A methodology based on data filtering to identify reference fleets to account for the abundance of fish species: Application to the Striped red mullet (*Mullus surmulletus*) in the Bay of Biscay

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Abstract :

For data-limited stocks (DLS), professional fishing data can be used as a potential source of information, especially in the absence of appropriate scientific survey, to understand abundance evolution under realistic hypothesis on resource catchability. This work focuses on a data-filtering approach, the selected fishing effort must reflect vessel activity that is least dependent on their technical characteristics and as stable as possible over time. The variable of interest is landing by fishing sequence (landing for a given gear, gear mesh, day and ICES statistical rectangle) called LPUE. In order to account for the abundance of the species, it was necessary to consider the discards. The method thus proceeds in 4 steps: (i) focus on LPUE variability and causes' prioritization; (ii) cluster definition to obtain a typology of vessels; (iii) average LPUE per cluster analysis; (iv) consideration of gear mesh classes and seasonal variations (quarters). This approach is outlined for the Striped red mullet of the Bay of Biscay that is currently in DLS category 5. Two reference fleets are thereby proposed: firstly the otter trawlers composed of small vessels (7.9–15.8 m) with a gauge of 2–43.9 grt, an engine power between 44 and 256 kW and a gear mesh of 70–79 mm; secondly the set gillnetters, which are defined by medium-sized vessels (8.2–14.8 m, 2–30.2 grt, 70–331 kW) whose gear mesh is either 50–59 mm (2nd and 3rd quarters), 60–69 mm (2nd quarter) or greater than 90 mm (2nd quarter). LPUEs of these fleets show a downward trend, significant in two out of four cases which may reflect a deterioration of the status of the Striped red mullet stock.

Highlights

► Data-filtering method maximizing usefulness of biological, catch, regulation data. ► Fishermen involvement to assess impact of regulation changes on indicators. ► Potential high bias induced by discards when using LPUE as proxy of abundance. ► For Striped red mullet, decreasing tendency of LPUEs over the study period.

Keywords : data-limited stock, commercial data, discards, LPUE, professional knowledge, data filtering

1 Introduction

The Common Fisheries Policy (EC 2371/2002), the Johannesburg 2002 World Summit on Sustainable Development, the 1995 United Nations Fish Stocks Agreement and the European plan for moving to maximum sustainable yield (COM (2006) 360 final) are all policy commitments that guide fisheries management decisions in EU waters. For biological resources within European fisheries, stock assessments are thereby required to provide information on the status of stocks in relation to maximum sustainable yield (MSY) objectives. These are established both in terms of stock abundance and fishing mortality rate for each individual stock (Le Quesne et al., 2013). Such targets are achievable for data-rich stocks even if they are not always easily attained. They are a challenge for data-limited stocks (DLS). These stocks lack analytical assessment and are currently the main focus of assessment methods development within the framework of the International Council for the Exploration of the Sea (ICES). The Workshop on the Development of Quantitative Assessment Methodologies (WKLIFE) is a working group which focuses on life-history traits, exploitation characteristics, and other relevant parameters. In the Northeast Atlantic European waters about half of all landings (by weight and value) under exclusive European management are taken from data-deficient unassessed stocks (Le Quesne et al., 2013).

Various reasons can lead to stock being considered as data-limited or data-deficient. This could be because there are uncertainties about the biology of the stock, limited data collection and reporting (lack of or unreliable data on catches, incomplete surveys and/or poor sampling regarding biological parameters, etc.) or limited human resources to develop and apply appropriate assessment models respecting the scientific advisory process (ICES, 2016; Le Quesne et al., 2013). For such stocks, a variety of stock assessment methods and management procedures are available. An important step forward came about in 2012 when ICES implemented the DLS framework to provide quantitative catch advice not only for data-rich stocks but also for data-limited stocks (O'Brien, 2016). Individual stocks are classified among six stock categories defined using available knowledge; categories 2 to 6

64 relate to DLS data categories (ICES, 2016, O'Brien, 2013). The category and the management

65 strategies agreed upon by relevant management bodies define the advice rule to be applied on

66 fishing possibilities.

67 In order to improve assessment and to classify an individual stock into a lower category, catch

68 information is of paramount importance. Especially in the absence of appropriate scientific survey,

69 professional fishing data can be potentially used, under realistic hypothesis on resource catchability,

70 as a source of information to understand abundance evolution. This requires the identification of

71 reference fleets for which catches per unit effort (CPUE) are studied. A source of bias when

72 identifying a derived index of abundance from fisheries rates can come from the available

73 commercial data. The best solution would be to work on catch data (to calculate catch per unit of

74 effort - CPUE) but for many fisheries only landing data (landing per unit effort - LPUE) are available in

75 reality. It is therefore important to understand which factors occur and explain the variability of the

76 commercial catch and landing rates.

77 Several factors may influence specific rates for a given species: on the one hand, the spatiotemporal

78 characteristics such as year, month and statistical rectangle; on the other hand, technical

79 characteristics of the vessels (primarily length, power, gauge) and characteristics of the gears (more

80 often mesh and length). The former characteristics are more closely related to the biological cycle of

81 the species (migration, concentration, feeding activity influencing availability of resources). The latter

82 characteristics however are more strongly linkedto human activities (fishermen choices or regulation

83 enforcement). In addition, strategy, fishing skill of fishermen, commercial and/or regulatory aspects

84 may also influence spatiotemporal distribution of the catch rates (Hilborn and Walters, 1992).

85 Maunder et al. (2006) provide details on sources of problems when using CPUE data as proxy of

86 abundance.

87 To investigate those influences and to find a way to reduce them when choosing the fleet of interest

88 and a catch rate, a design-based approach relying on data-filtering (Shearer, 2000) can be

89 implemented. With regards to potential species, the Striped red mullet is a good candidate for the

90 reasons which we shall set out bellow.

91 The Striped red mullet (*Mullus surmuletus*) - also named Surmullet - is a benthic species with a

92 distribution along the European coasts from the Strait of Gibraltar in the south to the south of

93 Norway and north of Scotland including the Faroe Islands (Davis and Edward, 1988; Gibson and Robb,

94 1997; Quéro and Vayne, 1997). For the North-East Atlantic, areas of management have been

95 identified using otolith shape and their degree of continuity regarding geographic sectors (Benzinou

96 et al., 2013). Individualization of stocks in Western Europe advanced by ICES concerns the Bay of

97 Biscay, the waters bordering the Iberian Peninsula as well as the Celtic Sea, namely for Striped red

98 mullet in Subareas and Divisions 6, 7a-c, e-k, 8, and 9a (and identified by ICES with the following

99 stock code: Mur.27.67a-ce-k89a) - see Figure 1. This stock is part of the DLS, currently classified in

100 category 5 (ICES, 2016); it is a stock for which only landing data are available. The advice rule on

101 fishing possibilities has hence been based on the precautionary approach since 2012. For 2013 and

102 2014, ICES recommended reducing landings by 20% compared to 2009-2011. In the absence of new

103 information on stock biomass or exploitation level, the precautionary buffer was applied again in

104 2017 (ICES, 2017). It led to landing advice of a maximum of 1,600 tonnes for 2018, 2019, and 2020.

105 As long as no supporting information clearly indicates that the current level of exploitation is

106 inappropriate for the stock, this approach will be repeated (ICES rules). However, this stock is part of

107 the top 15 landed species by value for South-western waters, a region of Northeast Atlantic

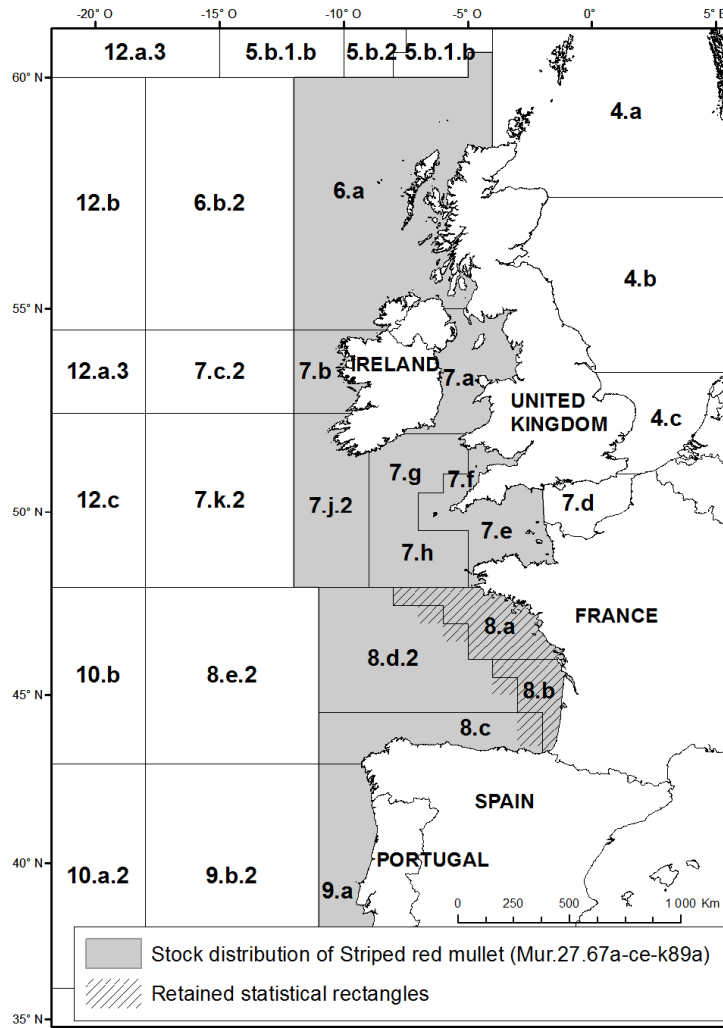108 European waters (Le Quesne et al., 2013).

109

Figure 1. Stock distribution of Striped red mullet (Mur.27.67a-ce-k89a) and retained spatial selection for the present study. Sources: ICES, ESRI.

The purpose of this study is to propose a data filtering approach to select relevant fleet or fleets whose LPUE can account for abundance. The proposed method consists of four steps and is thus enumerated for Striped red mullet stock in Subareas and Divisions 6, 7a-c, e-k, 8, and 9a. The approach integrates a valorisation of fishermen's expertise thanks to a specialised working group associating scientists and fishermen representatives.

2 Material and methods

2.1 Identification of potential fleets of interest regarding landings by country and gears

Landings regarding this stock are primarily taken from ICES Subareas 7 and 8; Subarea 8 being the main contributor. In the last three years, France accounts for two-thirds of landings (ICES, 2017), ahead of Spain, Portugal, UK and the Netherlands. The Surmullet is one species among a set of benthic (demersal) species targeted by the French fleet. Inputs are largely dominated by bottom trawls, gillnets and seines (Danish); these three combinations of gear accounted for 98% of the landings (for which a gear is specified) over the 2000-2015 period (Caill-Milly et al., 2017). Bottom trawls are basically single-vessel otter trawls and otter twin trawls. Trawls were largely predominant until the mid-2000s. For gillnets, set gillnets (anchored) make up the majority of this category with- to a lesser extent- trammel nets. For Danish seines, landings have been recorded from 2008 onwards and, since 2011, these landings have been even higher than those obtained with nets (Appendix A).

According to this landing information, five French fleets are identified as potentially of interest: fleets using otter bottom trawl (OTB); otter twin trawl (OTT); set gillnets (GNS); trammel nets (GTR) and Danish seine (SDN). We must stipulate that only French data will be used in the analysis.

2.2 Integration of stakeholder knowledge vs scientific knowledge

From the very beginning of the process analysing how fleets of interest are currently selected, a working group associating professionals (producer organisations, regional and national fisheries committees, Association du Grand Littoral Atlantique) and scientists (Ifremer and University of Pau & Pays de l'Adour) was set up. Its role was to discuss the available data and their limits, to identify the variability sources of the studied variables and to collectively define the thresholds applied.

141 **2.3   Initial data collection, description and quality**

142   Data on catches by commercial fishing fall under two categories: landing and discards data. For these

143   data, the statistical units are the fishing sequences for each vessel. These fishing sequences are

144   defined by the combination of the day, the gear, the gear mesh size and the statistical rectangle.

145   Landing data are validated, consolidated and qualified sets of production and effort data provided by

146   a cross validation algorithm (named SACROIS) for fisheries statistics (Demanèche et al., 2013;

147   http://sih.ifremer.fr/Description-des-donnees/Les-donnees-estimees/SACROIS). This tool meets the

148   EU requirement stipulated by article 145 of the EU implementing regulation (EC Reg. 404/2011).

149   SACROIS data are considered as the most comprehensive for reporting French vessel activity and

150   their inputs (landings). They have been available since 2000 and were extracted over the 2000-2015

151   period. For Surmullet, it represents 1,179,531 fishing sequences. Each line contains the amount of

152   Surmullet landing per fishing sequence and per vessel. It constitutes therefore a quantification of

153   landing per unit effort (LPUE).

154   Discards data originate from the "Observation on board fishing vessels" programme (hereby referred

155   to as the OBSMER French programme; Cornou et al., 2015). It is a collection of on-board catch data;

156   they are therefore sampling data whereas SACROIS data are considered as exhaustive. This national

157   programme enables observation at sea in the fishing areas of the part kept to be sold (landings) and

158   the part not retained on board (discards) as well as the gears used *in situ*. Therefore, for each fishing

159   operation, we have information about catches landed and discarded, fishing activity and effort.

160   OBSMER data have been available since 2003 and were extracted for the 2003 - 2015 period. For

161   Surmullet, it represents 14,950 fishing sequences.

162   Regarding vessels, their technical characteristics may change over time due to transformations (such

163   as remotorization, fishing gear shifts, etc.). To have the most precise information throughout the

164   boats' life cycle, annual characteristics were collected from the Community Fishing Fleet Register

165   (http://ec.europa.eu/fisheries/fleet/index.cfm).

166 **2.4 Data preparation**

167 **2.4.1 Data selection according to vessel activity, areas and time**

168 The study population was defined by activity criteria applied to the vessels and by the spatial extent

169 of the inputs.

170 We considered that a vessel had to be selected if its activity was equivalent to the mean of two

171 fishing trips per month, per year (all gears combined) with the presence of Striped red mullet

172 (initially regardless of the distribution of these fishing trips during the year).

173 Two criteria were applied concerning the spatial extent of the inputs. The first one is related to vessel

174 strategies. Within the geographical area defined for the Mur.27.67a-ce-k89a stock, vessels from

175 harbours of the Bay of Biscay and those coming from outside of the bay and catching Surmullet

176 develop different fishing strategies (Caill-Milly et al., 2017). To overcome a bias in the calculation of

177 the LPUE that would be related to these differences, we focused the analysis on the main input area

178 that presents consistent techniques, namely the divisions "27.8.a", "27.8.b", "27.8.c", "27.8.d", and

179 "27.8.e". The second criterion refers to the studied species biology. We retained the statistical ICES

180 rectangles (0.5° latitude and 1° longitude) consistent with the bathymetric distribution of Surmullet

181 that is less than or equal to 300 m (Suquet and Person-Le Ruyet, 2001; Mahé et al., 2005) (see Figure

182 1 presented before).

183 Moreover, regulatory changes may affect the indicators of catches and/or landings per unit of effort

184 (CPUE and/or LPUE). It is therefore important to identify them and limit their effects. For the

185 Surmullet, a preliminary graphical analysis of landings by fishing trip and statistical rectangle

186 between 2000 and 2015 showed clear trend changes in 2005 for both trawlers and netters (Appendix

187 B). Discussions held by the working group of the project allowed this observation to be linked to the

188 implementation of a selectivity device, later confirmed by the Council Regulation (EC) No.

189 1288/2009. To overcome this regulatory bias, we limited the various analyses to the 2005-2015

190 period. **Error! Reference source not found.** displays the mean annual landings per statistical

191 rectangle in the retained area (2005-2015 period; all fishing gears); Table 1 displays the mean

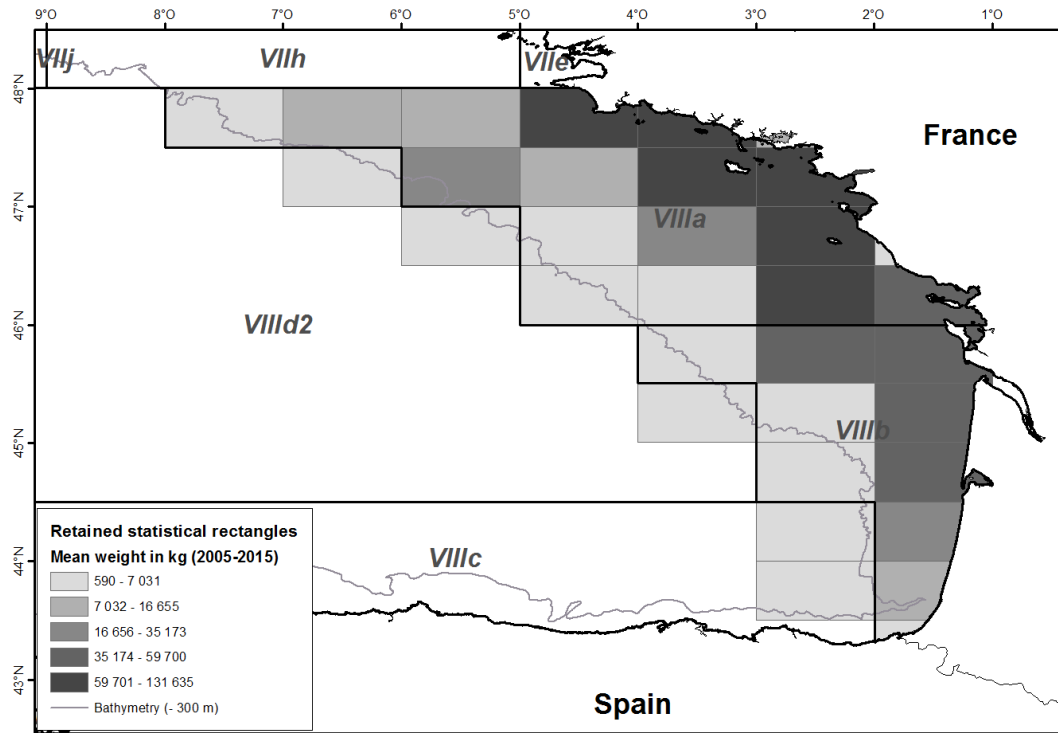192 characteristics of the retained vessels for the analysis.

193

Figure 2. Mean annual landings per retained statistical rectangle (2005-2015 period; all fishing

gears). Sources: ICES, ESRI, Sacrois data V3.3.5.

194

Group of gears	Number of vessels	Length (m)	Gauge (tjb)	Engine power (kW)	Years of service
Otter trawls (OTB)	249 (47)	14.4 (4.3)	44.6 (44.7)	223 (123.7)	30 (10)
Otter twin trawls (OTT)	200 (40)	16.7 (3.7)	67.7 (43.6)	289.6 (103)	29 (9)
Set gillnets (GNS)	136 (26)	10.4 (3.7)	18.4 (33.7)	125.2 (91)	31 (10)
Trammel nets (GTR)	128 (23)	11.9 (4.2)	29 (41.5)	156.1 (101)	31 (10)
Danish seines (SDN)	8 (5)	24.3 (5.9)	169.4 (70.9)	479.8 (89.7)	20 (11)

195 Table 1. Characteristics by gear of vessels having landed Surmullet (2005-2015 period).

2.4.2 Data cleaning process, calculations on aggregations and impact assessment of discards

The "cleaning" process concerned only the landing data. Three concepts for defining unappropriated data were identified: outliers pinpointed by expert opinions, data corresponding to vessels with fishing time equal to zero or not filled in and unavailable data regarding statistical rectangles.

Level indicators (mean, median) and dispersal indicators (interquartile range IQR, variance Var, standard deviation StD, and coefficient of variation CV) of the LPUE were calculated and displayed in columns using the following aggregation: year, month, rectangle, vessel registration, vessel length, vessel power, vessel tonnage, gear and gear mesh size (grouped in mesh class). Each information per individual vessel are conserved in this way. For discards, the calculated column parameters are the mean, the median and the standard deviation of the catches and the discards. The aggregation used was: year, month, rectangle and gear. For the latter, the level of aggregation is not as precise because it is based on a limited number of observations related to sampling. In addition, the total number of fishing sequences and the number of sequences only with Surmullet were also added, as well as the total weight of the fishing trip and added to the dataset in columns.

In our case study, the amount of Surmullet landing per fishing sequence and per vessel is potentially considered as a proxy of relative abundance. It is therefore essential to ensure, in advance, that the discards do not affect the variables studied. An analysis was thus conducted for each of the five identified French fleets (OTB, OTT, GNS, GTR and SDN) to evaluate the discards proportion and their characteristics. Different criteria were analysed 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 and the size composition of the discards (N.B. there is no minimum catch size for Surmullet but a minimal commercial landing weight at 40 grams (EC Regulation No. 2406/96) that amounts to a total length of around 18 cm). This preliminary work allows us to retain the gears that could be used to define the reference fleets.

2.5 Analytical process of landing data to select a representative fleet

The objectives of the study is to identify a derived index of abundance from fisheries rates. To select the fleet(s) of interest, the approach deployed consist of a four-step based data exploration using data mining tools and visualization techniques. This approach is applied to each of the potential fleets of interest (OTB, OTT, GNS, GTR and SDN).

2.5.1 Step 1: identification of the factors influencing LPUE level and dispersion

This first step focused on evaluating the different sources of variability of the LPUEs. It is based on the analysis of links between the variables of interest characterizing the LPUEs, the vessel characteristics and activity (length, gauge, engine power, gear mesh class), and the spatiotemporal factors (year, month, statistical rectangle). It is also a question of prioritizing each effect. Two statistical approaches were conducted on the same dataset. The first approach looked for linear links using a normalized principal components analysis (NPCA) (see **Error! Reference source not found.** for parametrization details) completed by the assessment of the discriminating power of each variable (Kruskal-Wallis test on the first component of the NPCA). The second one looked for other links (non-linear) and investigated possible interactions between explanatory variables using conditional regression trees. This analysis enables rules to be found, thereby giving the values of a target variable (here the log-transformed LPUE) from a set of explanatory variables (the previous active variables used for NPCA – see **Error! Reference source not found.**). The obtained rules can be displayed graphically using a binary tree (De'ath and Fabricius, 2000). The branches of the tree diagram are determined by the splitting rules (maximization of the homogeneity of the two resulting groups with respect to the response variable) (Prasad et al., 2006). Each node characterised a relevant variable allowing the value of this response variable to be divided. For each one, the mean response, the median response and the number of occurrences are detailed. A conditional tree performs a statistical test at each node using a p-value (see sections 3.2 and 3.3).

246

Type	Variables	Status	Abbreviation
Level indicators of LPUE*	Mean	Active	Moy
	Median		Med
Dispersal indicators of LPUE*	Variance		Var
	Standard deviation		StD
	Interquartile range		IQR
	Coefficient of variation		CV
Technical characteristics of vessels and gears	Length		Loa
	Gauge		Ton_Ref
	Engine power		Power_Main
	Gear mesh		Maillage
	Gear mesh class		Classes
Landing characteristics	Surmullet weight		Pds_MUR
	Total weight		Pds_Tot
Fishing sequences	Number of sequences with Surmullet		Nb_SqP_MUR
	Total number of sequences		Nb_SqP_Tot
Time	Month	Supple-mentary	Mois
	Year		Année
Space	Statistical rectangles		Rectangle

247   Table 2. Variables used to parametrize the NPCA.

2.5.2 Step 2: focus on those involved, vessel typology according to technical

249   **characteristics**

250   The objective of this step was to perform a vessel typology with the most homogeneous technical

251   characteristics (length, power, gauge) possible (over the period) within each group (cluster) and the

252   most heterogeneous possible from one cluster to another using Hierarchical Aggregation Clustering

253   (HAC with Ward aggregation criterion and Euclidean distance). The number of clusters was chosen

254   arbitrarily according to the visual cut of the dendrogram while avoiding too low numbers of vessels

255   per cluster. The monthly LPUEs means were then calculated for each cluster.

256 **2.5.3 Step 3: selection of the most meaningful cluster using a multicriteria**

257 **approach**

258 A list of mandatory and optional conditions was established to identify the relevance of each cluster

259 according to expert advice (Table 3) as we commonly do in operational research for decision-making

260 support. The mandatory criteria referred to the possibility of undertaking statistical inferences,

261 having a time series length consistent with the species' biology and selecting vessels displaying a

262 sufficient LPUE. Fulfilling those conditions was necessary but not sufficient, that is why we added

263 optional criteria which concern biological aspects (spatial and seasonal).

264

Type	Characteristics	Condition	Why?
Mandatory	Number of vessels	> 30	To have sufficient statistical units for classical statistical inferences
	Length of the LPUEs time series in the Bay of Biscay	> 11 years	Greater than the maximum longevity known for Striped red mullet (ICES, 2012; Quéro and Vayne, 1997)
	Minimum level of LPUE	> 5 kg	It was considered that the monthly mean value of the LPUE must be at least the median value of the LPUEs
Optional	Seasonal signal of the LPUEs	Amplitude with weak interannual variability Moderate variability of the periodicity	To be representative of the biological signal of abundance
	Spatial availability of the LPUEs	Activity available in the North and in the South of the Bay of Biscay	To consider as much as possible the entire range of Surmullet in this area

265 Table 3. Mandatory and optional conditions.

266 Optional criteria are not quantitative. Therefore to facilitate the selection process, a points system

267 was applied using three-levels coding: 1 - lack of correspondence to the criteria, 2 - medium

268 correspondence, 3 - strong correspondence. The sum of all the scores provided the final unique index

269 according to the entire optional criteria. Based upon the review of average LPUEs per cluster (in the

270 entire, in the north and in the south of the Bay of Biscay), the notations were proposed by the

271 scientists and subsequently validated during the working group associating the professionals.

272   Applying these conditions to the clusters obtained in § 2.5.2 allows us to preselect or not, one or

273   more potential candidate clusters to be the reference fleet for each of the gears.

274   **2.5.4 Step 4: final refinement of the reference fleet and temporal window to**

275   **consider LPUEs as proxy of abundance**

276   To refine the selection process, the representativeness of the gear meshes characteristics was

277   computed for each selected cluster and the following criteria were considered: the

278   representativeness of the landing levels of the whole cluster, continuity of use and a sufficient

279   number of uses. One or more cluster/gear mesh class combinations were thus retained. To identify

280   possible more relevant periods to reflect abundance, the monthly means of LPUEs over the 2005 to

281   2015 period for each combination were computed associated with their corresponding confidence

282   intervals. If a clear fishing period was identified (and confirmed during the working group associating

283   fishermen), only the LPUEs data for this period were selected. This filtering over the fishing season

284   avoids a bias related to the seasonal variability of the fishery (Laurec and Le Gall, 1975 in Girard et al.,

285   2000).

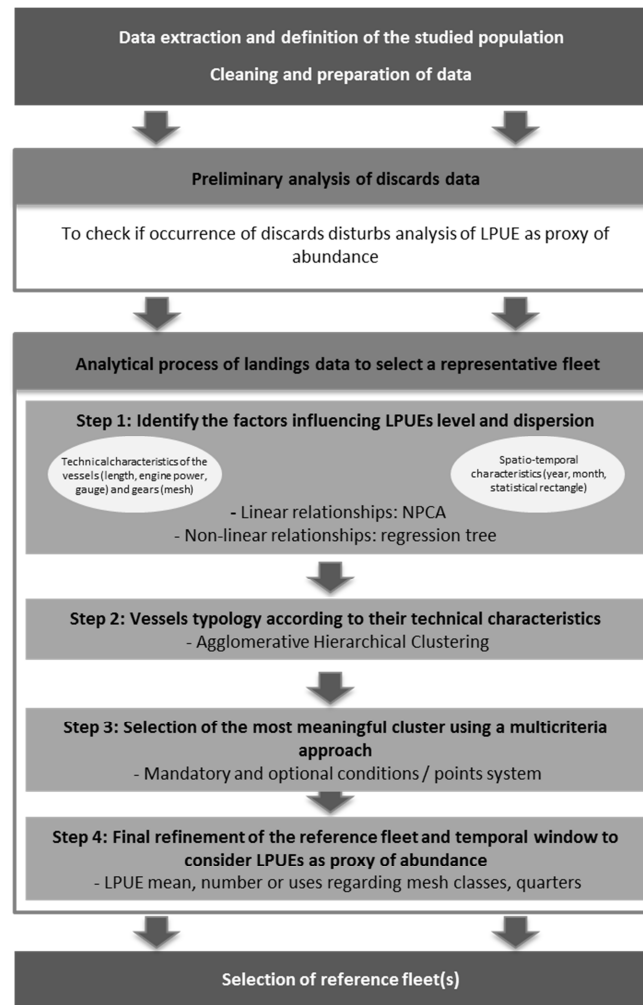286   The whole process is presented in Figure 3.

287

The flowchart contains the following elements:

Data extraction and definition of the studied population
Cleaning and preparation of data

Preliminary analysis of discards data
To check if occurrence of discards disturbs analysis of LPUE as proxy of abundance

Analytical process of landings data to select a representative fleet

Step 1: Identify the factors influencing LPUEs level and dispersion
Technical characteristics of the vessels (length, engine power, gauge) and gears (mesh)   Spatio-temporal characteristics (year, month, statistical rectangle)
- Linear relationships: NPCA
- Non-linear relationships: regression tree

Step 2: Vessels typology according to their technical characteristics
- Agglomerative Hierarchical Clustering

Step 3: Selection of the most meaningful cluster using a multicriteria approach
- Mandatory and optional conditions / points system

Step 4: Final refinement of the reference fleet and temporal window to consider LPUEs as proxy of abundance
- LPUE mean, number or uses regarding mesh classes, quarters

Selection of reference fleet(s)

Figure 3. Retained approach for the identification of reference fleets from the LPUE study.

For the identified fleets, the trend of the monthly LPUEs is considered as reflecting changes in Surmullet abundance and the slope of the regression line is tested. Calculations were carried out under R Software, using the packages: "FactoMineR" for the NPCA and HAC, "rpart" for the regression trees.

3   Results

3.1   Preliminary study to evaluate discards impacts

For the five selected gears *a priori* (OTB, OTT, GNS, GTR and SDN), we have enough discards data to decide on the importance of them (Appendix C). The Danish seines time series sea observations started in 2012 so we cannot consider a gear that moreover has only been used since 2010. For otter

298 trawlers and set gillnets the numbers of observations and their position within the year are

299 significant. However, the distribution of the OBSMER data along the 2003-2015 period reveals better

300 coverage of the fishing activity since 2009. This change corresponds to the decision taken by the

301 Ministry of Agriculture and Fisheries to intensify the observations aboard ships. Consequently, the

302 analysis is truncated to the 2009-2015 period for the four remaining gears (Appendix D). Otter

303 bottom trawls (OTB), Otter twin trawls (OTT) and Set gillnets (GNS) show low discards of fishes above

304 the commercial weight (essentially less than 3% on average for OTB; less than 1% for OTT; less than

305 5% for GNS). Regarding Trammel nets (GTR), the discard rates are regularly higher than 15%

306 (whether per year or per month). For trawlers, the phenomenon seems stationary over the period

307 (except in December when this rate reaches 11% for OTB). For gillnetters, the monthly average is

308 characterized by higher values for January and November. GTR shows a peak in March (40% on

309 average).

310 The analytical process of analysing landing data was therefore applied to OTB, OTT and GNS. For OTT,

311 a mandatory condition was not fulfilled (Step 4 - LPUEs below the set threshold value from 2012

312 onwards). Consequently, only results for OTB and GNS are presented (detailed for OTB, less detailed

313 for GNS). They potentially allow us to propose LPUEs as abundance proxy, but only for fishes above

314 the commercial weight - 40 gr.

3.2   Results for otter bottom trawls (OTB)

3.2.1   Step 1: identify the factors influencing LPUE

317 The sum of the two dimensions of the NPCA is equal to 81%, thus clearly accounting for the

318 variability of the LPUEs and their associated indicators of level and dispersion. However, it does not

319 highlight linear relationships between the LPUE levels, their variability indicators and the technical

320 characteristics of the vessels (Figure 4). Dim1 combines most of the indicators of level and dispersion

321 revealing correlation between level characteristics of LPUE and dispersion ones: the variance is high

322   if the level of LPUE is high. This dimension shows a size effect and to characterize it, the Kruskal-

323   Wallis test confirms that statistical rectangle, month, year and gear mesh classes are significant
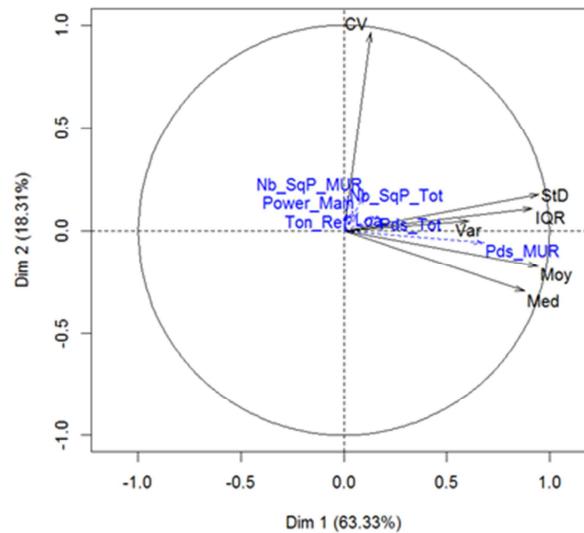
324   discriminant variables.

325

326   Figure 4. Correlation circle for OTB using the first two dimensions.

327   In order to evaluate the effect of technical characteristics to account for LPUE levels, a conditional

328   regression tree was used, considering values of log10moy to be explained and technical

329   characteristics as input variables (Figure 5). The highest LPUEs (bold values in the table in **Error!**

330   **Reference source not found.**) are associated with vessels of which:

331   • Rule 1: the engine power is greater than 405 kW when associated with a gear whose mesh is

332   less than 79 mm;

333   • Rule 2: the engine power is between 129 and 405 kW, and gear has a mesh less than 70 mm;

334   • Rule 3: the vessel length is less than or equal to 11.95 m and the gear associated with a gear

335   mesh equal to or less than 80 mm.

Node	5	6	8	9	12	13	14	15	19	21	22	25	26	27
LPUE (Mean)	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
LPUE (Median)	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
Number	1853	1013	2983	517	1533	24994	2356	865	10	2248	844	166	2485	38
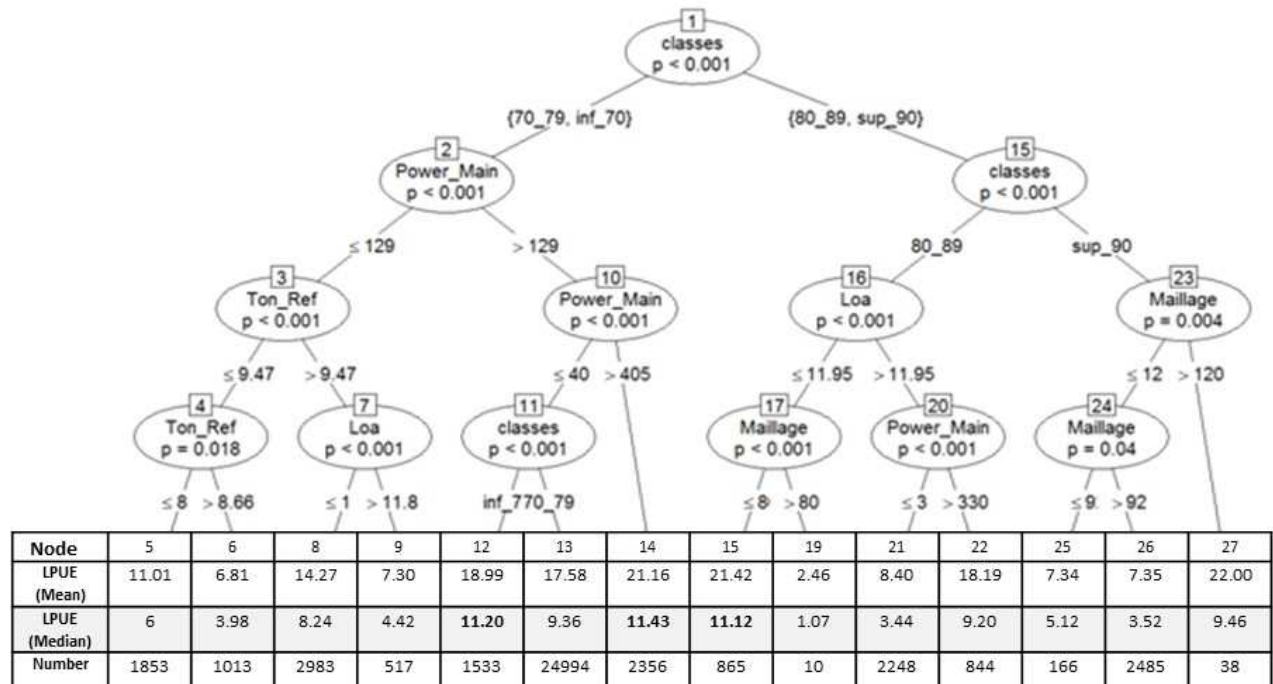
Figure 5. Conditional regression tree on log10Moy (standardized LPUE) with technical characteristics (the values in columns correspond to the values of each node).

336

3.2.2 Step 2: vessel typology

338 Implementation of HAC on the technical characteristics of the vessels allows for three distinct

339 clusters to be distinguished (characteristics displayed in Table 4). Small vessels (between 7.9 and 15.8

340 m) with a small gauge between 2 and 43.9 grt, and an engine power between 44 and 256 kW define

341 cluster 1. Cluster 2 is composed of large vessels (between 16.5 and 37.2 m), with a gauge between 58

342 and 361 grt and an engine power between 261 and 1080 kW. Cluster 3 is characterized by medium-

343 sized vessels (between 14.1 and 20.3 m), with a gauge between 29.5 and 115.8 grt and an engine

344 power between 200 and 351 kW.

345

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									

346 Table 4. Values of technical characteristics per cluster.

347 **3.2.3 Step 3: cluster selection**

348 For each cluster, changes in landing average calculated by month and by year are shown in Figure 6.

349 Cluster 2 presents a high variability at the end of the period. For clusters 1 and cluster 3, the

350 variability decreases during the studied period as well as the average landings of Surmullet. At the

351 end of the period, cluster 1 displays low variability and low average landings. Conversely, cluster 3,

352 which has a higher landing average, maintains some cyclicality in the levels of the LPUEs.

353
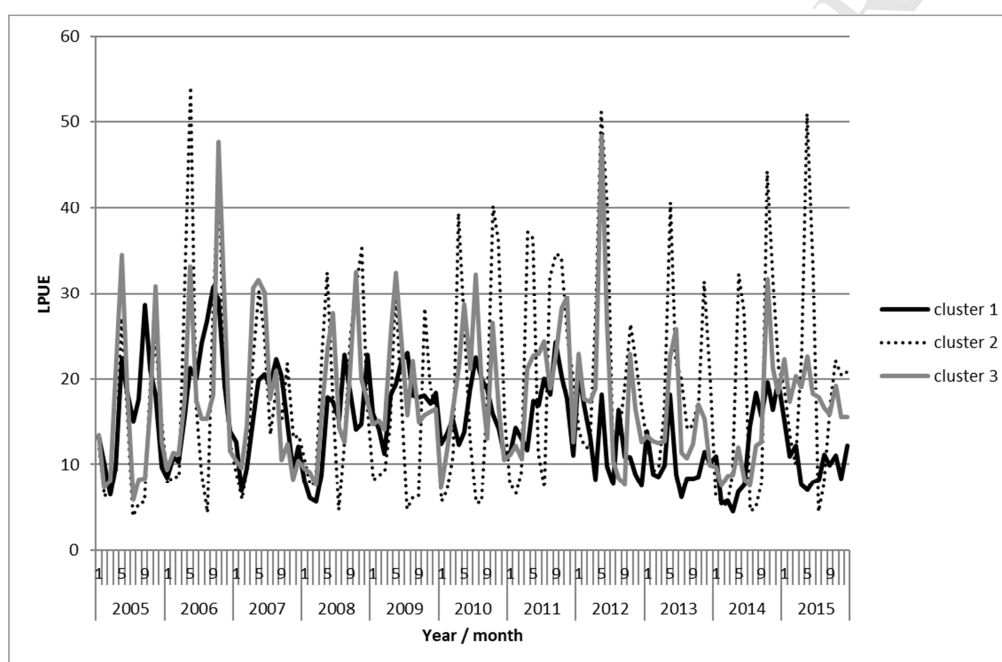
354 Figure 6. Average LPUEs per cluster for Surmullet in the Bay of Biscay.

355 To consider spatial availability of the LPUEs, the optional multi-criteria selection method focuses on

356 what happens in the north and in the south of the Bay of Biscay (see Appendix E). The activity of the

357 three clusters are present in both areas even if it is less true for cluster 2. Clusters 2 and 3 show high

358 variability on average with an increase in the north for cluster 2 and a decrease in the south for

359 cluster 3 at the end of the period. Cluster 1 is characterized by a slightly decreasing variability over

360 time.

361 Considering Figure 6 and Appendix E, all mandatory criteria are completed for the 3 OTB clusters.

362 Table 5 summarizes the results following the application of the optional conditions on the data

363 series. Although the results are close, this point system allows us to propose cluster 1 for OTB.

364

Multi-criteria selection method		Gear: OTB		
Level of obligation	Vessel typology (technical characteristics)	Cluster 1	Cluster 2	Cluster 3
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		**1**	3	2

365 Table 5. Classification of clusters for OTB.

3.2.4 Step 4: final refinement of the reference fleet

367 The monthly evolution of the LPUEs for each of the gear mesh classes used for cluster 1 - OTB is

368 shown in appendix F. The 70-79 mm mesh class is by far the most represented class for this cluster at

369 around 85%. We therefore focus, henceforth, on the LPUE cluster 1 - OTB - mesh 70-79 mm. For this

370 gear mesh size of interest, the average LPUEs oscillate between 10 and 20 kg per unit of effort

371 according to the month. They are the strongest between May and October (Figure 7).

372
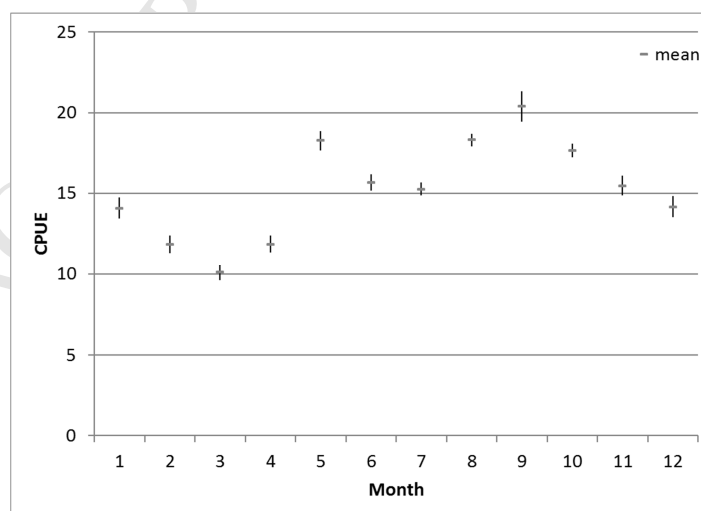
373 Figure 7. Average LPUEs per month over the 2005 to 2015 period for cluster 1 - OTB - 70 - 79 mm.

374 Based on these characteristics, working throughout the year on this fleet is proposed. For cluster 1 -

375 OTB with a 70 - 79 mm gear mesh size, the evolution of its use over time and of the LPUEs for the

376 whole Bay of Biscay are considered. The number of uses of the mesh 70 - 79 mm for OTB cluster 1

377 shows a slight decrease during the study period; however, this decrease is not significant. LPUE also

378 decreases over the period of study but significantly so in this case (Figure 8).

379
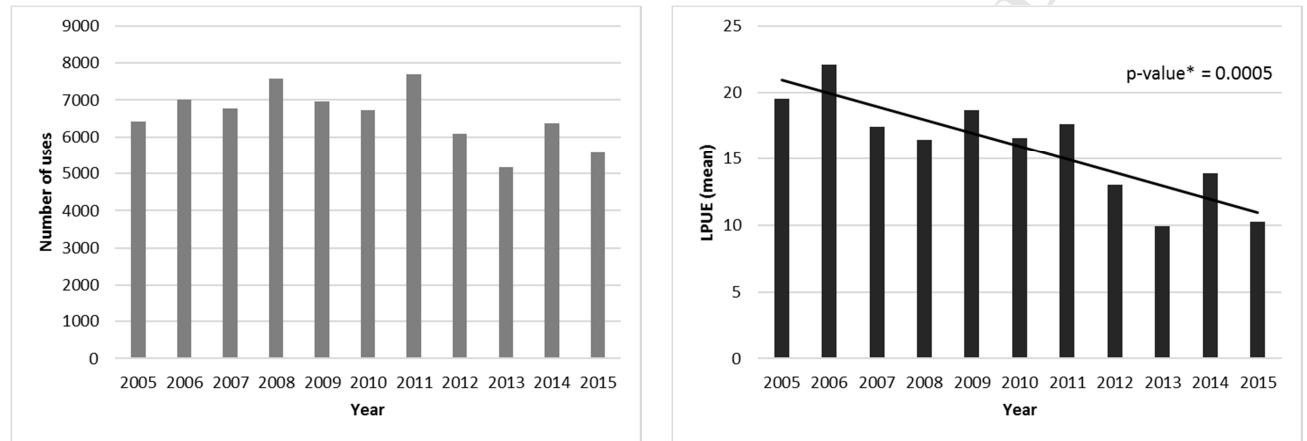
380 Figure 8. Number of uses and levels of associated LPUEs for the Bay of Biscay - OTB - cluster 1- mesh
381 class 70 - 79 mm.

3.3 Results for GNS

383 As for OTB, the same process was applied to GNS data. Its leads to the identification of 3 candidate

384 vessel clusters (Table 6).

385

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									

386 Table 6. Values of technical characteristics per cluster.

387 For each cluster, evolutions in monthly and annual landing averages are shown in Figure 9. According

388 to Figure 9 and Appendix G, all mandatory criteria are fulfilled for clusters 1 and 2. Cluster 3 is

389 excluded at this stage since it displays an inadequate length of the time series in the Bay of Biscay.
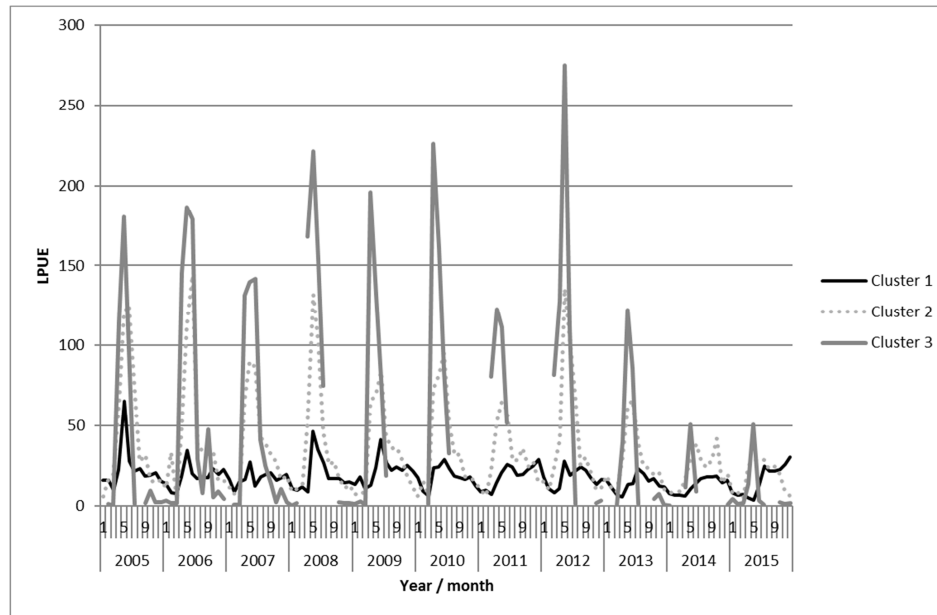
Figure 9. Average LPUEs per cluster for Surmullet in the Bay of Biscay.

390   Table 7 summarizes the results following the application of optional conditions on the data series.

391

Multi-criteria selection method		Gear: GNS		
Level of obligation	Vessel typology (technical characteristics)	Cluster 1	Cluster 2	Cluster 3
Optional	Stable seasonal signal (both in amplitude and periodicity) during the series	1/3	2/3	Excluded
	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		2	**1**	

392   Table 7. Classification of clusters for GNS.

393   Although the results are tight, this point system enables cluster 2 to be proposed for GNS. Appendix

394   H shows the monthly evolution of the LPUEs for each gear mesh class used for cluster 2 – GNS. We

395   focused on the most commonly used gear mesh classes (50 - 59 mm, 60 - 69 mm and higher than 90

396   mm) to refine the characteristics of the reference fleet. All of them are relevant for GNS according to

397   several criteria: sufficient level of LPUE, presence over a long period, representativeness of the

398   cluster, many uses and limited confidence interval. The relevant period was defined according to the

399   average LPUEs per month over the series 2005 to 2015 for each class: quarters 2 and 3 for 50 - 59

400   mm gear mesh, quarter 2 for the two others (Figure 10 to Figure 12).
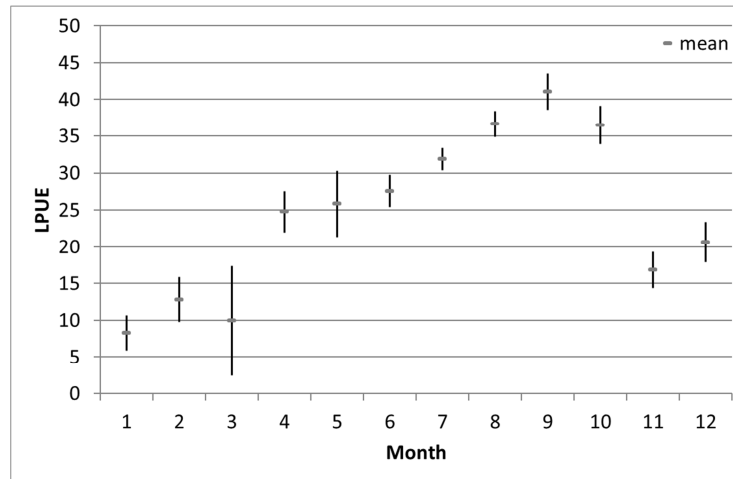
Figure 10. Average LPUEs per month over the series 2005 to 2015 for cluster 2 - GNS - 50 - 59 mm.
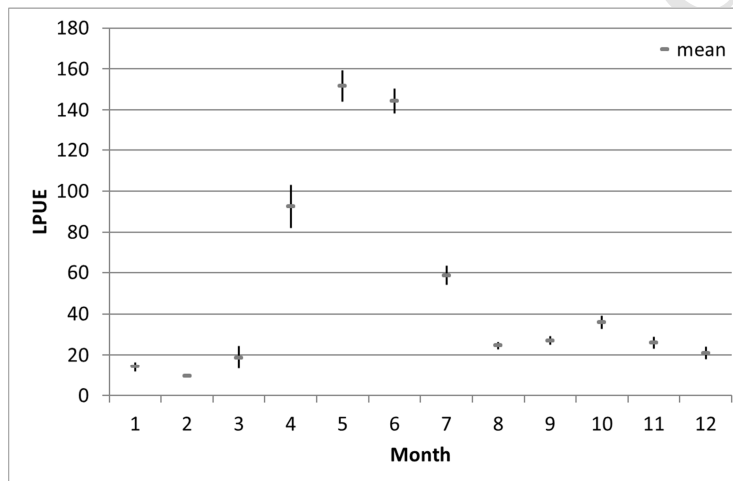
Figure 11. Average LPUEs per month over the series 2005 to 2015 for cluster 2 – GNS - 60 - 69 mm.
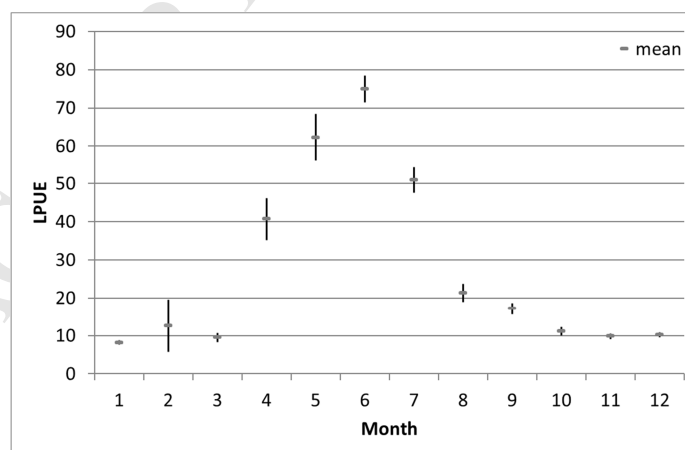
Figure 12. Average LPUEs per month over the series 2005 to 2015 for cluster 2 - GNS - greater than 90 mm.

401 For each of these combinations mesh / quarter of cluster 2 - GNS, the evolution of their use over

402 time and of their LPUEs for the entire Bay of Biscay is considered (Figure 13 to Figure 16). Gear

403 meshes 50 - 59 mm and 60 - 69 mm have their use levels that decrease significantly for the second

404 quarter. For the gear mesh 60 - 69 mm, this decrease is in conjunction with a significant decrease of

405 the LPUEs over the period. For the other couples of gear mesh classes / quarter, the numbers of uses

406 and the LPUEs seem to decrease but it is not significant.

407
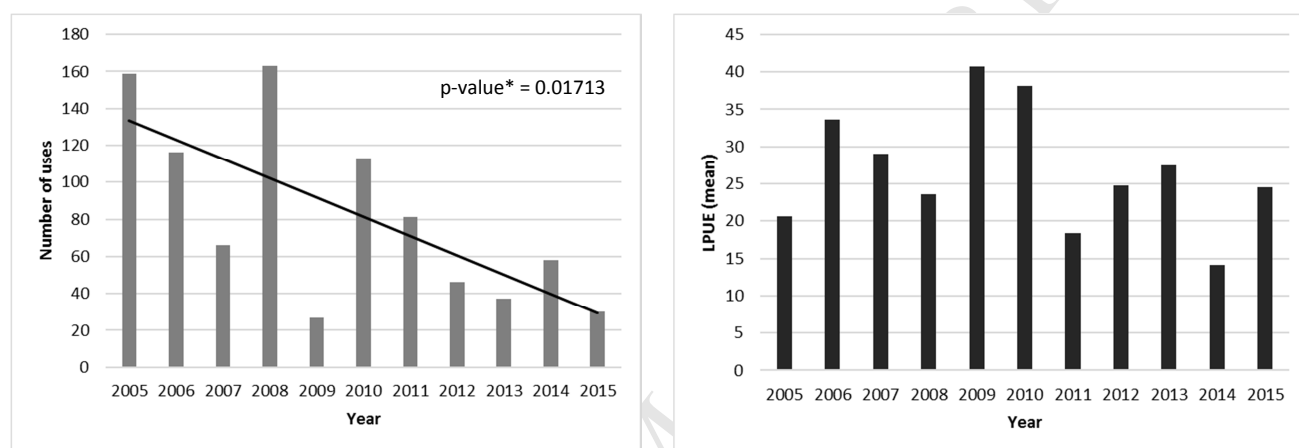
408 Figure 13. Number of uses and levels of associated mean LPUEs for the Bay of Biscay - 2nd quarter -

409 GNS - cluster 2 - gear mesh class 50 - 59 mm.

410
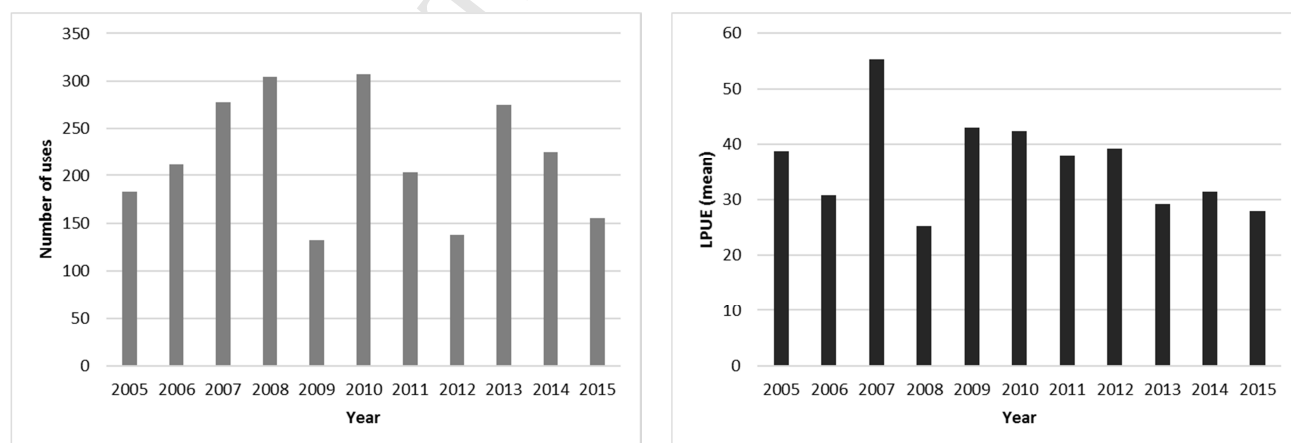
411 Figure 14. Number of uses and levels of associated mean LPUEs for the Bay of Biscay – 3rd quarter -

412 GNS - cluster 2 - gear mesh class 50 - 59 mm.

413
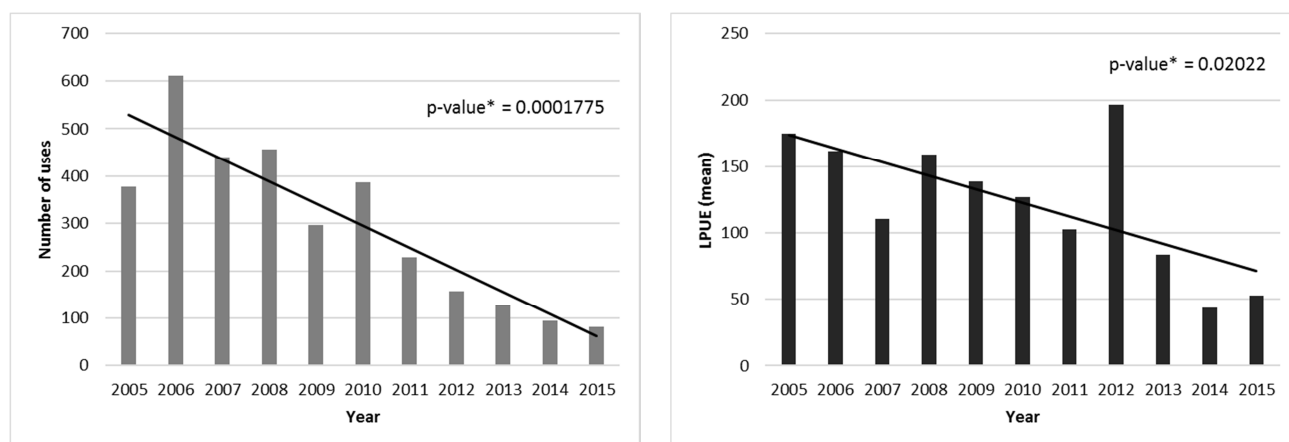
Figure 15. Number of uses and levels of associated mean LPUEs for the Bay of Biscay - 2nd quarter - GNS - cluster 2 - gear mesh class 60 - 69 mm.
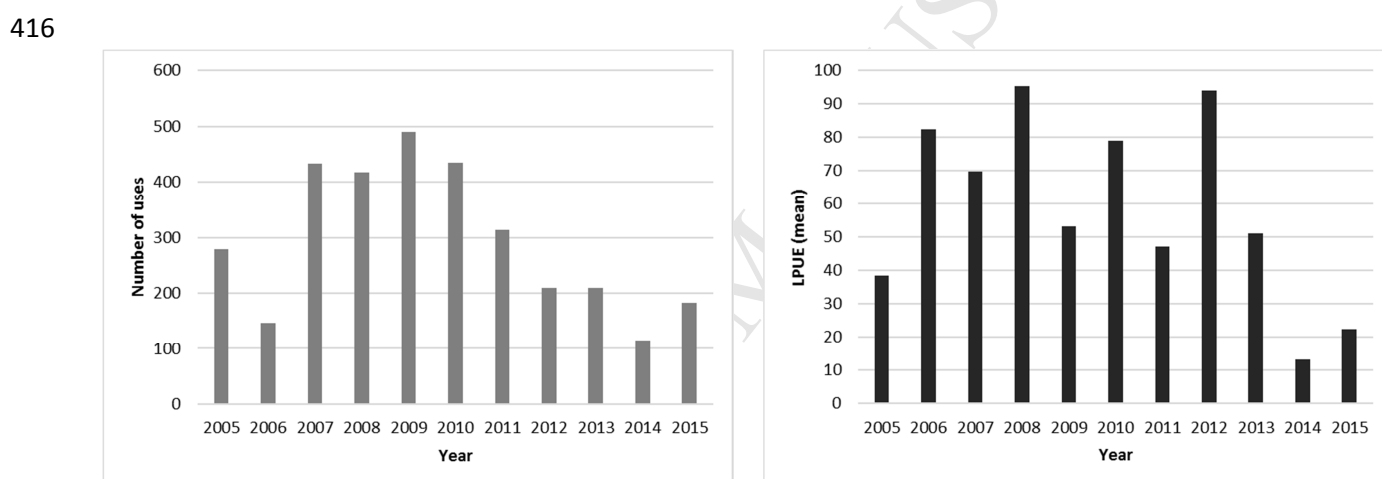
Figure 16. Number of uses and levels of associated mean LPUEs for the Bay of Biscay - 2nd quarter - GNS - cluster 2 - gear mesh class higher than 90 mm.

Starting with 5 potential fleets of interest (OTB, OTT, GNS, GTR, SDN), the analyses of the discards and the analytical process of the landing data lead us to propose two reference fleets: OTB and GNS defined by technical characteristics of the vessels, mesh class and, in the case of GNS, with temporal selection.

4   Discussion

4.1   Various origins of bias identified and choices to overcome them

One of the first sources of difficulties experienced when working on commercial fisheries data is linked to the nature of the available data. Most of the time, only landing data are available. That necessitates being well versed in the conditions under which the catches are made and, in particular, the possible effects of discards when landing based abundance indices are considered. For some species, discards can be assumed to be virtually absent (Guijarro et al., 2009; Sbrana et al., 2006). For others it is not the case (Lorance and Dupouy, 2001); discarding of marketable fish may bias CPUE (Quirijns et al., 2008). These two variables are often assimilated (García-Rodríguez et al., 2006; Quirijns et al., 2008) for small scales fisheries (e.g. Surmullet, octopus) and yet, this simplification may result in additional uncertainty. That is why we undertook a preliminary study of the discards using OBSMER data. This information, based on sampling of fishing trips, displays very low and stable percentages of discards with restricted confidence intervals for trawlers. For netters, only gillnetters presented satisfactory results (low and stable releases except in January and November). Trammel netters and Danish seiners were eliminated at this point. For the former, percentages of discards were not only high in certain months but also presented an important range of confidence intervals throughout the year. They are far from negligible and induce too high a level of uncertainty in any relative index of abundance from landings. For the latter, its exclusion comes from a lack of observed quantified data while important discards have been noted, notably on small individuals at the beginning of the implementation of the technique (Léauté et al., 2018).

Another source of known bias is related to catchability modifications (Laurec and Le Guen, 1981). Fish stock or fleet dynamics contribute in how catchability changes over time and various studies have already focused on these aspects (Kendrick et Bentley, 2010; Maunder et al., 2006; Paloheimo and Dickie, 1964; Rose and Kulka, 1999). This simple basic relationship between catchability and abundance is particularly affected when fishes aggregate (Maunder et al., 2006). No such behaviour

449   is described for Surmullet (Caill-Milly et al., 2017). This does not preclude taking into account the

450   ecology of the species when the spatial extent of the study area was fixed. Only the statistical ICES

451   rectangles consistent with the bathymetric distribution of Striped red mullet that is less than or equal

452   to 300 m (Mahé et al., 2005, Suquet and Person-Le Ruyet, 2001) were selected. Another aspect is

453   that catchability of a species can be greatly affected when a fleet changes its targeting practice from

454   one species to another. It also often increases over time as the efficiency of the fleet increases

455   (Maunder et al., 2006). Due to strategies, Bourdaud et al. (2017) suggest that fishermen target rather

456   than sample fish densities. Lorance and Dupouy (2001) highlighted a possible effect of the fishing

457   strategy on the amount of effort expended on species due to the accuracy of the catch and effort

458   data available (statistical rectangles versus trawl hauls). Cooperation between vessels targeting the

459   same species can increase their ability to locate areas of high abundance and thereby increase the

460   CPUEs of each vessel (Hilborn and Walters, 1992). We consider this is not the case for the retained

461   gears. Surmullet is part of a set of sought-after demersal species (but not specifically targeted) both

462   for trawlers and for netters, mainly for its high commercial value. It would certainly have been

463   different if Danish seiner had been selected because the implementation of this type of seine

464   appeared in the late 2000s (Léauté et al., 2018).

465   Distinguishing between causes related to fleet dynamics and management measures is not always

466   obvious. However, in some cases, the relationship is highlighted and management measures can

467   clearly interfere with the studied indices (Maunder et al., 2006). We detected clear changes in the

468   trend of landings per fishing trip in 2005 for trawlers and netters. Discussions with professional

469   fishermen and their representatives associated with this work enabled these observations to be

470   linked to the implementation of a selectivity device confirmed later by the Council Regulation (EC)

471   (No 1288/2009). To overcome this regulatory bias, we focused the analysis on the 2005-2015 period.

472   For many fisheries, a quota consumption effect is also described (Maunder et al., 2006; Quirijns et

473   al., 2008). This is not the case here seeing as Striped red mullet is not a quota species at this stage.

4.2 Main factors influencing LPUEs

474

475 We chose to undertake a data filtering approach and not a classic statistical analysis on all of the

476 data. While GLMs have been used since the 1980's, they exhibit limitations in the relationship

477 between the CPUE and the explanatory variables as they are relative to linear relationships. In a

478 generally nonlinear world, analyses should account for relationships that are more complicated.

479 General additive models, neural networks and regression trees are for example more general in their

480 functional forms than GLMs (Hinton and Maunder, 2003). Habitat based models use in addition

481 analytical reasoning to define this functional form of the relationship between CPUE and the

482 explanatory variables (Hinton and Nakano, 1996 in Hinton and Maunder, 2003).

483 Both NPCA and regression trees highlighted the strong concomitance between spatiotemporal

484 variables and LPUEs (level, variability). Such results were expected and are widely recognised in the

485 literature (Denis et al., 2002; Gladston et al., 2018; Goodyear, 2003; Zhang et al., 2015). For OTB, it is

486 more pronounced regarding spatial considerations, the south being characterized by higher LPUEs.

487 However when clusters are considered, the differences are less obvious. Caill-Milly et al. (2017)

488 described a level of landing per statistical rectangle strong enough along the whole coast (especially

489 corresponding to depths of less than 100 m) which would indicate that it makes sense to keep

490 information from the Bay of Biscay and not to make any spatial restrictions when selecting the fleets.

491 For GNS, important differences are detected regarding spatial considerations but they concern three

492 statistical rectangles. They were too sparse to lead to spatial selection. In contrast, monthly

493 differences appear important and are indeed confirmed at the cluster level. This instigated the

494 application of a time filter for this gear. Such selection is applied for gill nets catches in lakes

495 (Lauridsen et al., 2008); it seems less common for trawlers.

496 Once those spatiotemporal variables had been removed, non-linear links between LPUEs and

497 characteristics of the vessels and of the gears appeared. For OTB, it concerns gear mesh size and

498 engine power. Such a result is concordant with what Rijnsdorp et al. (2000) already demonstrated, in

499 that CPUE of beam trawlers is strongly affected by the engine power of the vessel. For GNS, it

500 concerns gear mesh, length and tonnage of the vessel. Again, these results are consistent with work

501 done by Kalaycı and Yeşilçiçek (2014) and Marchal et al. (2006).

502 Abundance series in general showed high variability. Some aspects can be attributed to the use of

503 various gear meshes and that is why optional criteria were applied to limit the variability in the LPUE

504 data (for both otter trawlers and set gillnetters). For set gillnetters, the activity is seasonal.

505 Fishermen tend to target other species the rest of the year; in fact they use nets that are not suitable

506 for catching Striped red mullet.

4.3 An original approach in line with ICES expectations regarding DLS

508 The approach we implemented is different from most work on CPUE (or LPUE) in that it relies on a

509 collaborative approach that associated scientists and fishermen to better identify the sources of

510 variability of the studied variables and define the thresholds applied. This association contributes to

511 maximising usefulness of the available data for this stock. This was the case in particular for the

512 validation of the minimum level of LPUE, the coherent grouping of the gear meshes regarding

513 management measures, the validation of seasonal selections, but also professional practices, the

514 identification of regulations concomitant to trend changes in the dataset or the removal of some

515 gears from the analysis. Such beneficial relationships between scientists and fishermen were

516 described by Wilson (1999). They also contribute to a common ground in the course of discussions

517 between fishermen, fisheries managers and scientists on the state of the stock (Quirijns et al., 2008).

518 It is also innovative because it proposes prior consideration of the impact of discards on landings,

519 which are in most cases the only real data available to study catches. However, discarding practices

520 on which information is often limited can be of concern when using CPUE or LPUE as proxy of

521 abundance (Rijnsdorp et al., 2007). The original aspect of the approach is also based on ecology or

522 life-history considerations which can potentially have an important impact on the studied variables

523 (Figueiredo et al., 2013; Laurec and Le Gall, 1975). All these data were used in a complementary way.

524 It is a possible response to what is expected from ICES for DLS, which is, valuing all the available data

525 to improve knowledge on the stock status (Le Quesne et al., 2013). We make use of the wealth of

526 various information available (e.g. biology, population dynamics, and total catches) as recommended

527 by Maunder et al. (2006). Decisions on how to improve management of data-deficient stocks need to

528 be balanced with practical considerations (ICES, 2012). Indeed, particularly for DLS, it requires a

529 continuous balance between improving data collection and reporting, refining assessment methods

530 adapted to limited data, and developing robust management control rules (ICES, 2012).

531 Other approaches have been developed recently to overcome the aforementioned issues. It is

532 particularly the case of the simultaneous implementation of commercial fishing data (CPUE) and

533 PRCF (partial rate correlation function) to see contributions of endogenous and exogenous factors

534 (Vazquez-Prada, 2014). Bourdaud et al. (2017) and Kristensen et al. (2014) also proposed combined

535 valorisations of commercial fisheries data and scientific surveys data. This work contributes at its

536 respective level to one of the objectives of ICES that is increasing the number of DLS European

537 Atlantic waters with quantitative catch advice (Le Quesne et al., 2013). For Surmullet, they reduce

538 somewhat the gap regarding knowledge between this studied stock and the one found in Subarea 4

539 (North Sea), Divisions 7.d (Eastern English Channel) and 3.a (Skagerrak, Kattegat). A considerable

540 research effort has been conducted for almost fifteen years on these particular divisions (Mahé et al.,

541 2005; Mahé et al., 2013).

542 For the Striped red mullet in Subareas and Divisions 6, 7a-c, e-k, 8, and 9a, the target category is

543 category 4 (ICES, 2013). The two selected fleets can provide a solution to emerge from the current

544 situation (applying the precautionary buffer) and use catch information to evaluate whether the

545 stock is fished sustainably or whether a reduction in catches or landings is required to achieve

546 sustainability. In this case, the landing reduction recommended by ICES in 2017 was adapted to the

547 situation, as the retained abundance indicators appear to decrease significantly in two out of four

548 cases over the period. Nevertheless, in the absence of any existing measures to limit catches, this

549 recommendation may not be followed in reality.

550

551 5 Conclusions

552 This study considered the factors affecting landing rates (LPUE) of *M. Surmuletus* Bay of Biscay

553 French fisheries over an eleven-year period and enabled us to determine the relative contribution of

554 fleet technical characteristics (vessels and gears) and intra- and inter-annual variation. It led to the

555 identification of two reference fleets. Firstly the trawlers composed by small vessels (7.9 - 15.8 m)

556 with a gauge of 2 to 43.9 grt, an engine power between 44 and 256 kW and a gear mesh of 70 – 79

557 mm; secondly the gillnetters, which are defined by medium-sized vessels (8.2 - 14.8 m, 2 - 30.2 grt,

558 70 - 331 kW) whose gear mesh is either 50 – 59 mm (2nd and 3rd quarters), 60 – 69 mm (2nd

559 quarter) or greater than 90 mm (2nd quarter). LPUE of these fleets show a downward trend,

560 significant in two out of four cases that may reflect deterioration in the status of the Striped red

561 mullet stock.

562 The complementary use of various sources of data (fisheries data, ecological considerations,

563 professional knowledge) is a solution for selecting reference fleet. A filtering approach could be

564 implemented on other DLS-whiting and pollack for instance. We can state that this study approach is

565 both innovative and can be applied more generally.

566 Since it is considered that the retained LPUEs are proxy of abundance, they can also be used to

567 detect spatiotemporal variability of abundance in relation to environmental forcing, especially those

568 that can be linked to climate change. For such a purpose, the use of GLM or other statistical models

569 (taking into account their predictive power) will be very useful and are currently being tested using

570 the knowledge ascertained in this paper.

571

Acknowledgments

580

No conflicts of interests

582   We declare that we have no conflict of interest.

583

584 **References**

585   Benzinou, A., Carbini, S., Nasreddine, K., Elleboode, R., and Mahé, K., 2013. Discriminating stocks of

586   Striped red mullet (*Mullus surmuletus*) in the Northwest European seas using three

587   automatic shape classification methods. Fish. Res. 143, 153–160.

588   Bourdaud, P., Travers-Trolet, M., Vermard, Y., Cormon, X., and Marchal, P., 2017. Inferring the

589   annual, seasonal, and spatial distributions of marine species from complementary research

590   and commercial vessels' catch rates. ICES J. Mar. Sc. 74(9), 2415-2426. Publisher's official

591   version: http://doi.org/10.1093/icesjms/fsx092

592   Caill-Milly, N., Lissardy, and M. Léauté, J.-P., 2017. Improvement of the fishery knowledge of Striped

593   red mullet of the Bay of Biscay. Working Document for the Working Group on Widely

594   Distributed Stocks (WGWIDE), 30 August - 5 September 2017, Copenhagen (Denmark), 30 p.

595   Cornou, A.-S., Quinio-Scavinner, M., Delaunay, D., Dimeet, J., Goascoz, N., Dube, B., Fauconnet, L.,

596   and Rochet, M.-J. 2015. Observations à bord des navires de pêche professionnelle. Bilan de

597   l'échantillonnage 2014. http://dx.doi.org/10.13155/39722

598   Davis, P.S. and Edward, A.J. 1988. New records of fishes from the northeast coast of England, with

599   notes on the rediscovery of part of the type collection of marine fishes from the Dove Marine

600   Laboratory, Cullercoats. Trans. Nat. Hist. Soc. Northumbria. 55, 39–46.

601   De'ath, G. and Fabricius K. E., 2000. Classification and Regression Trees: a powerful yet simple

602   technique for ecological data analysis. Ecology, 81(11), 2000, 3178–3192.

603   Demanèche, S., Bégot, E., Gouëllo, A., Campéas, A., Habasque, J., Merrien, C., Leblond, E., Berthou,

604   P., Harscoat, V., Fritsch, M., Leneveu, C., and Laurans, M., 2013. PROJET SACROIS « IFREMER

605   / DPMA » V 3.2.5 - 11/2013. 43 p.

606   Denis, V., Lejeune, J., and Robin, J. P., 2002. Spatio-temporal analysis of commercial trawler data

607   using General Additive models: patterns of Loliginid squid abundance in the north-east

608   Atlantic. ICES J. Mar. Sc. 59, 633–648. doi:10.1006/jmsc.2001.1178

609   Figueiredo, I., Natário, I., Moura, T., and Carvalho, M. L., 2013. Modelling the dynamics of the

610   deepwater shark *Centroscymnus coelolepis* off mainland Portugal. Aquat. Living Resour. 26,

611   355–364.

612   Gibson, R.N. and Robb, L. 1997. Occurrence of juvenile red mullet (*Mullus surmuletus*) on the west

613   coast of Scotland. J. Mar. Biol. Assoc UK. 77(3): 911–912.

614   Girard, M., Lorance, P., and Biseau, A., 2000. Catch Per Unit Effort of deep-sea species off the

615   continental slope to the west of British Isles. Cybium 24(3), 97-104.

616   García-Rodríguez, M., Fernández A.M., and Esteban, A., 2006. Characterisation, analysis and catch

617   rates of the small-scale fisheries of the Alicante Gulf (SE Spain) over a 10 years time series.

618   Fish. Res. 77(2), 226-238. doi: 10.1016/j.fishres.2005.09.002

619   Gladston, Y., Martin Xavier, K. A., Ajina, S. M., Om Pravesh Kumar Ravi, Manoharmayum Shaya Devi,

620   Thakurdas, Chakraborty, S. K., and Latha Shenoy, 2018. Operational performance and catch

621   composition of pomfret gillnets of Maharashtra, India. Reg. Stud. Mar. Sc. 22, 31-37.

622   Goodyear, C. P., 2003. Spatio-temporal distribution of longline catch per unit effort, sea surface

623   temperature and Atlantic marlin. Mar. Freshwater Res. 54(4), 409-417.

624   Guijarro, B., Massutí, E., Moranta, J. E., and Cartes, J., 2009. Short spatio-temporal variations in the

625   population dynamics and biology of the deep-water rose shrimp *Parapenaeus longirostris*

626   (Decapoda: Crustacea) in the western Mediterranean. Sci. Mar. 73(1), 183-197, doi:

627   10.3989/scimar.2009.73n1183

628 Hilborn, R. and Walters, C. J., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics &
629   Uncertainty. Chapman and Hall, London. 570 pp.

630 Hinton, R. and Maunder, M. N.,2003. Methods for standardizing cpue and how to select among
631   them. SCTB16 Working Paper MWG-7, 13 pp.

632 ICES, 2012. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and
633   Skagerrak (WGNSSK), 27 April - 03 May 2012, ICES Headquarters, Copenhagen. ICES CM
634   2012/ACON:13. 1346 p.

635 ICES, 2013. Report of the Workshop on the Development of Quantitative Assessment Methodologies
636   based on LIFE-history traits, exploitation characteristics, and other key parameters for Data-
637   limited Stocks (WKLIFE III), 28 October–1 November 2013, Copenhagen, Denmark. ICES CM
638   2013/ACOM:35, 98 pp.

639 ICES. 2016. Advice basis. In Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1,
640   section 1.2.
641   http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/Introduction_to_a
642   dvice_2016.pdf

643 ICES, 2017. Advice on fishing opportunities, catch, and effort Bay of Biscay and the Iberian Coast,
644   Celtic Seas. Greater North Sea, and Oceanic Northeast Atlantic Ecoregions. DOI:
645   10.17895/ices.pub.3032 mur.27.67a-ce-k89a, 5 pp.

646 Kalaycı, F. and Yeşilçiçek, T., 2014.Effects of Depth, Season and Mesh Size on the Catch and Discard of
647   Whiting (*Merlangius merlangus euxinus*) Gillnet Fishery in the Southern Black Sea, Turkey.
648   Turk. J. Fish. Aquat. Sc. 14, 449-456.

649 Kendrick T. H. and Bentley N., 2010. Fishery characterisation and catch-per-unit-effort indices for
650   trevally in TRE 7, 1989–90 to 2007–08. New Zeal. Fish. Rep. 41, 58 pp.

651 Kristensen, K., Thygesen, U.H., Andersen, K.H., and Beyer, J.E., 2014. Estimating spatio-temporal

652   dynamics of size-structured populations. Can. J. Fish. Aquat. Sci. 71: 326–336.

653 Laurec, A. and Le Gall, J.-Y., 1975. De-seasonalizing of the abundance index of species. Application to

654   the albacore (*Thunnus alalunga*) monthly catch per unit of effort (C.P.U.E.) by the Atlantic

655   Japanese longline fishery. Bull. Far. Seas Fish. Res. 12, 145-169.

656 Laurec, A. and Le Guen, J.-C., 1981. Dynamique des populations marines exploitées. Tome 1.

657   Concepts et modèles. Publications du C.N.E.X.O. Série "Rapports scientifiques et techniques",

658   (45), 1-120. Open Access version: http://archimer.ifremer.fr/doc/00000/1126/

659 Lauridsen, T. L., Landkildehus, F., Jeppesen, E., Jørgensen, T. B., and Søndergaard, M., 2008. A

660   comparison of methods for calculating Catch Per Unit Effort (CPUE) of gill net catches in

661   lakes. Fish. Res. 93, 204-211.

662 Léauté, J.-P., Caill-Milly, N., Lissardy, M., Bru, N., Dutertre, M.-A., and Saguet, C., 2018. ROMELIGO.

663   Amélioration des connaissances halieutiques du ROuget-barbet, du MErlan et du LIeu jaune

664   du GOlfe de Gascogne. RBE/HGS/LRHLR et ODE/UL/LERAR/18-001.

665   http://archimer.ifremer.fr/doc/00440/55126/

666 Le Quesne, W., Brown, M., De Oliveira, J., Casey, J., and O'Brien, C., 2013. Rapport parlement

667   européen DATA-DEFICIENT FISHERIES IN EU WATERS - STUDY, 74 pp.

668 Lorance, P. and Dupouy, H., 2001. CPUE abundance indices of the main target species of the French

669   deep-water fishery in ICES Sub-areas V–VII. Fish. Res. 51(2-3), 137-149.

670 Mahé, K., Destombes, A., Coppin, F., Koubbi, P., Vaz, S., Le Roy, D., and Carpentier, A., 2005. Le

671   rouget barbet de roche *Mullus surmuletus* (L. 1758) en Manche orientale et mer du Nord.

672   Rapport de Contrat IFREMER/CRPMEM Nord-Pas-de-Calais, 187p.

673 Mahé, K., Coppin, F., Vaz, S., and Carpentier, A., 2013. Striped red mullet (*Mullus surmuletus*,

674   Linnaeus, 1758) in the eastern English Channel and southern North Sea: growth and

675   reproductive biology. J. Appl. Ichthyol. 29(5), 1067-1072. Publisher's official version:

676   http://doi.org/10.1111/jai.12266

677 Marchal, P., Andersen, B., Caillart, B., Eigaard, Guyader, O., Hovgaard, H., Iriondo, A., Le Fur, F.,

678   Sacchi, J., and Santurtun, M. 2007. Impact of technological creep on fishing effort and fishing

679   mortality, for a selection of European fleets. ICES J. Mar. Sci. 64, 192–209.

680 Maunder, M. N., Sibert, J. R., Fonteneau, A., Hampton, J., Kleiber, P., and Harley, S. J., 2006.

681   Interpreting catch per unit effort data to assess the status of individual stocks and

682   communities. ICES J. Mar. Sci. 63, 1373-1385. doi:10.1016/j.icesjms.2006.05.008

683 Maynou, F., Demestre, M. and Sánchez, P., 2003. Analysis of catch per unit effort by multivariate

684   analysis and generalised linear models for deep-water crustacean fisheries off Barcelona (NW

685   Mediterranean). Fish. Res. 65(1–3), 257–269.

686 O'Brien, C., 2013. Review of latest ICES' advice: Improving stocks/declining stocks/implications – and

687   overview of global stock status. Seafish Common Language Group, 6th November 2013,

688   London, 37 p.

689 O'Brien, C., 2016. Management: New Approaches to Old Problems, in: Jakobsen, T., Fogarty, M. J.,

690   Megrey, B. A., Moksness, E., 2016. Fish Reproductive Biology: Implications for Assessment

691   and Management - Print version: Fish reproductive biology Second edition. Chichester, West

692   Sussex, U.K.; Hoboken, NJ: Wiley-Blackwell, 9781118752746.

693 Paloheimo, J.E. and Dickie, L.M., 1964. Abundance and fishing success. Rapp. P.-V. Reun. Cons. Int.

694   Explor. Mer. 155: 152-163.

695   Prasad, A M., Iverson, L. R., and Liaw, A., 2006. Newer Classification and Regression Tree Techniques:

696   Bagging and Random Forests for Ecological Prediction. Ecosystems. 9 (2): 181-199.Quéro, J.C.

697   and Vayne, J.J. 1997. Les poissons de mer des pêches françaises. Ifremer, Ed. Delachaux &

698   Niestlé, Lausanne - Paris.

699   Quirijns, F.J., Poos, J.J., and Rijnsdorp, A.D., 2008. Review, Standardizing commercial CPUE data in

700   monitoring stock dynamics: Accounting for targeting behaviour in mixed fisheries. Fish. Res.

701   89, 1–8.

702   Rijnsdorp, A.D., Dol,W., Hooyer, M., and Pastoors, M.A., 2000. Effects of fishing power and

703   competitive interactions among vessels on the effort allocation on the trip level of the Dutch

704   beam trawl fleet. ICES J. Mar. Sci. 57, 927–937.

705   Rijnsdorp, A. D., Daan, N., Dekker, W., Poos, J. J., and Van Densen, W.L.T., 2007. Sustainable use of

706   flatfish resources: Addressing the credibility crisis in mixed fisheries management. J. Sea Res.

707   57(2–3), 114-125. https://doi.org/10.1016/j.seares.2006.09.003

708   Rose, G.A. and Kulka, D.W. 1999. Hyperaggregation of fish and fisheries: how catch-per-unit-effort

709   increased as the northern cod (*Gadus morhua*) declined. Can. J. Fish. Aquat. Sci. 56(1), 118–

710   127.

711   Sbrana, M., C. Viva, and Belcari, P., 2006. Fishery of the deepwater rose shrimp *Parapenaeus

712   longirostris* (Lucas, 1846) (Crustacea: Decapoda) in the northern Tyrrhenian Sea (western

713   mediterranean). Hydrobiologia 557, 135-144.

714   Shearer, C., 2000. The CRISP-DM model: the new blueprint for data mining. J. Data Warehousing 5

715   (4), 15.

716   Suquet, M. and Person-Le Ruyet, J., 2001. Les rougets barbets (*Mullus barbatus, Mullus surmuletus*).

717   Biologie, pêche, marché et potentiel aquacole. Ifremer eds., Brest.

718   Vázquez-Prada, G., 2014. Analyzing fish stocks dynamics using CPUE and PRCF: a new approach for

719   the fishery management. J. Coastal Life Med. 2(1), 1-6.

720   Wilson, D. C., 1999. Fisheries Science Collaborations: The Critical Role of the Community. Institute for

721   Fisheries Management and Coastal Community Development, Res. Publ. 45, 24 p.

722   Zhang,H., Zhang, S. M., Cui, X. S., Yang, S. L., Hua, C. J., and Ma, H. Y., 2015. Spatio-temporal dynamics

723   in the location of the fishing grounds and catch per unit effort (CPUE) for Chilean jack

724   mackerel (*Trachurus murphyi* Nichols, 1920) from Chinese trawl fleets on the high seas of the

725   Southeast Pacific Ocean, 2001–2010. J. Appl. Ichtyol. 31 (4), 646-656.

726   https://doi.org/10.1111/jai.12765

727

728 **Appendix**

729 **Appendix A**
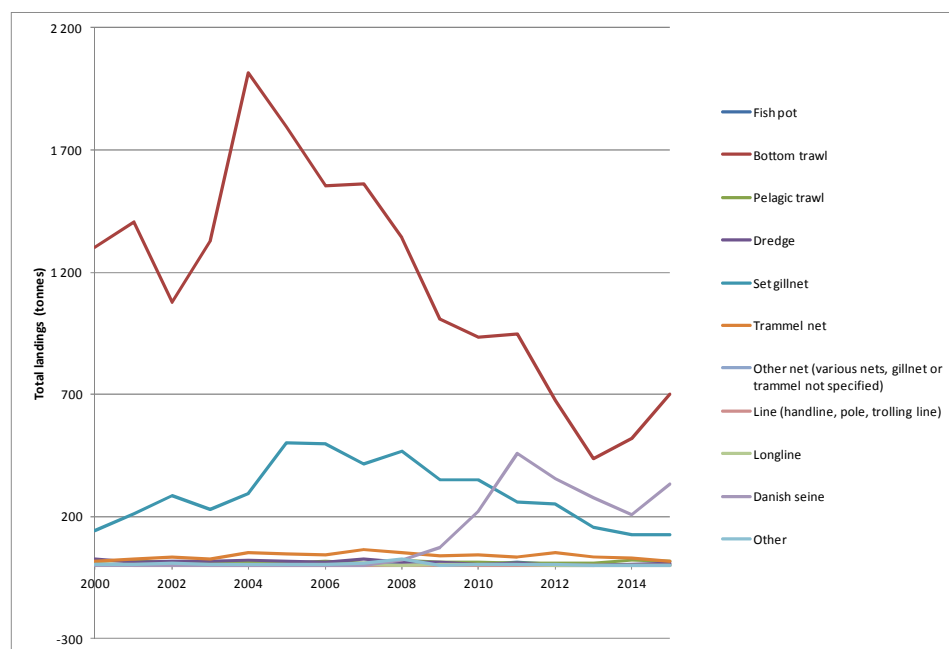
Figure A.1. Evolution of total landings from 2000 to 2015 by groups of gears (Sacrois data). Gear

representing less than 0.5 tonnes per year over the period is not specified but grouped under "other"

(translated from Caill-Milly et al., 2017).

733

734   **Appendix B**
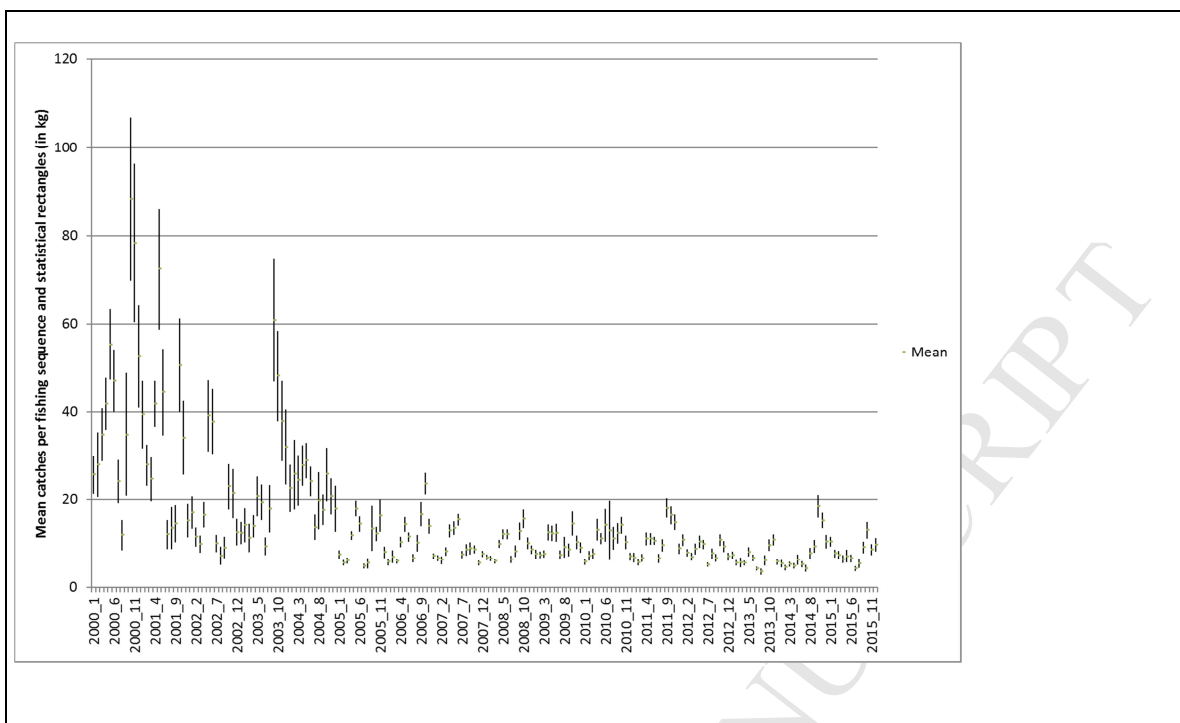
735   Figure B.1: Landings by fishing sequence and statistical rectangle (2000 - 2015) for Trawlers
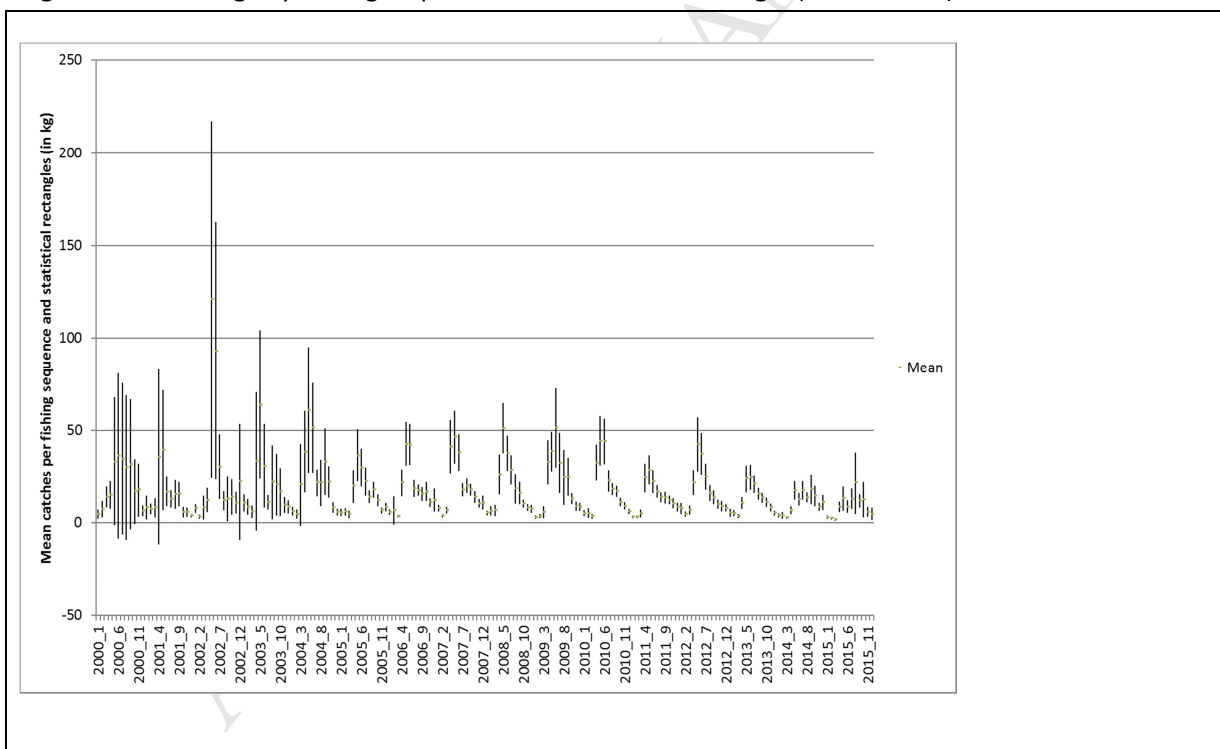
736   Figure B.2: Landings by fishing sequence and statistical rectangle (2000 - 2015) for Gillnetters

737

738 **Appendix C**

739 Discards data (Summary of the number of trip sequences (Obsmer) for the 4 selected gears)

740

Years	JA	FE	MA	AP	MA	JU	JY	AU	SE	OC	NO	DE	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

741 Figure C.1. Number of trip sequences per month and year for OTB

742

Years	JA	FE	MA	AP	MA	JU	JY	AU	SE	OC	NO	DE	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

743 Figure C.2. Number of trip sequences per month and year for OTT

744

745

Years	JA	FE	MA	AP	MA	JU	JY	AU	SE	OC	NO	DE	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

746   Figure C.3. Number of trip sequences per month and year for GNS

747

Years	JA	FE	MA	AP	MA	JU	JY	AU	SE	OC	NO	DE	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

748   Figure C.4. Number of trip sequences per month and year for GTR

749

750 **Appendix D**

751 Discards analyses

752 **OTB**
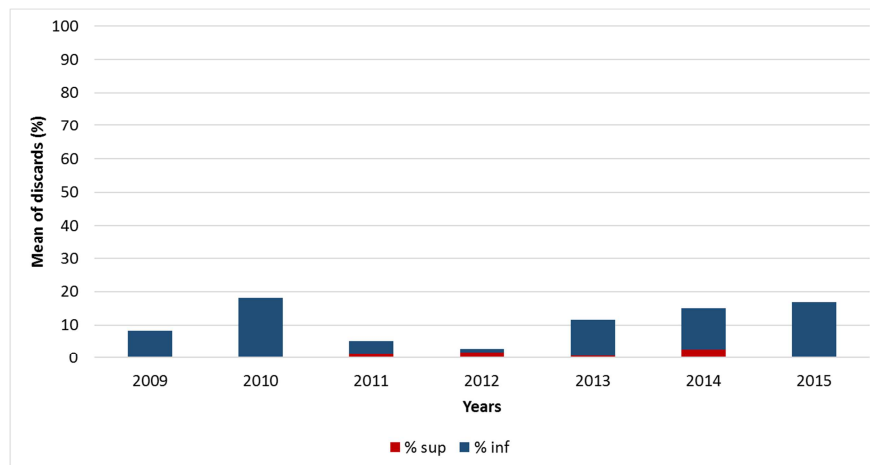
753 Figure D.1. Discard mean for all the series for OTB (2009-2015) per year in %
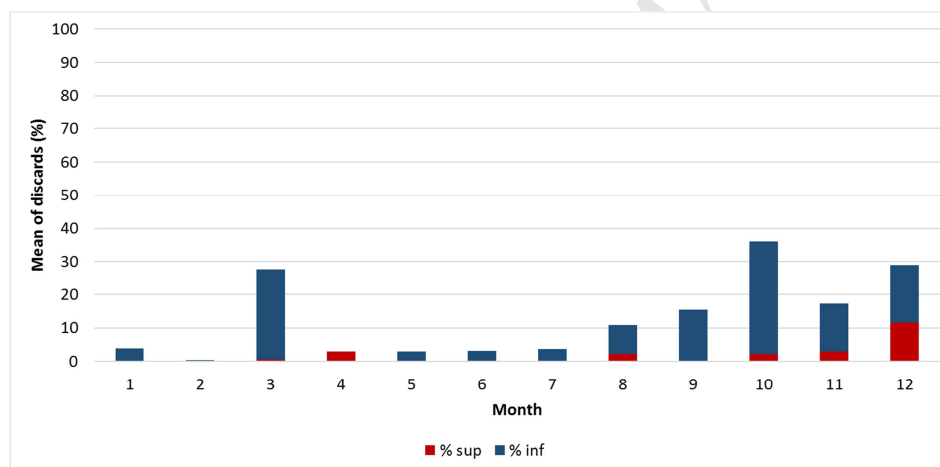
754 Figure D.2. Discard mean for all the series for OTB (2009-2015) per month in %

755

756   OTT
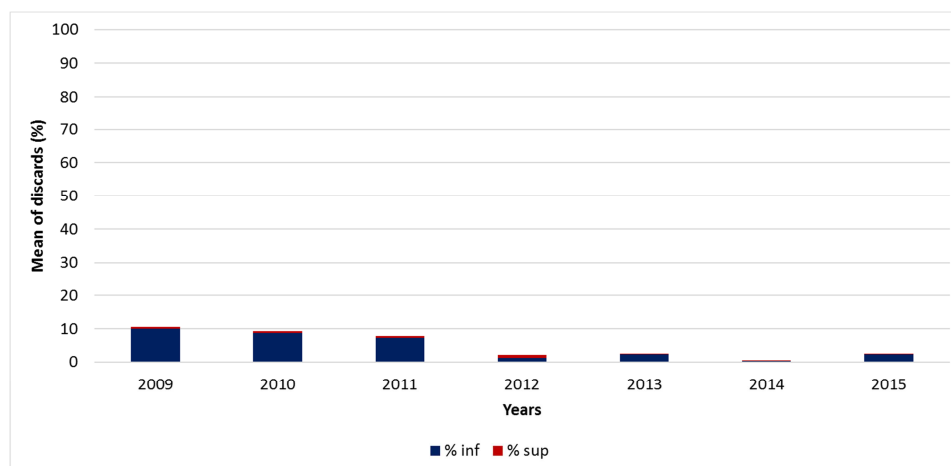
757   Figure D.3. Discard mean for all the series for OTT (2009-2015) per year in %
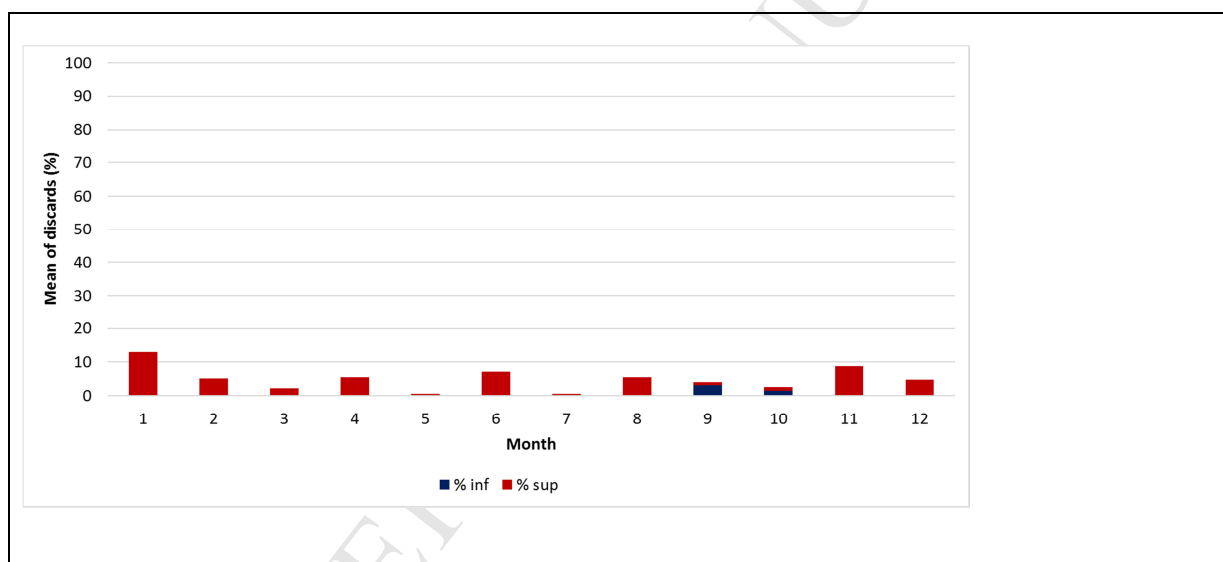
758
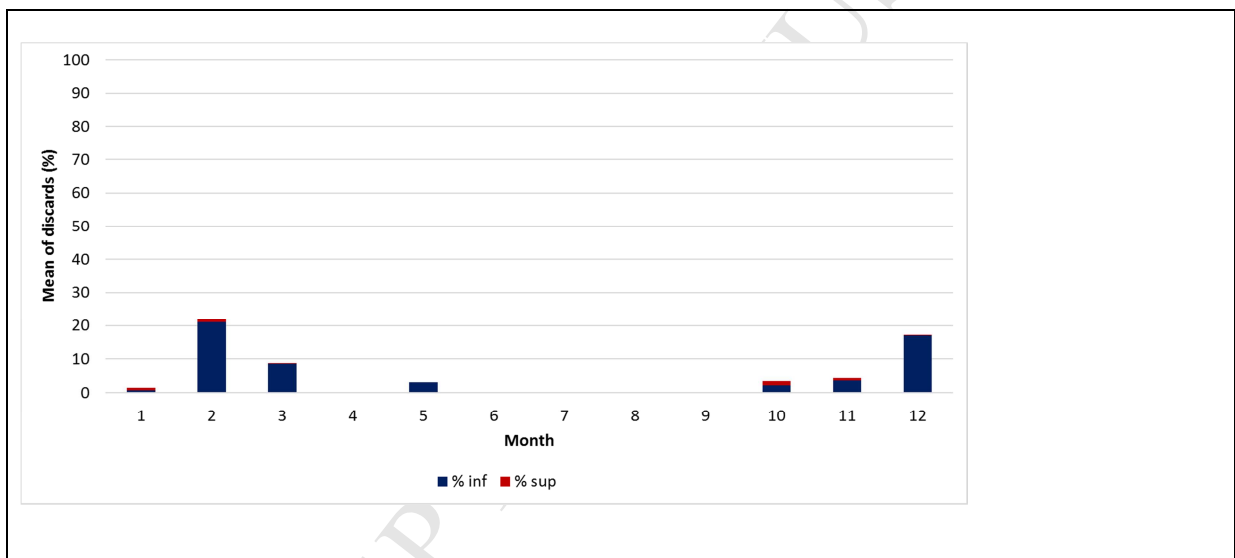
759   Figure D.4. Discard mean for all the series for OTT (2009-2015) per month in %
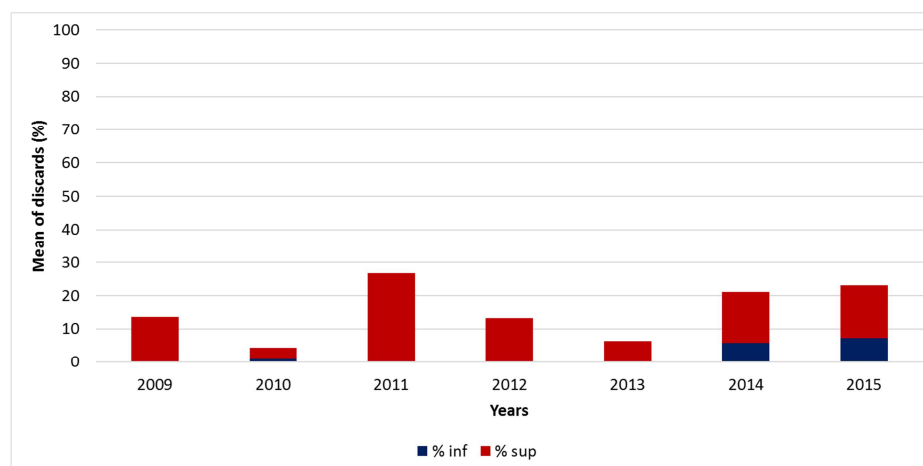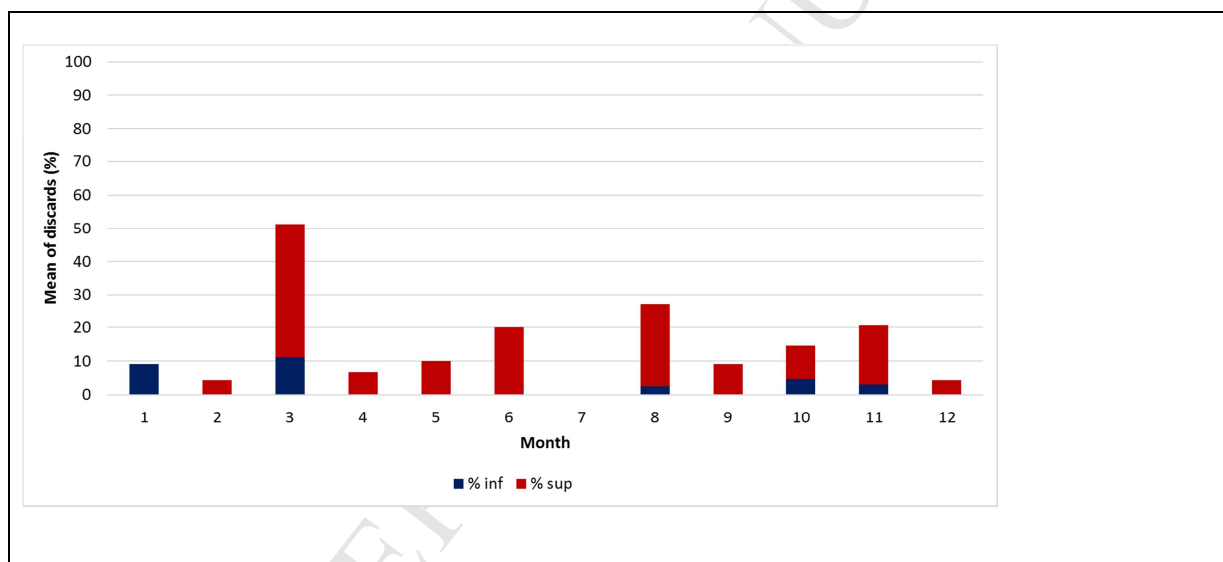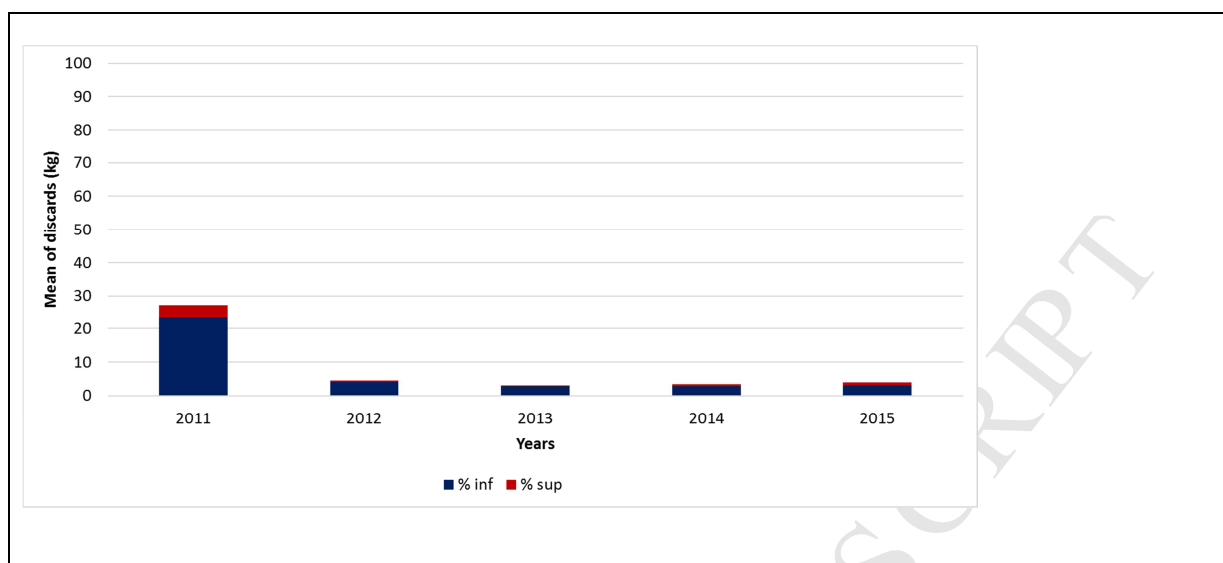
760   GNS
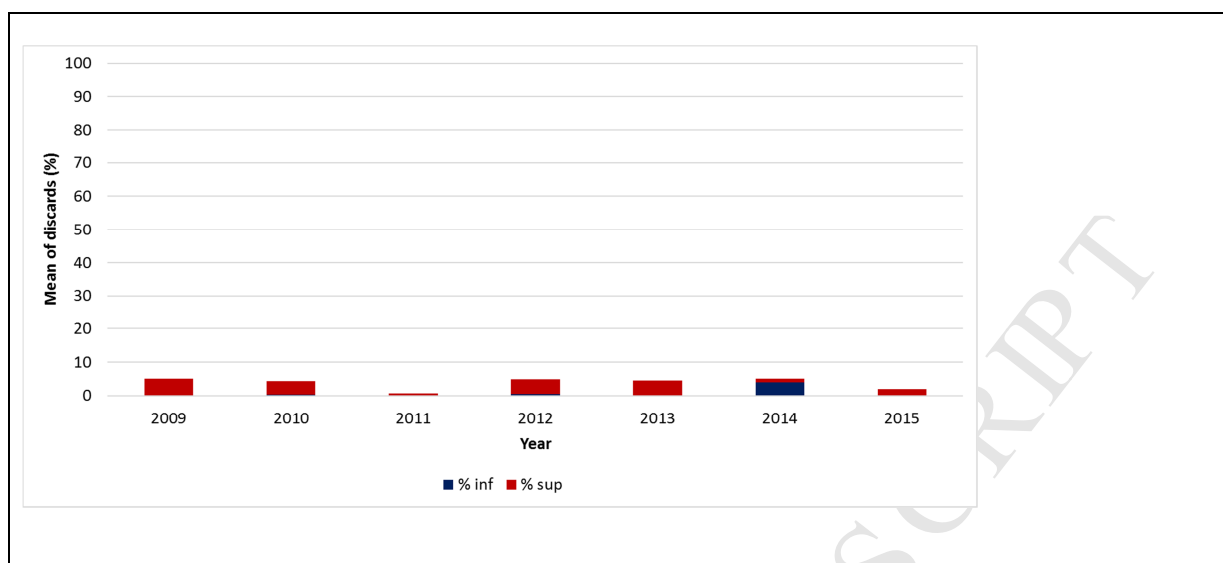
761   Figure D.5. Discard mean for all the series for GNS (2009-2015) per year in %

762

763   Figure D.6. Discard mean for all the series for GNS (2009-2015) per month in %
764   GTR

765   Figure D.7. Discard mean for all the series for GTR (2009-2015) per year in %
766

767   Figure D.8. Discard mean for all the series for GTR (2009-2015) per month in %

768   SDN

769   Figure D.9. Discard mean for all the series for SDN (2011-2015) per year in %

770
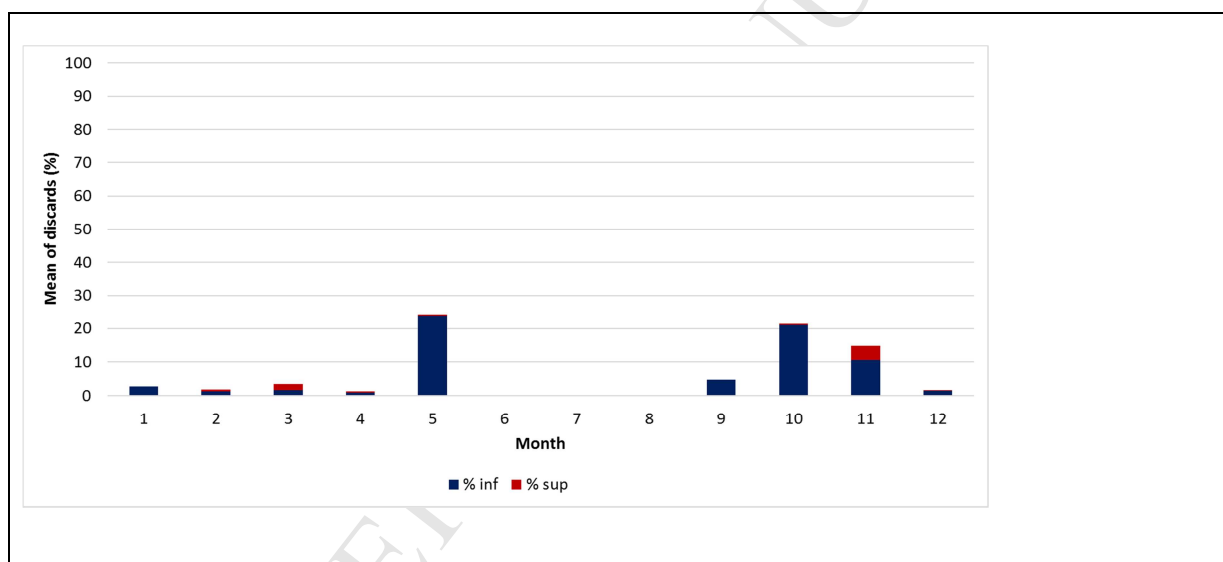
771   Figure D.10. Discard mean for all the series for SDN (2011-2015) per month in %

772

773 **Appendix E**

774
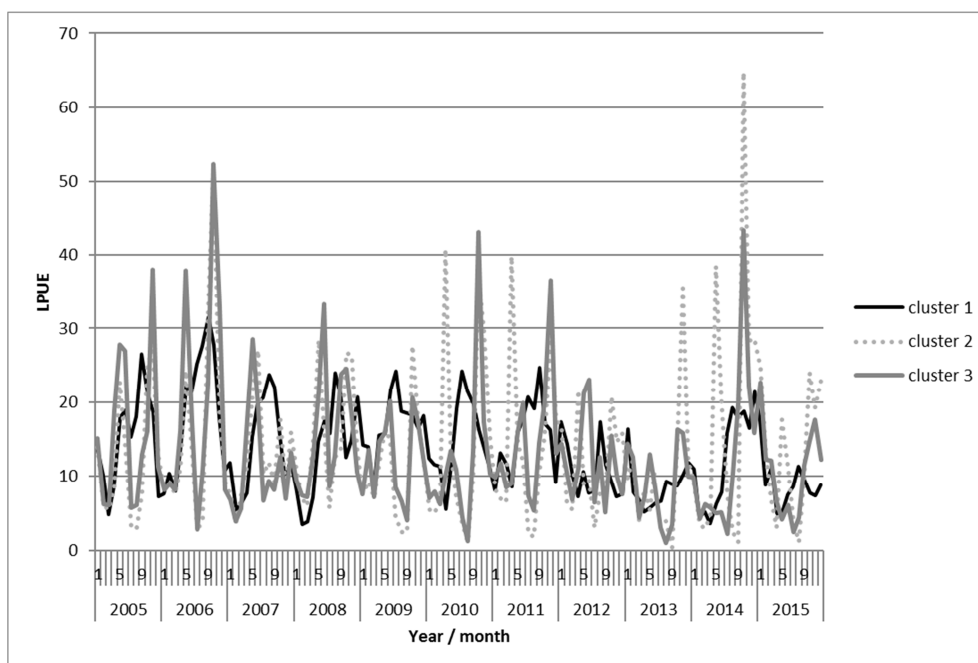
775   Figure E.1. Average LPUEs per cluster for Surmullet in the north of Bay of Biscay.

776
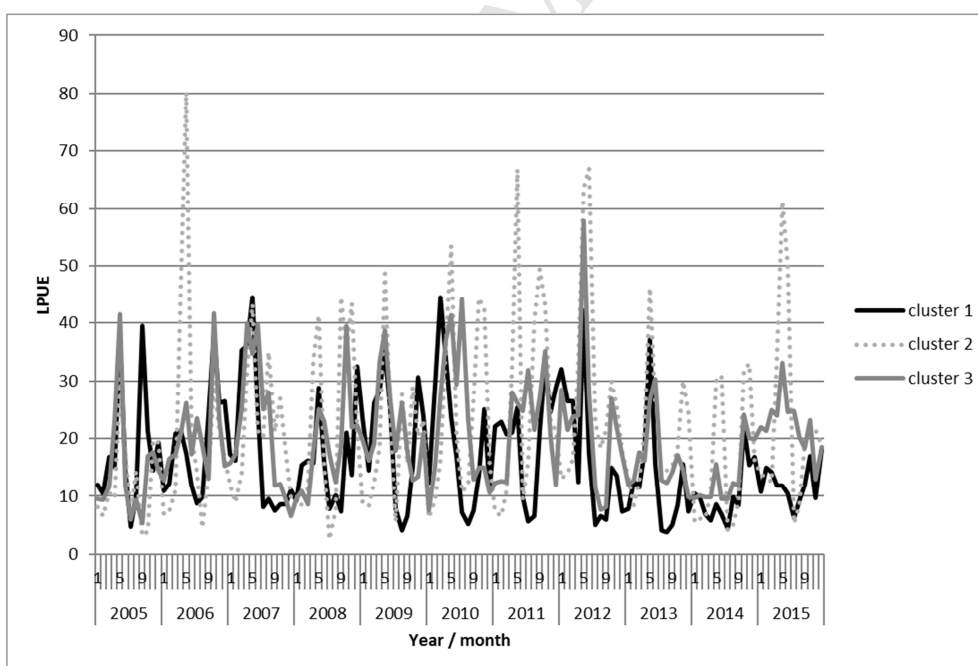
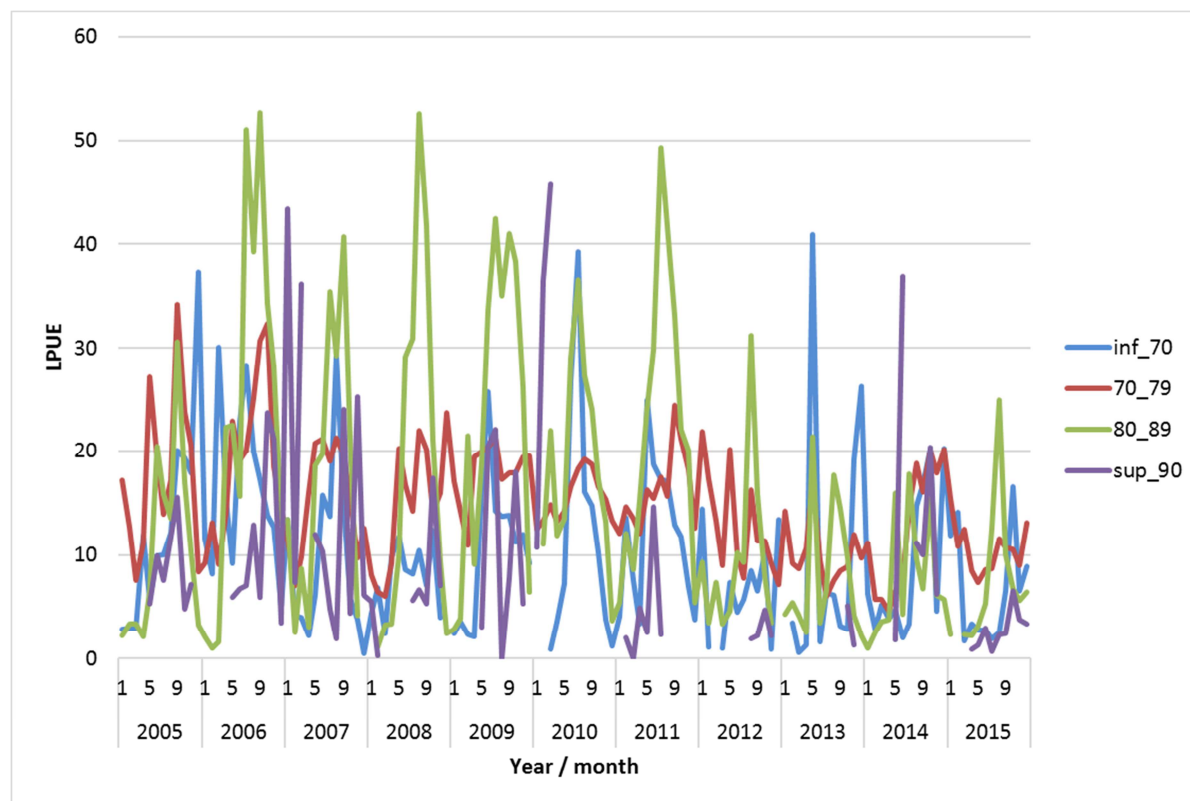777   Figure E.2. Average LPUEs per cluster for Surmullet in the south of Bay of Biscay.

778

779

780 **Appendix F**

781

782

783 Figure F.1. Evolution of LPUEs mean by years and months for the different gear mesh classes for
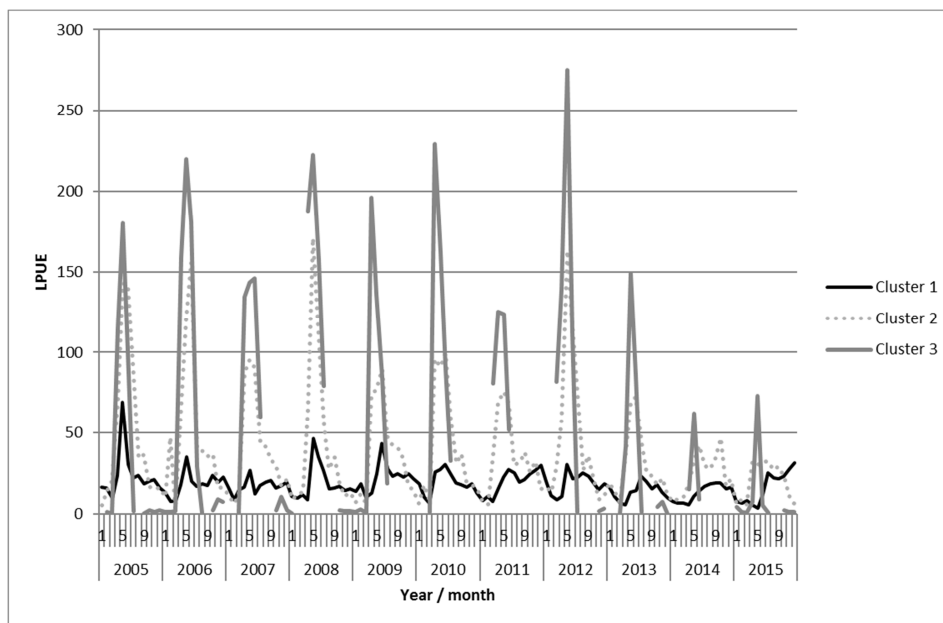784 cluster 1 - OTB in the Bay of Biscay

785

786 **Appendix G**

787

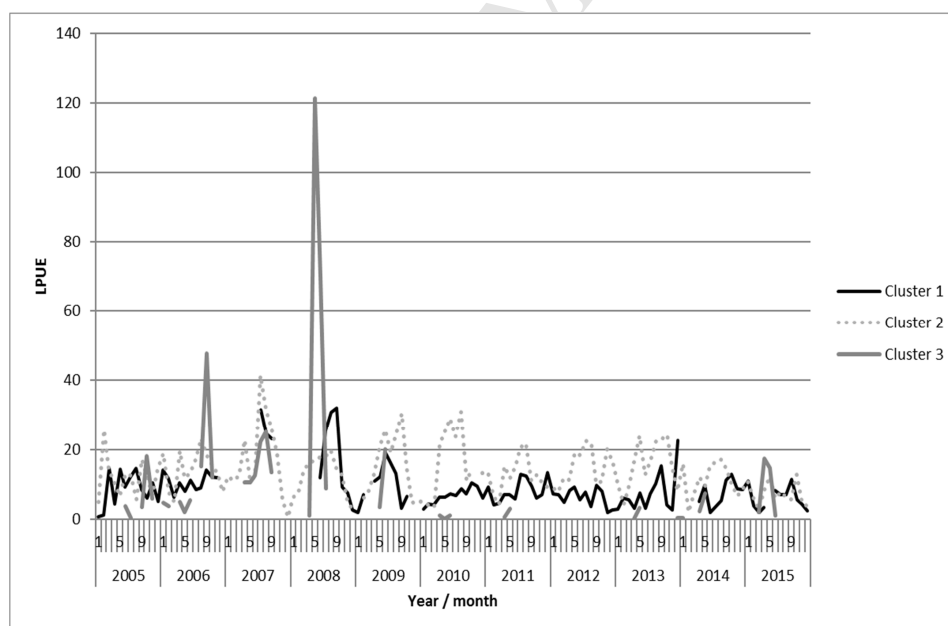Figure G.1. Average LPUEs per cluster for Surmullet in northern Bay of Biscay.

Figure G.2. Average LPUEs per cluster for Surmullet in southern Bay of Biscay.

788

789

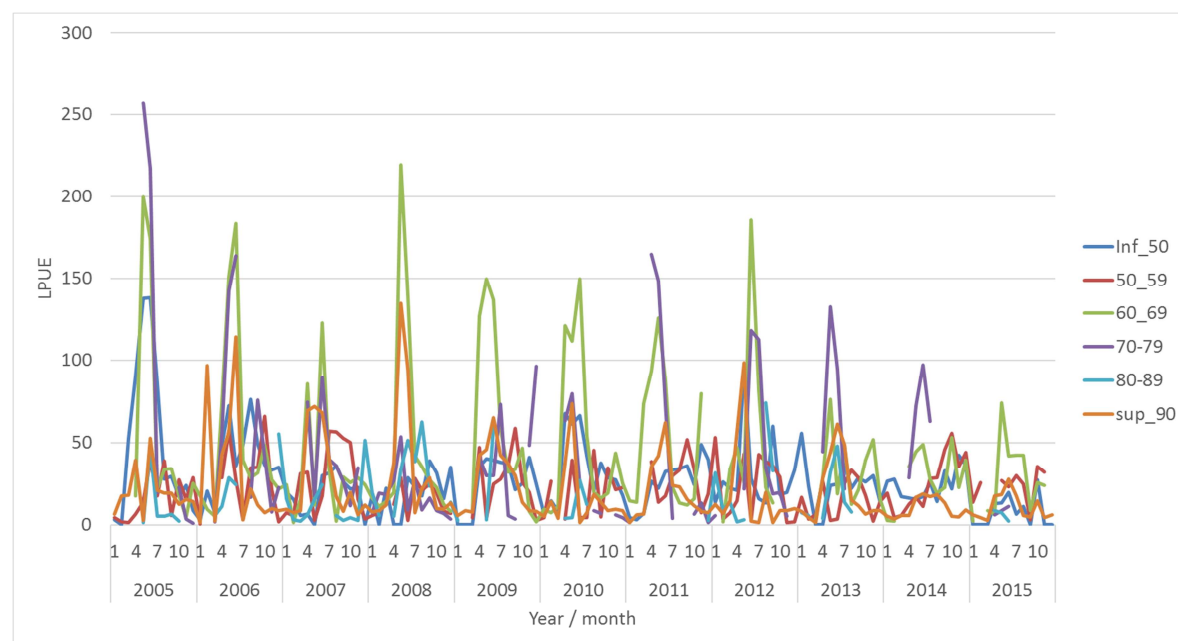790 **Appendix H**

791

792

793 Figure H.1. Evolution of LPUEs mean by years and months for the different gear mesh classes for
794 cluster 2 - GNS in the Bay of Biscay

Highlights

Data-filtering method maximizing usefulness of biological, catch, regulation data

Fishermen involvement to assess impact of regulation changes on indicators

Potential high bias induced by discards when using LPUE as proxy of abundance

For Striped red mullet, decreasing tendency of LPUEs over the study period