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## Are fisheries regulations influencing the biology and reproduction of the surmullet *Mullus surmuletus* Linnaeus, 1758 on the south-eastern coasts of France (NW Mediterranean)?

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2  
3 **Are fisheries regulations influencing the biology and reproduction of the surmullet**  
4 ***Mullus surmuletus* Linnaeus, 1758 on the south-eastern coasts of France (NW**  
5 **Mediterranean)?**

6  
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17  
18 **Abstract.** –

19  
20 The surmullet *Mullus surmuletus* Linnaeus, 1758 is one of the main target and high value  
21 species for small coastal fisheries in the North-Western Mediterranean. Morphometric and  
22 reproduction indices of surmullet were determined in fisheries regulated and non-regulated  
23 zones neighbouring the Port-Cros National Park (South-Eastern France) in autumn 2019 and  
24 spring 2020. Total length of individuals ranged between 12 and 32 cm, with a mode (?)  
25 between 17 and 23 cm. Significantly larger individuals were measured in the regulated fishing  
26 zones than in non-regulated ones, and in autumn rather than in spring. Females dominated in  
27 all zones and seasons, particularly in size classes > 24 cm in spring. Higher gonado-somatic  
28 index and more advanced gonadal development stages were observed in both sexes in spring  
29 than in autumn. Higher percentages of individuals with mature gonads and high gonado-  
30 somatic index were found in the fisheries regulated zone, engendering a higher reproductive  
31 potential. These results highlighted the importance of fisheries management with regard to the  
32 life-history traits of targeted fish species.

33

34 **Key words:** *Mullus surmuletus*, total length and weight, relative body condition, gonado-  
35 somatic index, gonadal development stages, Port-Cros marine protected area, North-Western  
36 Mediterranean

37

38 **Résumé.** – Le rouget de roche *Mullus surmuletus* est l'une des principales espèces cibles et  
39 commerciales des pêcheries côtières artisanales de la Méditerranée nord-occidentale. La  
40 morphométrie et les indices de reproduction du rouget ont été déterminés dans les zones de  
41 pêche réglementées et non réglementées autour du Parc National de Port-Cros (Sud-Est de la  
42 France) à l'automne 2019 et au printemps 2020. La longueur totale des individus variait entre  
43 12 et 32 cm, avec un mode entre 17 et 23 cm. Des individus significativement plus grands ont  
44 été mesurés dans la zone de pêche réglementée comparativement aux zones non réglementées,  
45 et en automne par rapport au printemps. Les femelles dominaient dans toutes les zones et  
46 saisons, en particulier dans les classes de taille > 24 cm au printemps. Un indice gonado-  
47 somatique plus élevé et des stades de développement gonadiques plus avancés au printemps  
48 qu'en automne ont été observés chez les deux sexes. Des pourcentages plus élevés d'individus  
49 avec des gonades matures et un indice gonado-somatique élevé ont été trouvés dans la zone de  
50 pêche réglementée, induisant un plus fort potentiel reproducteur. Ces résultats mettent en  
51 évidence l'importance de la gestion des pêches sur les traits d'histoire de vie des espèces de  
52 poissons ciblés.

53

54 **Mots clés :** *Mullus surmuletus*, longueur et poids totaux, indice corporel relatif, indice  
55 gonado-somatique, stades de développement des gonades, Aire marine protégée de Port-Cros,  
56 Méditerranée nord-occidentale

## INTRODUCTION

57  
58  
59 The surmullet *Mullus surmuletus* Linnaeus, 1758 (Osteichthyes, Perciformes, Mullidae) is a  
60 teleost fish species commonly found in the Mediterranean, the Black Sea and the East Atlantic  
61 (Hureau, 1986). This benthic-demersal species occurs from shallow waters down to 400 m,  
62 being more abundant between 50 and 200 m depth (Hureau, 1986, Tserpes *et al.*, 2002). *M.*  
63 *surmuletus* juveniles settle in shallow coastal habitats and disperse in deeper waters when  
64 growing, while adults undergo seasonal migrations toward deep habitats for reproduction  
65 (Garcia-Rubies and Macpherson, 1995; Machias *et al.*, 1998). *M. surmuletus* is a major target  
66 species in the Mediterranean Sea, exploited by various artisanal small fisheries using trawls  
67 and nets. However, the General Fisheries Commission for the Mediterranean-GFCM stock  
68 assessment in the French Mediterranean area is performed only for the red mullet *M.*  
69 *barbatus*, a related species considered as over-exploited (Biseau, 2020). No biomass data are  
70 available for the populations of the south-eastern coast of France, the scientific MEDITS  
71 trawling campaigns covering only the Gulf of Lion and the east coast of Corsica (Ifremer,  
72 2021; <https://campagnes.flotteoceanographique.fr>). These two sympatric Mullidae species are  
73 among the 15 most important species in the French Mediterranean Sea in terms of landings  
74 and value (Demaneche *et al.* 2009). FAO fishery databases reported 292 tonnes of catches for  
75 *M. barbatus* and 90 tonnes for *M. surmuletus* along the entire French Mediterranean coast in  
76 2018 ([www.fao.org](http://www.fao.org)). They represent together the third most important species groups in terms  
77 of annual average landings in 2008-2018 of the fleet of gillnetters [6-12m] of the Var region  
78 (south-eastern coast of France). Their landings represent 6% of the average annual value in  
79 Euros and 3% (25 tonnes) of the average annual volume landed by the Var fleet  
80 (<https://sih.ifremer.fr/>; Sock, 2020). In addition, fisheries landings in the south-east of France  
81 are probably largely underestimated due to the absence of auctions and direct sales at ports  
82 and to restaurants (CRPMEM PACA, 2016).  
83 By selecting individuals of a certain size and exploiting specific areas, fisheries may affect  
84 mean body length, population demography, sex-ratio and reproduction (Froese *et al.*, 2016).  
85 The gonado-somatic index and gonadal development are generally related to body length,  
86 with higher values in larger individuals (Michaletz, 1998). Fisheries regulation of fishing  
87 effort, nets and mesh size, etc) is shown to have positive effects on mean body length,  
88 population structure and reproduction indices (Roberts and Polunin, 1991; Lloret and Planes,  
89 2003; Boudouresque *et al.*, 2021). It is thus essential to study species life-history traits in order

90 to understand how fish populations are impacted by fisheries, and whether the existing fishery  
91 regulations would allow their sustainable exploitation (King and McFarlane, 2003).  
92 The morphometrics and growth of *M. surmuletus* have been studied in different  
93 Mediterranean areas, such as the Adriatic Sea (Jukic and Piccinetti, 1981), the Balearic  
94 Islands (Reñones *et al.*, 1995) and the Aegean Sea (Karakulak *et al.*, 2006; Gökhan *et al.*,  
95 2007, Arslan and Ismen, 2013; Kousteni *et al.*, 2019). However, to our knowledge, the only  
96 available data concerning these parameters for *M. surmuletus* on the French Mediterranean  
97 coasts were provided by Campillo (1992) for the populations of the Gulf of Lion. Kousteni *et*  
98 *al.* (2019) indicated in the Aegean Sea a reproduction period between March and July, while  
99 in the Gulf of Lion it occurs between June and August (Campillo, 1992). The aim of this study  
100 was to characterize the main biological parameters (length–weight relationship, relative body  
101 condition, sex ratio, gonado-somatic index and gonadal development stage) of *M. surmuletus*,  
102 as well as their spatial and seasonal variations, for the south-eastern coasts of France, where it  
103 represents one of the major exploited fish species of high commercial value. As *M.*  
104 *surmuletus* is traditionally exploited by small scale fisheries mainly in spring and autumn in  
105 this area, when this species is present in the coastal area, these two seasons were chosen for  
106 sampling. By comparing data from fisheries regulated and non-regulated zones, it would be  
107 possible to provide evidence of the effects of the existing fisheries management on the life  
108 history traits of these populations, necessary for proper stock assessment.

## 110 MATERIAL AND METHODS

### 112 Sampling and study zones

113 Sampling was done in the Var region, on the south-eastern coast of France (North-Western  
114 Mediterranean Sea), at four sites located in a fisheries regulated zone, the adjacent marine  
115 area (AMA) of Port-Cros National Park (PCNP), and at four sites located in non-regulated  
116 zones to the west and east of this area (Fig. 1). The AMA in the central part of Var  
117 encompasses Hyères Bay and Lavandou Bay, with Port-Cros Island fishing regulated since  
118 1963, Porquerolles island fishing regulated since 2007 and Le Levant Island which is a  
119 military zone with limited access for any activity. In this oldest marine protected area in  
120 Europe, regulations governing sites, fishing gear, catches, fish size, etc. are applied to both  
121 professional and recreational fishing (Boudouresque *et al.*, 2005; Robert, 2013; Astruc *et al.*,  
122 2018; Barcelo *et al.*, 2018). In addition to the regulations implemented by the PCNP, there are  
123 also regulations imposed by the local *Prud'homies* for access to some areas on certain dates

124 with a limit on the number of authorized vessels or regulations on the duration of setting the  
125 nets and their mesh and length. These coasts are influenced by the Northern Current flowing  
126 in an east-west direction along the continental slope (Millot, 1999). Sampling was done with  
127 professional fishermen partners using bottom-set trammel nets between 15 and 30 m depth.  
128 Sampling was performed at the West and AMA sites in autumn 2019 (October to December)  
129 and at all sites in spring 2020 (April to June). A total number of 263 individuals were  
130 analyzed (Table 1).

131

### 132 **Sample treatment**

133 For each specimen, total length (LT) was recorded to the nearest millimetre (mm), while total  
134 weight (WT), eviscerated weight (WE) and gonad weight (WG) were recorded to the nearest  
135 gram (g). Sex was determined by macroscopic observation of gonads and gonadal  
136 development stages were assessed according to Nikolsky's scale (1963): I: immature, II:  
137 resting, III: developing, IV: maturing, V: mature, VI: spent. Sex ratio, expressed as the  
138 number of females per male, was calculated by size, by zone and by season.

139

### 140 **Data analysis**

141 Data analyses were performed using STATISTICA 12.7. Normality and homogeneity of  
142 variances were tested using Shapiro-Wilk and Levene tests prior to analyses (Underwood,  
143 1997). Power regression analysis was used to describe the total length-total weight relation  
144 according to the equation:  $TW = a \times TL^b$  (Ricker, 1975). Differences in length between sexes,  
145 zones and seasons were tested using Kruskal-Wallis non-parametric tests and multiple  
146 comparisons of average rank. To examine the variation in fish condition with zone and  
147 season, while avoiding the effect of size, the relative condition factor Kn was used (Le Cren  
148 1951). Kn was computed with the formula:  $Kn = WE/WE'$ , here WE is the observed  
149 individual eviscerated weight and  $WE'$  is the estimated eviscerated weight from the  
150  $\text{Log}_{10}WE - \text{Log}_{10}TL$  relationship ( $WE' = 10^{-\text{intercept}} \times TL^{\text{slope}}$ ). The gonado-somatic index (GSI)  
151 was calculated according to the equation:  $GSI = (WG / WE) \times 100$ , where WG is the gonad  
152 weight and WE the eviscerated weight of specimen. Both GSI and Kn were calculated per  
153 sex, per zone and per season. Differences in mean gonado-somatic index for both sexes were  
154 analyzed by ANCOVA with TL as covariate to remove the effect of individual size, and zone  
155 and season as factors.

156

157

## RESULTS

### Morphometry

Of a total number of 263 individuals measured, 179 were females, 66 males, and 18 were undetermined, including mostly immature specimens. Their size (TL) ranged between a minimum of 12.2 cm and a maximum of 32.0 cm, with most individuals measuring between 17 and 23 cm (Fig. 2).

Mean ( $\pm$  SD) total lengths of females ( $21.5 \pm 3.8$  cm) and males ( $20.5 \pm 2.9$  cm) did not differ statistically ( $p > 0.05$ ) and were significantly greater than immature individuals ( $18.1 \pm 3.3$  cm) ( $H = 13.65$ ;  $p = 0.001$ ). The relationship between TL and WT indicated an isometric growth ( $a = 0.011$ ;  $b = 3.080$ ), similar between females ( $a = 0.011$ ;  $b = 3.074$ ) and males ( $a = 0.077$ ;  $b = 3.180$ ).

The surmullet sampled in the AMA zone were significantly larger than those sampled in the West and East zones ( $H = 46.41$ ;  $p < 0.0001$ ) (Fig. 3). Between-zones differences were significantly higher for females ( $H = 31.06$   $p < 0.0001$ ) than for males ( $H = 6.85$   $p = 0.032$ ). Females measured  $23.0 \pm 0.4$  cm TL in the AMA compared to  $20.4 \pm 0.5$  and  $19.5 \pm 0.6$  cm in the West and East zones respectively. Males were larger ( $21.3 \pm 0.5$  cm) in the AMA than in the East zone ( $19.2 \pm 0.8$  cm), but did not significantly differ from those of the West zone ( $20.2 \pm 0.6$  cm) (Fig. 3). On average larger individuals were sampled in autumn than in spring ( $H = 10.59$ ;  $p < 0.001$ ), for both females ( $22.1 \pm 0.5$  and  $21.1 \pm 0.4$  cm, respectively) and males ( $22.5 \pm 0.8$  and  $19.6 \pm 0.3$  cm, and respectively) ( $H = 4.63$   $p = 0.031$  and  $H = 14.26$   $p < 0.0001$ , respectively).

### Relative body condition

No difference in relative body condition (Kn) was found between males and females ( $p > 0.05$ ) or between study zones ( $p > 0.05$ ). Kn was higher in autumn ( $1.04 \pm 0.09$ ) than in spring ( $0.99 \pm 0.10$ ) for the whole population ( $H = 7.88$ ;  $p = 0.005$ ). However, contrasted seasonal tendencies occurred between zones with higher mean Kn values in the AMA in spring and in the West zone in autumn (Table 2).

### Reproduction

### Sex-ratio

191 Juveniles dominated the 12 cm TL size class and mature individuals started to dominate from  
192 the 14 cm size class (> 75%). Females strongly dominated in all size classes with an  
193 increasing female-male sex-ratio with size (Fig. 2). The sex-ratio was 1:1 in the 15-16 cm size  
194 class and reached 10:1 in the 26 cm size class. Some size classes larger than 27 cm were even  
195 exclusively composed of females.

196 Higher sex-ratio values were measured in the West and East zones (3:1) than in the AMA  
197 (2:1) (Fig. 4A), and in autumn than in spring (4:1 and 2:1, respectively) (Fig. 4B).

198

### 199 **Gonado-somatic index**

200 The gonado-somatic index increased with size for both females and males (Fig. 5). Females  
201 showed a higher increase in GSI with size than males. The linear relationships between  
202 individual size class and GSI by sex presented a higher slope for females (0.248) than for  
203 males (0.030). The highest GSI values were found in the 31 cm size class for females and in  
204 the 24 cm size class for males (Fig. 5).

205 Mean GSI differed among zones only for males ( $F = 5.39$ ;  $p = 0.007$ ), with higher values in  
206 the AMA compared to the West and East zones (Fig. 78A). The apparently higher GSI for  
207 females in the AMA was not significant and was related to the greater individual size of  
208 females in this zone ( $F = 24.35$ ;  $p < 0.0001$ ). Season had a significant effect on GSI  
209 independently of size, which was a significant covariate for females and males ( $F = 54.30$ ;  $p <$   
210  $0.0001$  and  $F = 10.14$ ;  $p = 0.002$ , respectively). Both females and males showed a higher GSI  
211 in spring than in autumn ( $F = 31.35$ ;  $p < 0.0001$  and  $F = 9.19$ ;  $p = 0.004$ , respectively) (Fig.  
212 6B). Gonad weight and gonado-somatic index were positively correlated with Kn ( $p < 0.0001$ ;  
213  $r = 0.28$  and respectively  $p = 0.004$ ;  $r = 0.18$ ).

214

### 215 **Gonadal development stages**

216 The gonadal development stages increased with size for both females (Fig. 7A) and males  
217 (Fig. 7B), but there were no significant differences between females and males ( $p > 0.05$ ). For  
218 females, stage I dominated in the 14 cm size class, stage II in 20 cm, stage III between 22 and  
219 28 cm, while stage V showed its highest percentage in the 30 cm size class (Fig. 7A). For  
220 males stage II dominated in size class between 14 and 18 cm, III between 20 and 22 cm, IV in  
221 24 cm, stage V in 26 cm, while stages III and IV were equally represented in 30 cm size class  
222 (Fig. 7B). For females, gonadal development stage III dominated in all zones, while stage VI  
223 was observed only in the AMA and West zones (Fig. 8A). For males, stage II dominated in all  
224 zones (Fig. 8B). For both females and males individuals in stage V were more numerous in



225 the AMA. However, differences in gonadal development stage between zones were not  
226 significant ( $p > 0.05$ ) and were related only to differences in the individual size for both  
227 females and males ( $F = 44.20$ ;  $p < 0.0001$  and respectively  $F = 9.16$ ;  $p = 0.004$ ).  
228 Lower gonadal development stages dominated in autumn for both females (II and III) ( $F =$   
229  $50.12$ ;  $p < 0.0001$ ) (Fig. 8C) and males (II and III) ( $F = 7.00$ ;  $p = 0.010$ ) (Fig. 8D). Significant  
230 seasonal differences, independent of size, were also observed for both females ( $F = 70.63$ ;  $p <$   
231  $0.0001$ ) and males ( $F = 18.21$ ;  $p < 0.0001$ ). However, development stages in males seemed to  
232 be in advance compared to females in autumn, as stage IV and V were observed for males,  
233 while stage I were still present in females. More advanced gonadal development stages  
234 occurred in spring, with stages IV, V and VI observed in similar percentages in both sexes.

## 235 236 **DISCUSSION** 237

238 The results of this article provide new original data on life-history traits of *Mullus surmuletus*  
239 in the Var region, South- Eastern France (NW Mediterranean), and enabled the comparison of  
240 life-history traits of *Mullus surmuletus* in fisheries regulated and non-regulated zones in the  
241 Port Cros National Park and neighbouring areas.

242 The total length and total weight of *Mullus surmuletus* were within the range of those  
243 recorded in other Mediterranean regions (Campillo, 1992; Arslan and Ismen, 2013 and  
244 references therein; Kousteni *et al.*, 2019). In 2019 and 2020, their mean total length was in the  
245 upper range or higher than those sampled in the Gulf of Lion during summer  
246 (<https://campagnes.flotteoceanographique.fr>; [www.ifremer.fr](http://www.ifremer.fr)). In spring, new cohorts of  
247 young individuals were observed in the study area, which lowered the mean total length of the  
248 analyzed individuals.

249 In this study no significant differences between the growth curves of male and female *M.*  
250 *surmuletus* were found, in accordance with the results of Machias *et al.* (1998), but in contrast  
251 to those of other authors (Reñones *et al.*, 1995; Karakulak *et al.*, 2006; Arslan and Ismen,  
252 2013). The functional regression  $b$  value showed an isometric growth for both females and  
253 males, as also reported in previous studies (Campillo, 1992; Bensahla-Talet *et al.*, 2014). This  
254 result differed from studies carried out in Majorca (Reñones *et al.*, 1995), Morocco (Lamrini,  
255 2010), the Aegean Sea (Arslan and Ismen, 2013 and references therein) and in the Bay of  
256 Biscay (N'Da *et al.*, 2006) which indicated a positive allometric growth.

257 Differences in the relationship between length and weight may be related to environmental  
258 and trophic factors as well as reproduction and stage of maturity (Pauly, 1984; Cherif *et al.*,

259 2007). The study area is impacted by the oligotrophic Northern Mediterranean current (Millot,  
260 1999) and is probably less productive than other marine coastal areas (Diaz *et al.*, 2001).  
261 Moreover, trophic conditions and diet may influence the relative body condition. Condition  
262 factors compare the well-being of fish based on the assumption that heavier fish of a given  
263 length are in better condition (Froese, 2006). Fish condition is relevant because it influences  
264 growth, reproduction and survival (Lambert and Dutil, 1997; Shulman and Love, 1999). In  
265 this study relative body condition did not differ significantly between sexes, in accordance  
266 with the results published by Lloret and Planes (2003). However, body condition was  
267 positively correlated with gonad mass and gonado-somatic index, confirming the influence of  
268 body condition on reproductive success.

269 Previous studies showed that the adults of *Mullus surmuletus* are carnivores rather  
270 opportunistic feeders and feed on diverse benthic prey according to their size, but also to  
271 zones and seasons (Bautista-Vega *et al.*, 2008). Their main prey are amphipods, decapods and  
272 annelids, but they also feed on mysids, brachyurans, euphausiids, mollusks, and ophiurids  
273 (Bautista-Vega *et al.*, 2008 and references therein). Spatial differences in relative body  
274 condition potentially related to diet were also discussed by Bautista-Vega (2007) for different  
275 areas of the Gulf of Lion. In contrast, no significant differences in Le Cren relative body  
276 condition were observed between zones in our study. However, Bautista-Vega (2007) used  
277 Fulton index, which may be influenced by stomach content and gonad weight. In our study, a  
278 lower relative body condition was observed in spring, that may be related to a higher  
279 reproduction investment for gonad development during this season, as previously discussed  
280 by Shulman and Love (1999).

281 In this study the size at first maturity was 14 cm for females and 15 cm for males. This size  
282 should correspond to the first year of life, as maturation during the first year was apparently a  
283 common trait in the two *Mullus* species (Reñones *et al.* 1995). These results were similar to  
284 those of previous studies, which reported that the mean length at first maturity was 14 cm in  
285 the Gulf of Lion (Campillo, 1992) and between 13 and 15 cm in Mallorca and on the Egyptian  
286 Mediterranean coast (Morales-Nin, 1991; Reñones *et al.*, 1995; Mehanna, 2009).

287 In the south-east of France, the percentage of females increased with size and size classes >  
288 27 cm were sometimes exclusively composed of females, as recently observed by Kousteni *et*  
289 *al.* (2019) in the Aegean Sea. This was also observed by Reñones *et al.* (1995) in Mallorca,  
290 where individuals > 23 cm presented very low proportions of males. Females largely  
291 dominated in all zones and in both seasons. A sex-ratio in favour of females in *M. surmuletus*  
292 was recorded in previous studies in the Eastern Channel and the North Sea (Mahé *et al.*,

293 2005), but also in the Mediterranean Sea (Kousteni *et al.*, 2019 and references therein),  
294 Morocco (Lamrini, 2010) and Spain (Reñones *et al.*, 1995). This might be attributed to  
295 differences in spatial distribution between sexes. Coastal areas, probably more productive,  
296 could be more favourable for feeding for females preparing for reproduction. The high  
297 proportions of females in our samples might thus be due to the females coming close to the  
298 coast for feeding, before and after reproduction, which takes place in deeper waters (Machias  
299 *et al.*, 1998). The observed imbalance in the relative proportions of sexes in our samples  
300 suggested that males and females displayed different spatial behaviour, with males living  
301 offshore most of the time (Machias *et al.* 1998). In our study, the sex-ratio was less  
302 unbalanced in the AMA (2:1) than in the West and East areas (3:1). Marine protected areas  
303 are known to have positive effects on population demography and sex-ratio compared to  
304 fisheries non-regulated areas (Grüss *et al.*, 2014; Boudouresque *et al.*, 2021). The sex-ratio of  
305 the Var *M. surmuletus* population differed from those of the Gulf of Lion, where males  
306 generally dominated and the sex-ratio females-males reached 1:8 in 2011. However, annual  
307 variations were observed in the Gulf of Lion, with the sex-ratio females-males varying from  
308 1:2 in 2019 to 1:1 in 2020.

309 Reñones *et al.* (1995) showed that gonad maturity occurs earlier in the year for males  
310 (December to June) compared to females (March to June). They also indicated that for  
311 females the period of reproductive activity was shorter than for males and reached a  
312 maximum in April and May. Kousteni *et al.* (2019) indicated in the Aegean Sea a maximum  
313 in the spawning period for both sexes between March and July. This is in agreement with the  
314 results of our study, since the highest gonado-somatic index and the highest percentage of  
315 mature gonads for both females and males were observed during spring (May to June). Some  
316 authors reported a maximum spawning period in May and June (Papaconstantinou *et al.*,  
317 1981). Campillo (1992) indicated that reproduction occurs from June to August in the Gulf of  
318 Lion (NW Mediterranean), while in the Aegean Sea Arslan and Ismen (2013) observed the  
319 highest GSI between January and May. However, increasing seawater temperature related to  
320 global change may impact the annual reproduction cycle of marine species (Wootton, 1998 in  
321 Kousteni *et al.*, 2019). This might explain the gonad development stages (developing and  
322 maturing) observed during autumn (October to December) in this study. In the future,  
323 sampling should be completed with a larger number of individuals and cover all seasons at a  
324 larger spatial scale, from coastal to deeper waters, in order to confirm the annual reproduction  
325 cycle of *M. surmuletus* in the Var region.

326 In our study higher percentages of *M. surmuletus* reproducers were found in the AMA for  
327 both females and males compared to adjacent areas. Several studies reported the effects of  
328 marine reserve protection on the spawning biomass of different marine species (e.g. review by  
329 Roberts and Polunin, 1991). By selecting size and targeting specific zones, fishing may  
330 influence population mean size, size distribution, sex ratio, age and size at maturity, and  
331 reproduction indices (Rochet, 1998). For species such as *M. surmuletus*, highly targeted by  
332 commercial fisheries, information on morphometrics, population demography, growth and  
333 reproduction are essential for population regulation (King and McFarlane, 2003; Winemiller,  
334 2005). Generally, improving knowledge of growth and the reproduction cycle as well as  
335 migration related to reproduction is necessary for sustainable fisheries management (Mullen,  
336 1994; Machias *et al.*, 1998).

337 The combination of the quality of the coastal and island habitats of the PCNP and the  
338 management measures and fishing practices in the PCNP AMA thus appear to have a positive  
339 effect on the mean total length of the surmullet population, its sex-ratio, and the gonado-  
340 somatic indices, potentially inducing a positive effect on reproduction and stock enhancement.

341

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355

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512 Figures and tables legends

513

514 Figure 1. – Sampling sites in West, AMA (Adjacent Marine Protected Area of Hyères Bay) and East zones on  
515 the south-eastern coast of France, NW Mediterranean sea.

516 Figure 2. – Percentage of individuals of *M. surmuletus* analyzed by two-cm size class (total length in cm) and by  
517 sex. N = number of individuals, F = females, M = males, Unidentif. = unidentified group includes immature  
518 individuals and those whose sex could not be identified.

519 Figure 3. – Mean ( $\pm$  SE) total length (TL, cm) of *M. surmuletus* in West, AMA and East zones. N = number of  
520 analyzed individuals per sex in zones.

521 Figure 4. – Percentages of both sexes and females:males sex-ratio of *Mullus surmuletus* by zone (A) and season  
522 (B).

523 Figure 5. – Mean gonado-somatic index (GSI, %) of *Mullus surmuletus* with size (LT, cm) by sex.

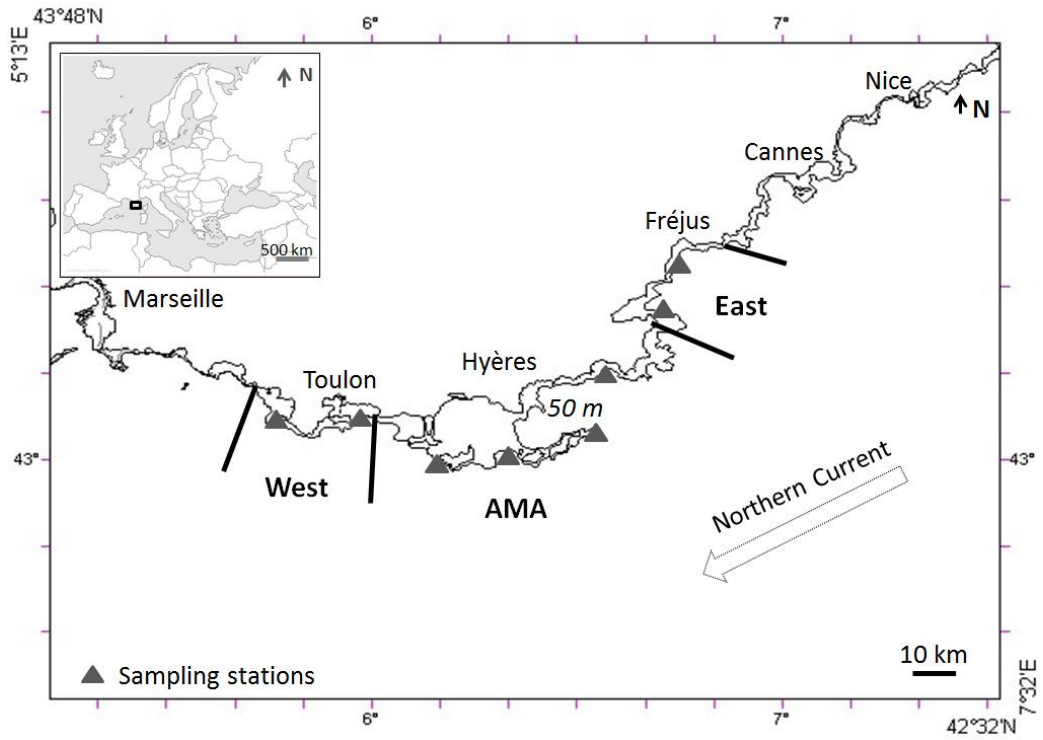
524 Figure 6. – Mean gonado-somatic index (GSI, %) of males and females of *Mullus surmuletus* by A) zone and B)  
525 season.

526 Figure 7. – Mean percentage of gonadal development stages of *Mullus surmuletus* by 2-cm size class (LT, cm)  
527 and sex for A) females and B) males. N = number of individuals.

528 Figure 8. – Mean percentages of gonadal development stages (GDS) of *Mullus surmuletus* A) by zone for  
529 females B) by zone for males C) by season for females and D) by season for males. N = number of individuals.

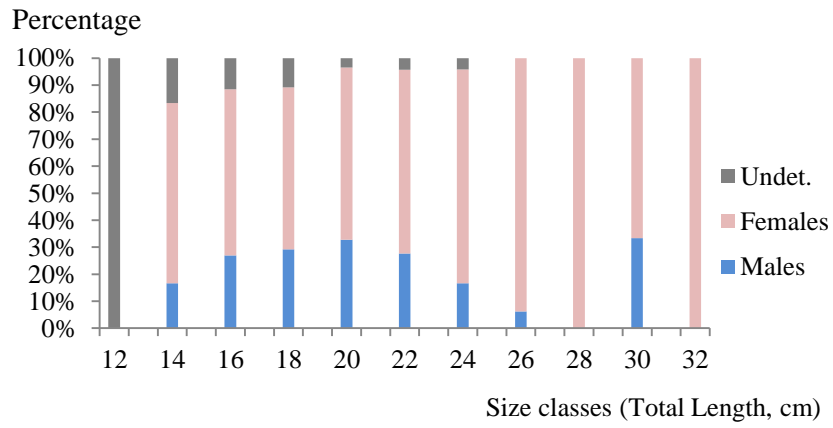
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532

533 Figure 1

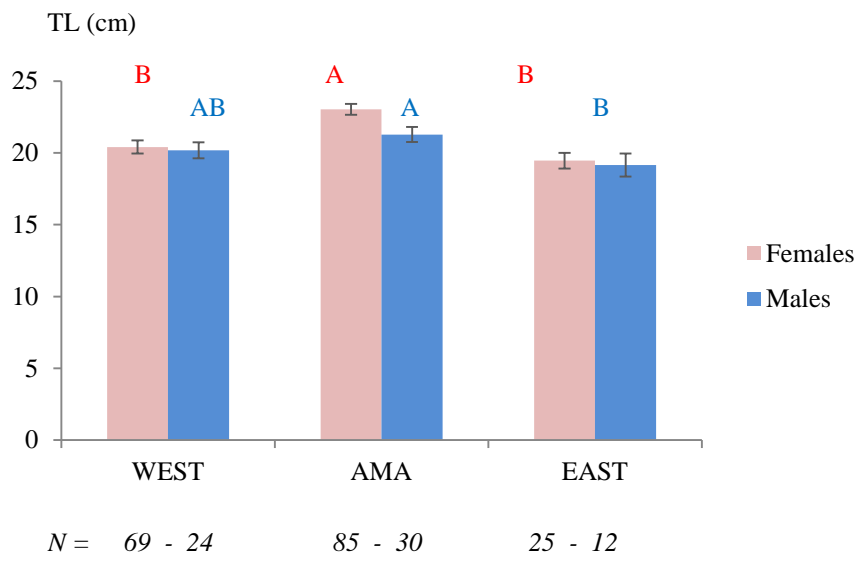


<i>Sex-ratio</i>	
<i>F:M</i>	4:1 2:1 2:1 2:1 3:1 5:1 15:1 2:1
<i>N =</i>	2 6 26 65 58 47 24 16 12 6 1

534

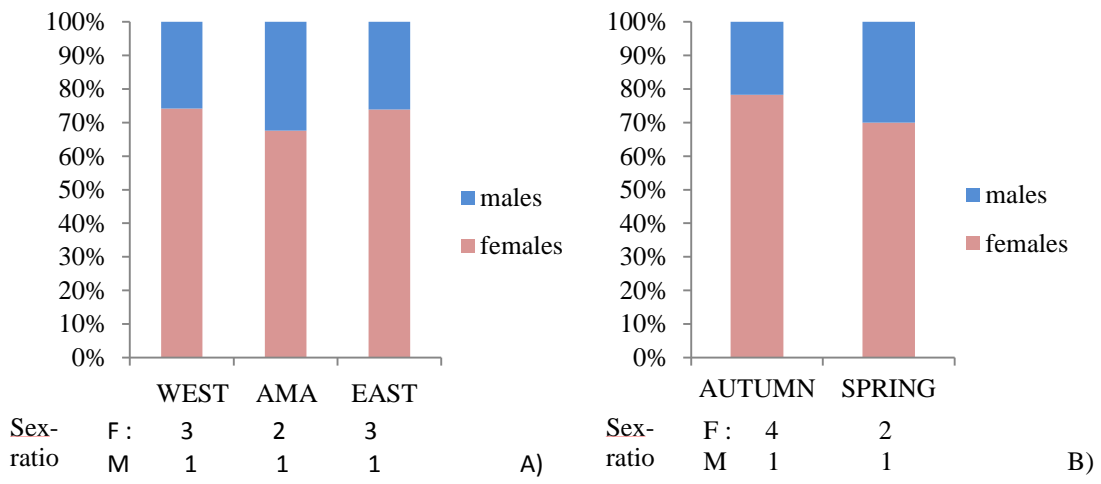
535 Figure 2

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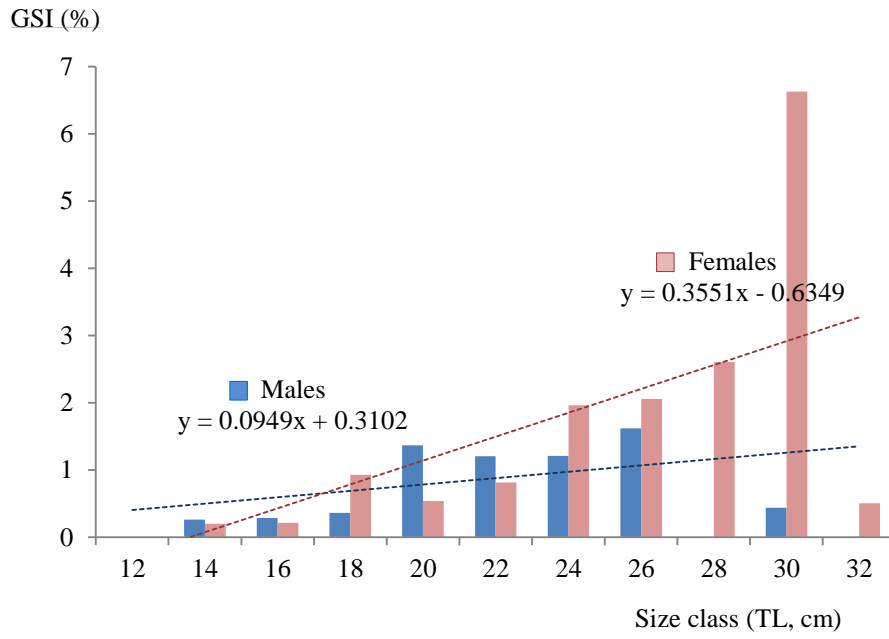
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538 Figure 3



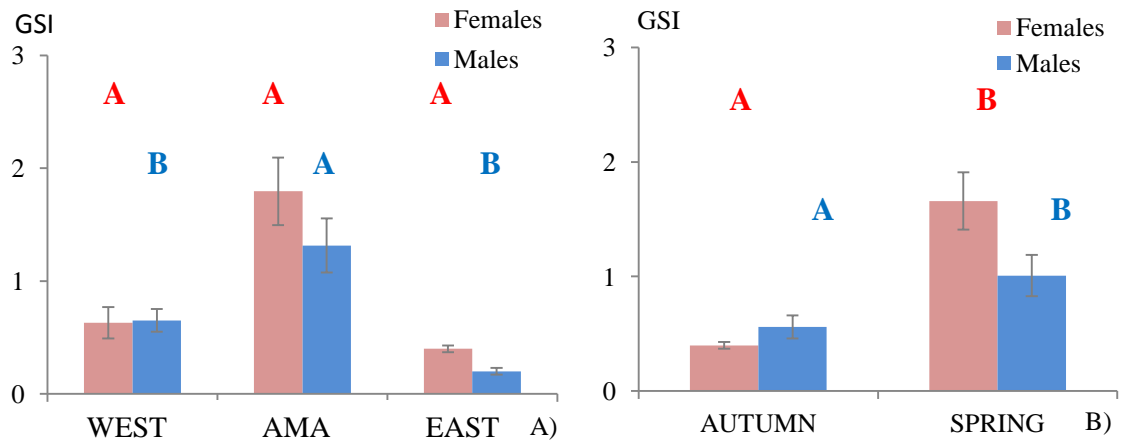
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540 Figure 4



541

542 Figure 5

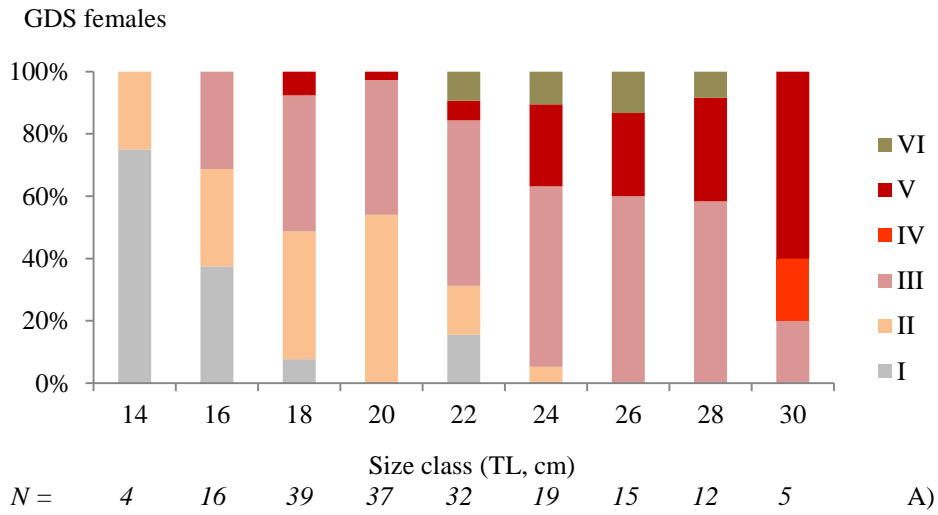


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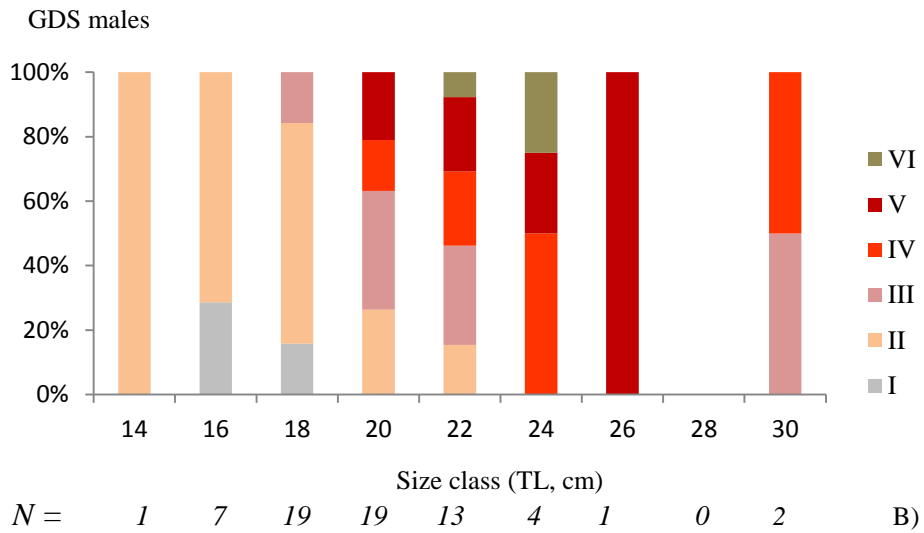
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545 Figure 6



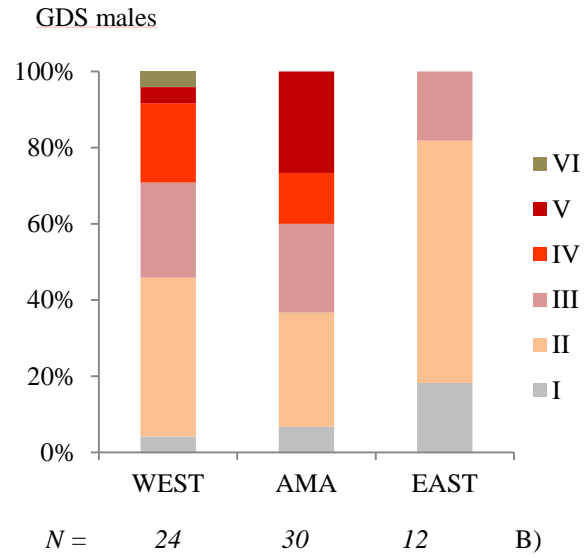
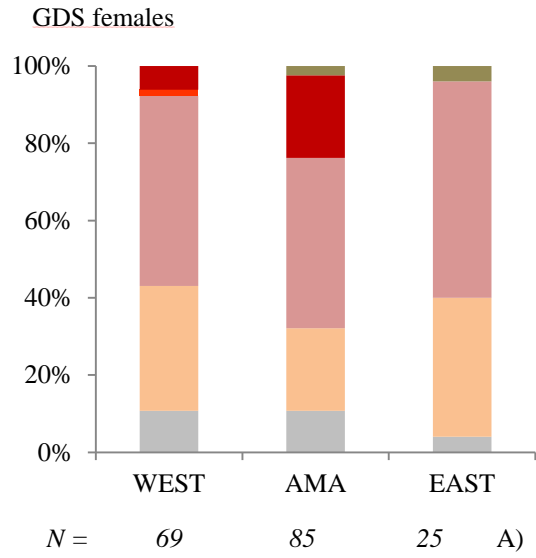


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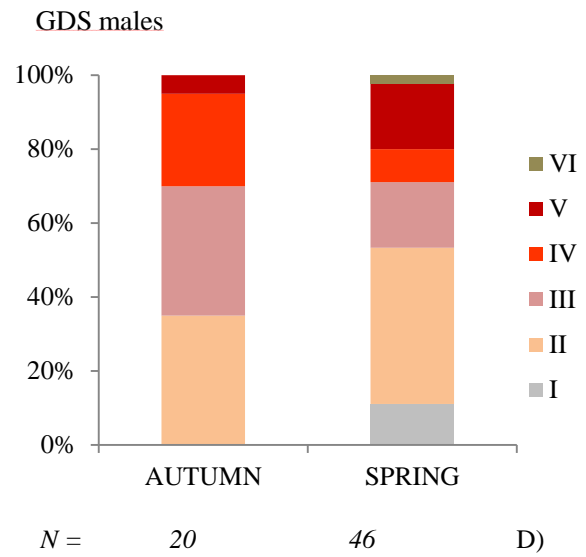
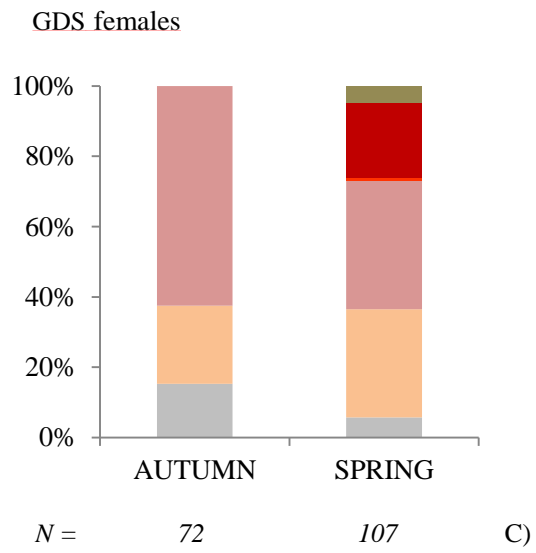


547

548 Figure 7



549



550

551 Figure 8

552

553 Table 1. – Number of individuals analyzed by zone and season. For each zone and season, the number of  
554 individuals by month is detailed in italic characters.

555 Table 2. – Mean ( $\pm$  SE) relative body condition (Kn) by sex, zone and season.

556 Table 1

Month/Season/Zone	West	AMA	East
<i>October</i>	30	60	
<i>December</i>	9		
Autumn 2019	39	60	
<i>April</i>		6	27
<i>Mai</i>	30	24	
<i>June</i>	30	31	16
Spring 2020	60	61	43

557

558 Table 2

Sex	Season	West		AMA		East	
Females	Autumn	1.07	$\pm 0.01$	1.00	$\pm 0.01$	-	-
Males		1.05	$\pm 0.03$	0.99	$\pm 0.02$	-	-
Females	Spring	0.96	$\pm 0.01$	1.06	$\pm 0.02$	0.99	$\pm 0.01$
Males		0.92	$\pm 0.02$	1.01	$\pm 0.02$	1.00	$\pm 0.02$

559

560