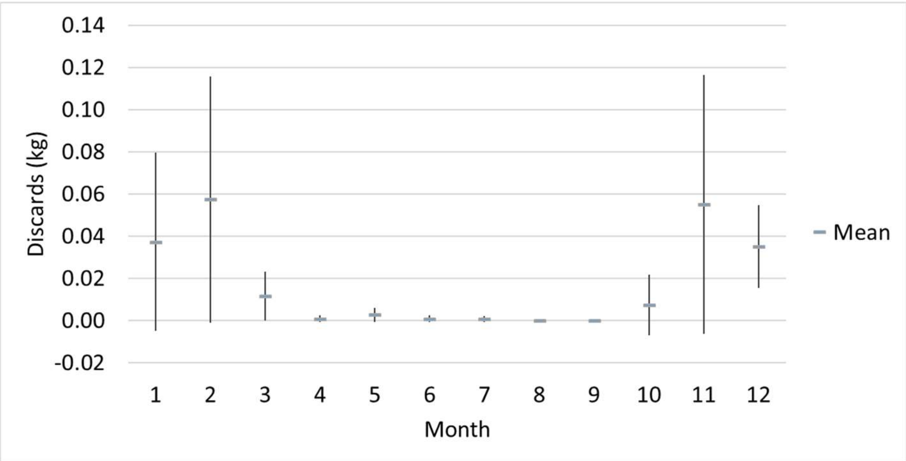


Figure 47: Mean of discards for all the series for OTT (2009-2015) – by months in kg

GNS

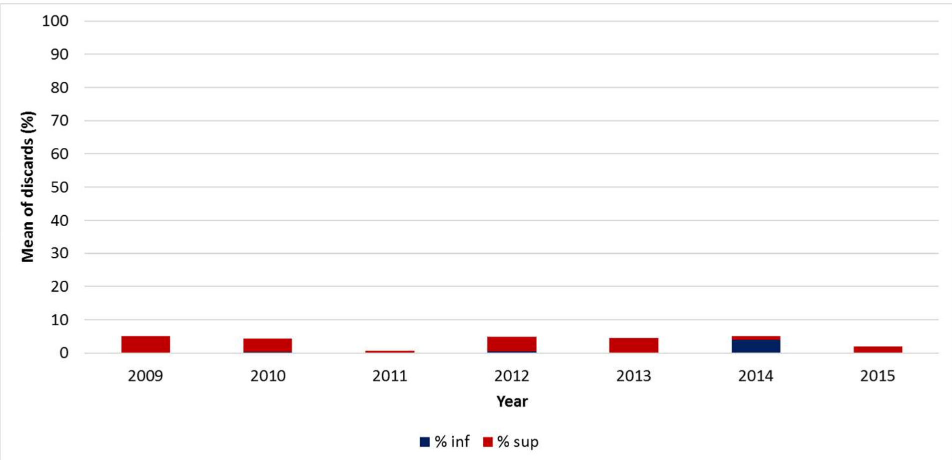


Figure 48: Mean of discards for all the series for GNS (2009-2015) – by years in %

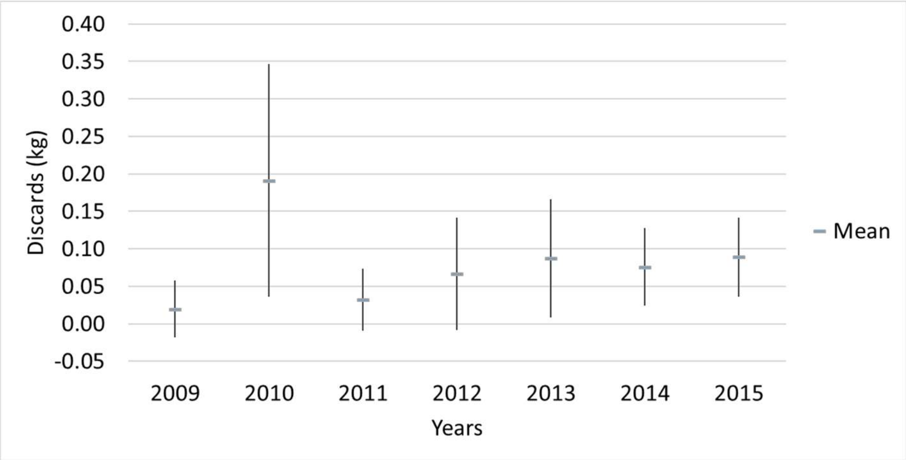


Figure 49: Mean of discards for all the series for GNS (2009-2015) – by years in kg

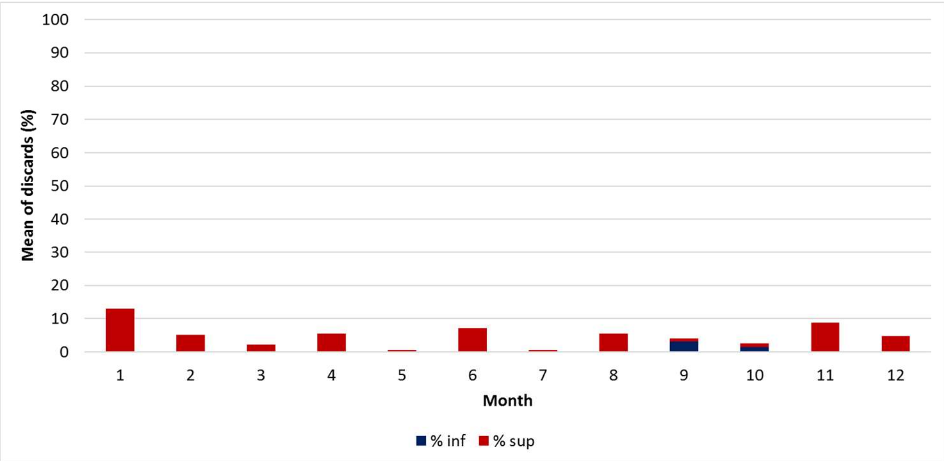


Figure 50: Mean of discards for all the series for GNS (2009-2015) – by months in %

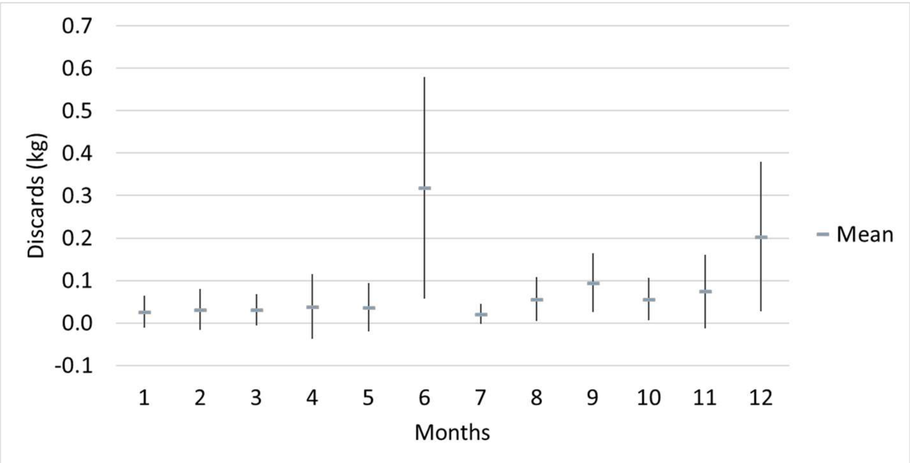


Figure 51: Mean of discards for all the series for GNS (2009-2015) – by months in kg

GTR

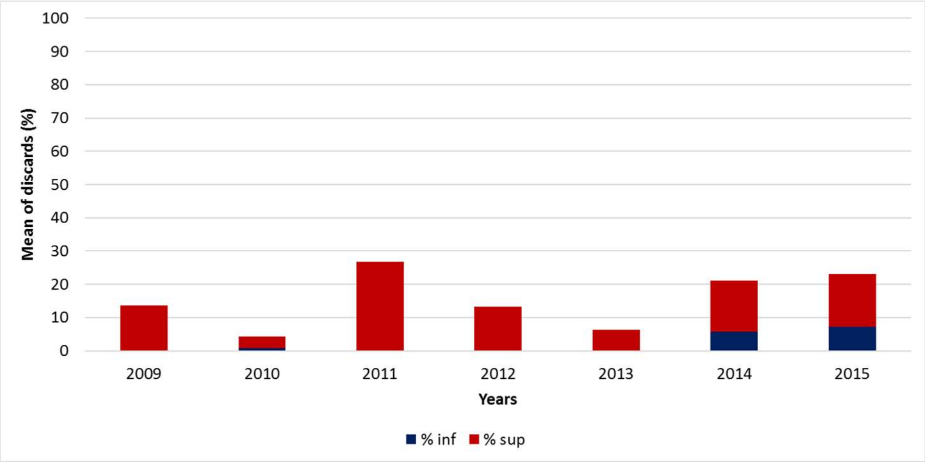


Figure 52: Mean of discards for all the series for GTR (2009-2015) – by years in %

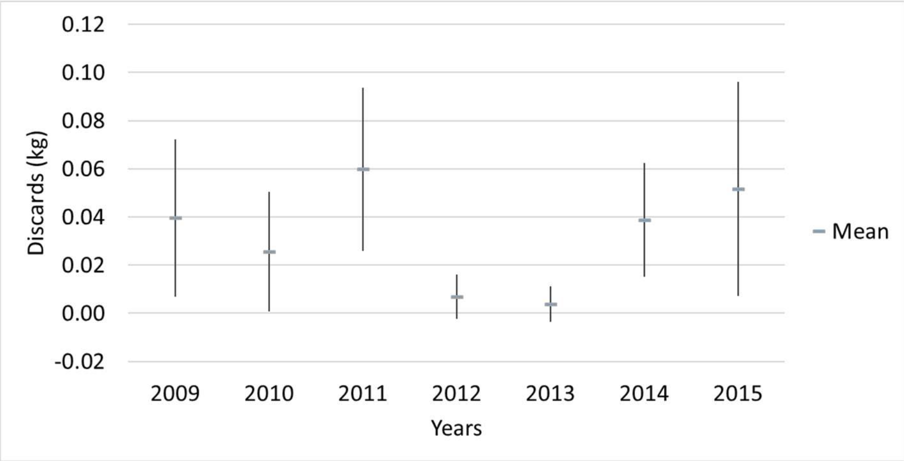


Figure 53: Mean of discards for all the series for GTR (2009-2015) – by years in kg

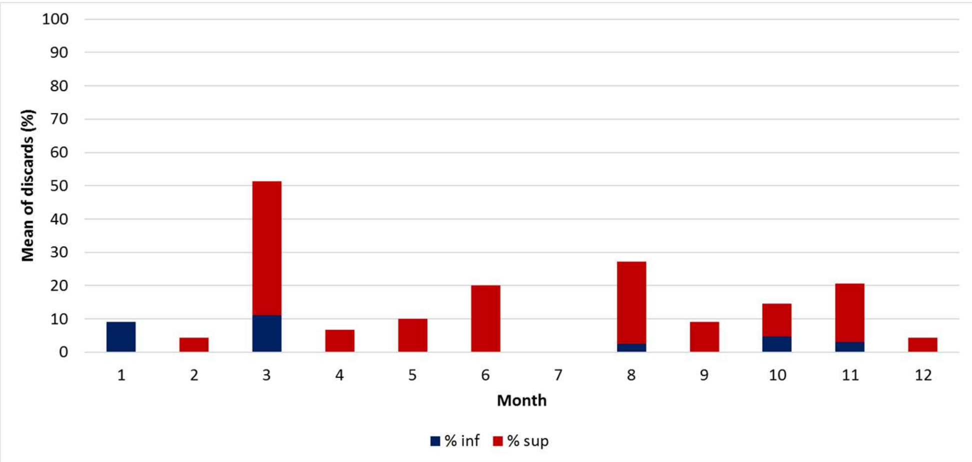


Figure 54: Mean of discards for all the series for GTR (2009-2015) – by months in %

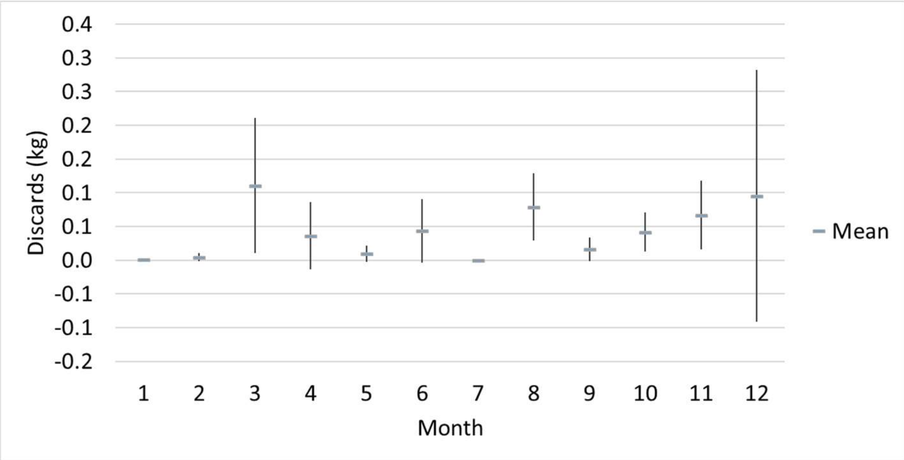


Figure 55: Mean of discards for all the series for GTR (2009-2015) – by months in kg

SDN

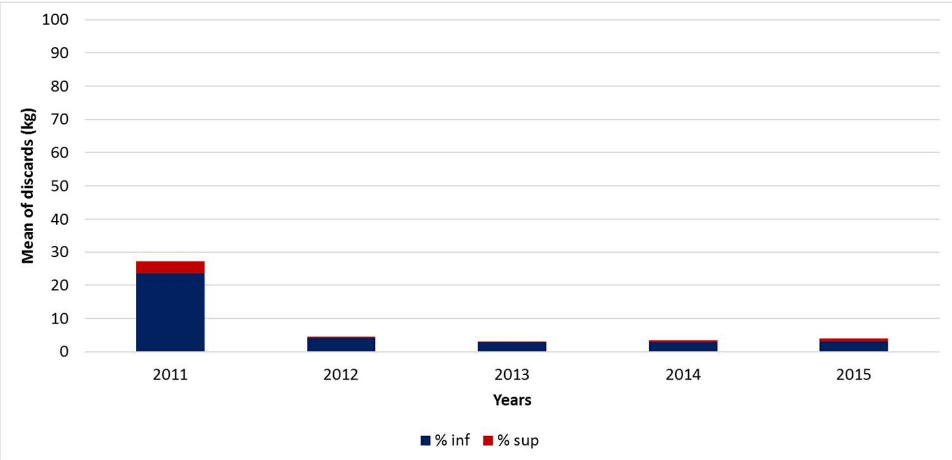


Figure 56: Mean of discards for all the series for SDN (2011-2015) – by years in %

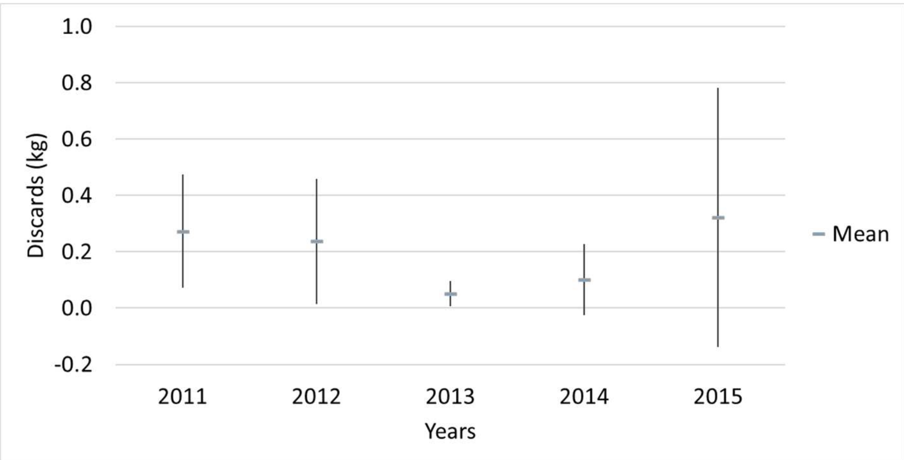


Figure 57: Mean of discards for all the series for SDN (2011-2015) – by years in kg

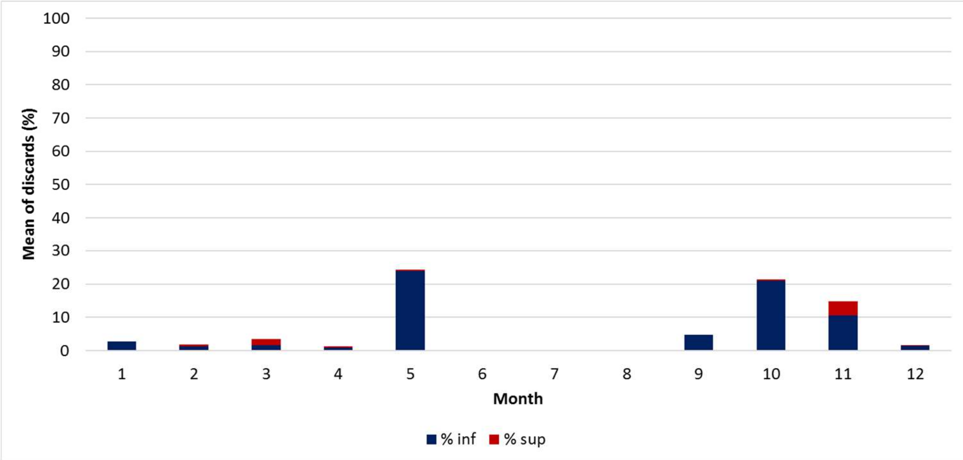


Figure 58: Mean of discards for all the series for SDN (2011-2015) – by months in %

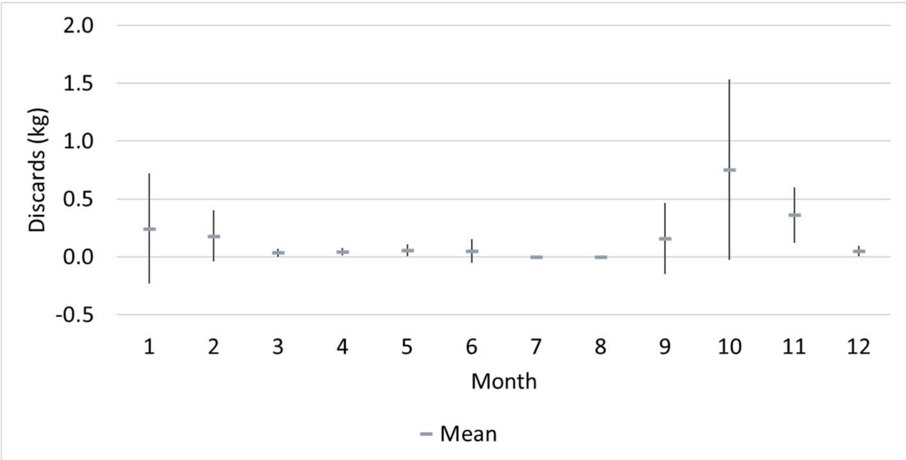


Figure 59: Mean of discards for all the series for SDN (2011-2015) – by months in kg

Appendix 4 – Evolution of LPUEs

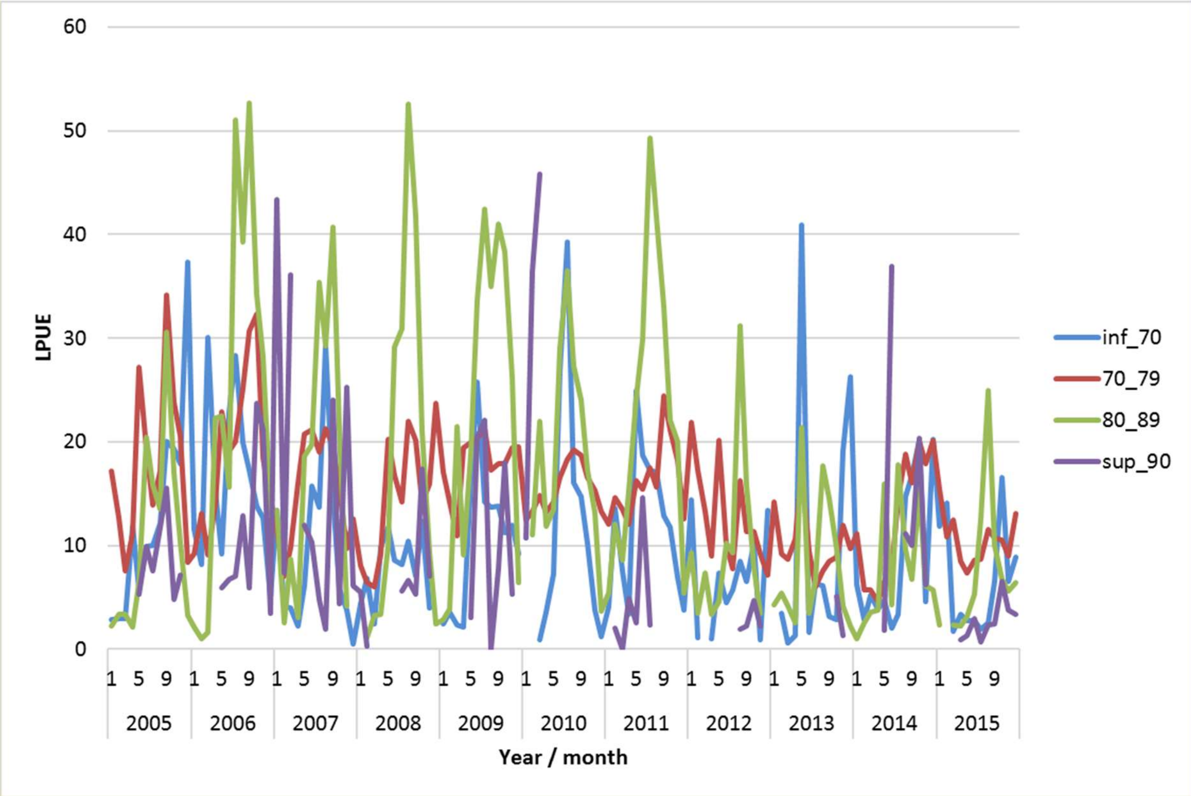


Figure 60: Evolution of LPUEs mean by years and months for the different gear mesh classes for cluster 1 - OTB in the Bay of Biscay

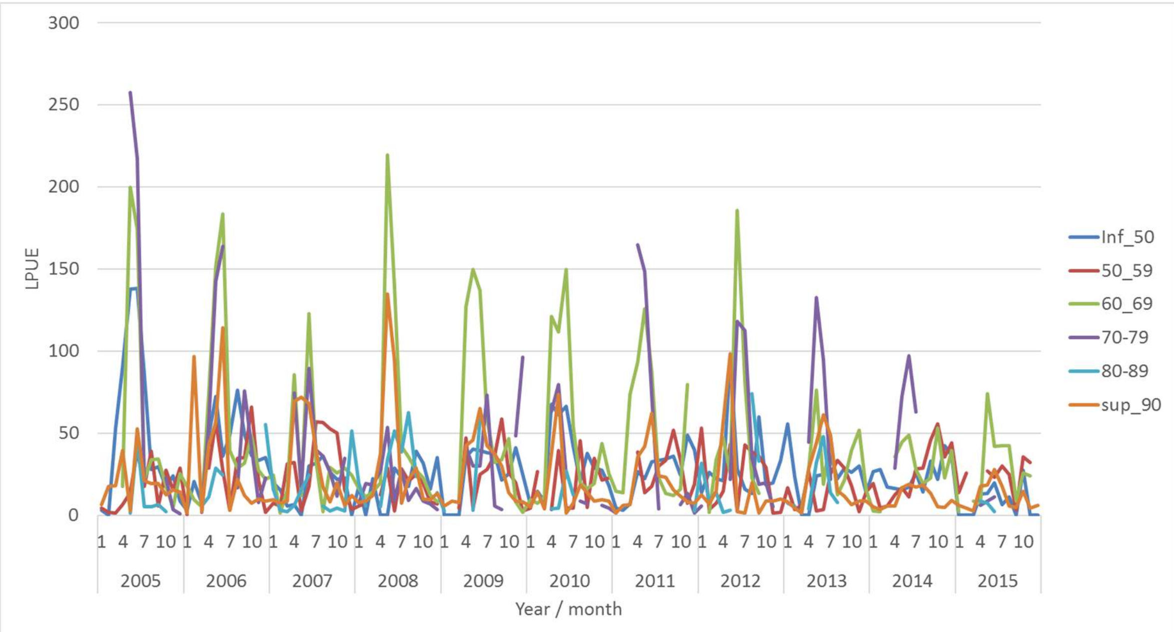


Figure 61: Evolution of LPUEs mean by years and months for the different gear mesh classes for cluster 2 - GNS in the Bay of Biscay