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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
7 Daniela Bănaru *(1), Laurence Le Diréach (2), Guillaume Crest (1), Melissa Tenaille (1),
8 Mireille Harmelin-Vivien (1)

9
10 (1) Aix-Marseille University, University of Toulon, CNRS, IRD, MIO (Mediterranean Institute of
11 Oceanography) UM 110, Marseille, France. [daniela.banaru@univ-amu.fr] [guillaume.crest@live.fr]
12 [melissa.tenaille@etu.univ-amu.fr] [mireille.harmelin@mio.osupytheas.fr]

13 (2) GIS Posidonie, Aix-Marseille University, OSU Pythéas, Campus de Luminy, Marseille, France.
14 [laurence.ledireach@univ-amu.fr]

15 * Corresponding author [daniela.banaru@univ-amu.fr]; No. ORCID: 0000-0002-8126-4328

16 M. Harmelin-Vivien: No. ORCID: 0000-0003-3085-2899

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). 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.

109

110 MATERIAL AND METHODS

111

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 ± 3.8 cm) and males (20.5 ± 2.9 cm) did not differ statistically ($p > 0.05$) and were significantly greater than immature individuals (18.1 ± 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 ± 0.4 cm TL in the AMA compared to 20.4 ± 0.5 and 19.5 ± 0.6 cm in the West and East zones respectively. Males were larger (21.3 ± 0.5 cm) in the AMA than in the East zone (19.2 ± 0.8 cm), but did not significantly differ from those of the West zone (20.2 ± 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 ± 0.5 and 21.1 ± 0.4 cm, respectively) and males (22.5 ± 0.8 and 19.6 ± 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 ± 0.09) than in spring (0.99 ± 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). 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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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.

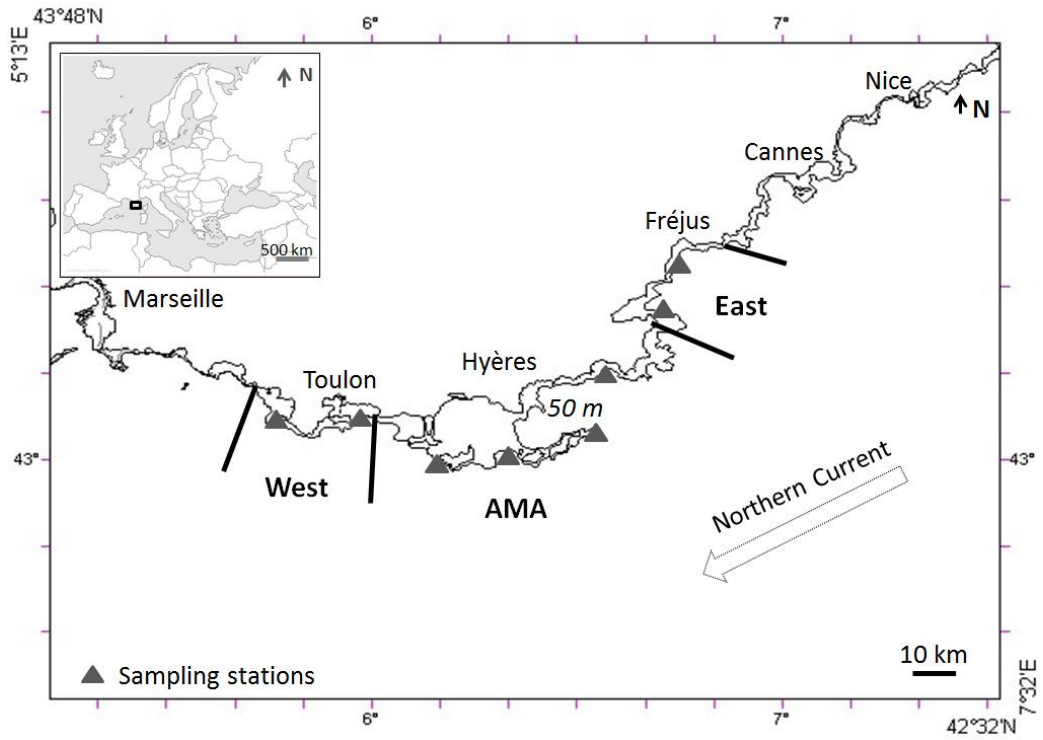
524 Figure 6. – Mean gonado-somatic index (GSI, %) of males and females of *Mullus surmuletus* by A) zone and B)
525 season.

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.

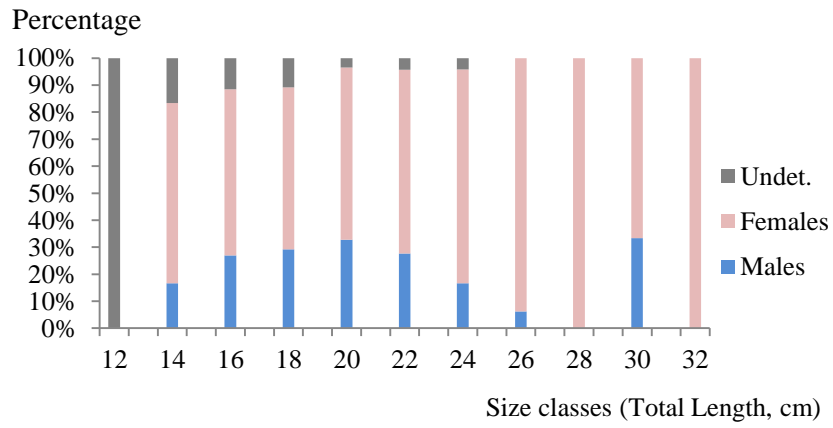
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533 Figure 1

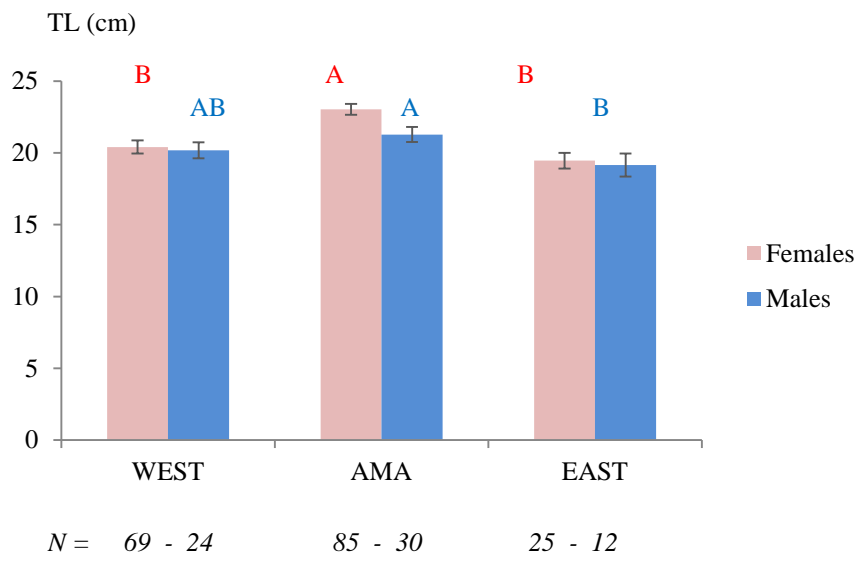


<i>Sex-ratio</i>	
<i>F:M</i>	4:1 2:1 2:1 2:1 3:1 5:1 15:1 2:1
<i>N =</i>	2 6 26 65 58 47 24 16 12 6 1

534

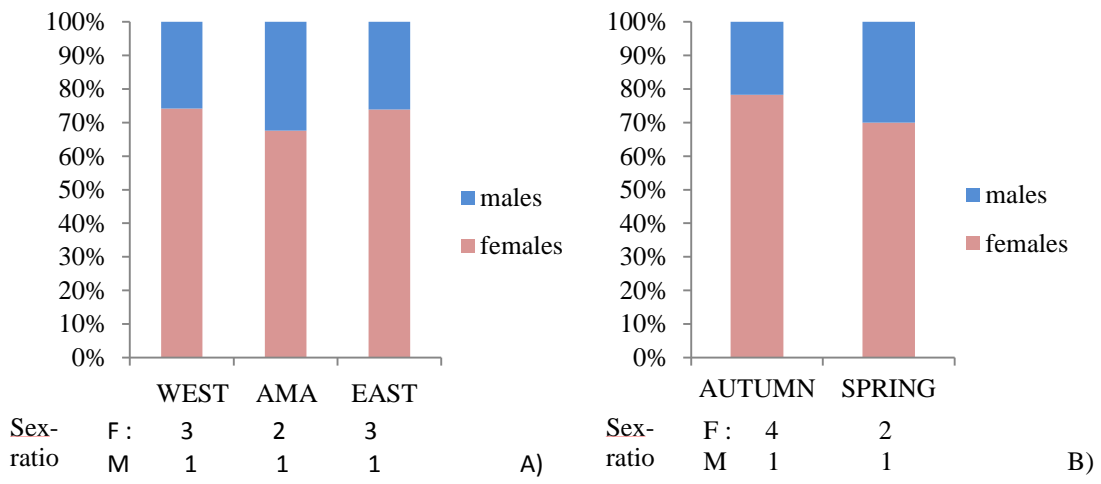
535 Figure 2

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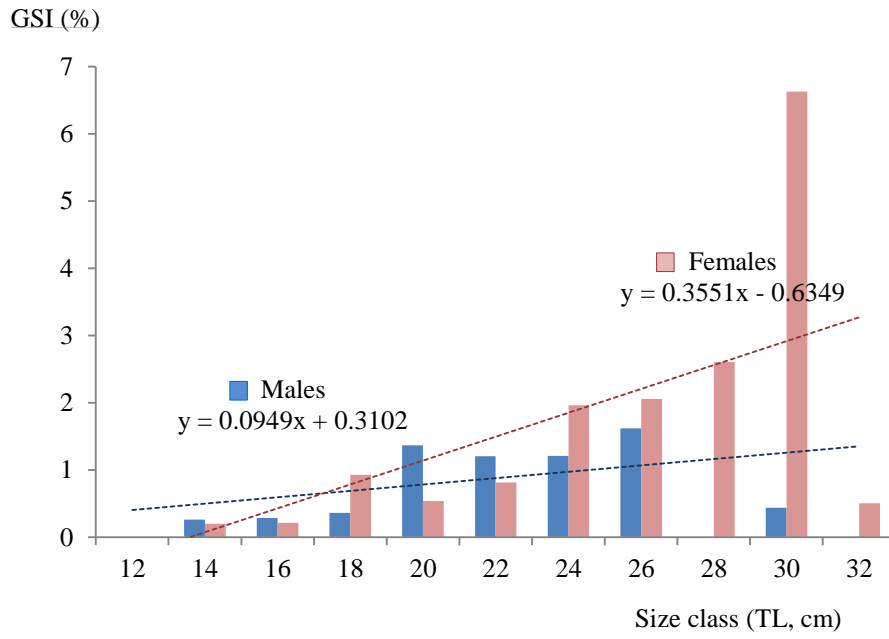
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538 Figure 3



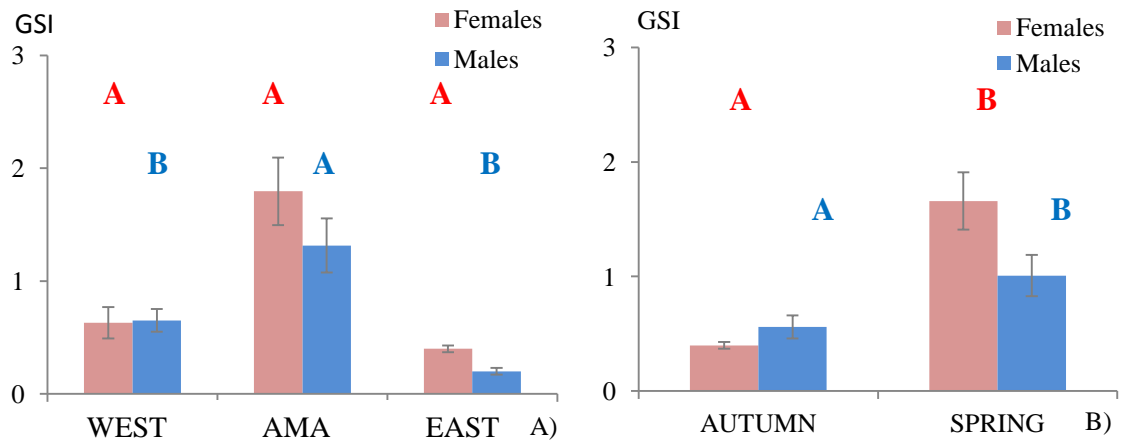
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540 Figure 4



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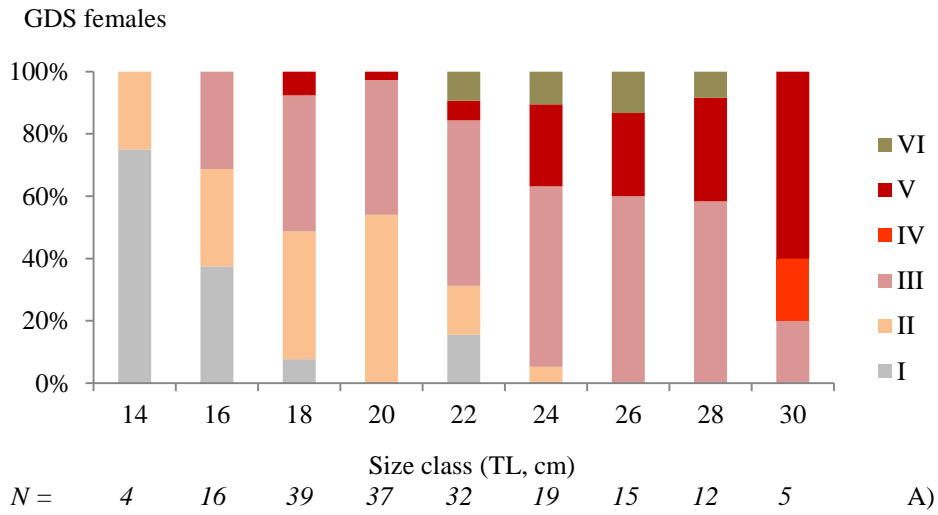
542 Figure 5



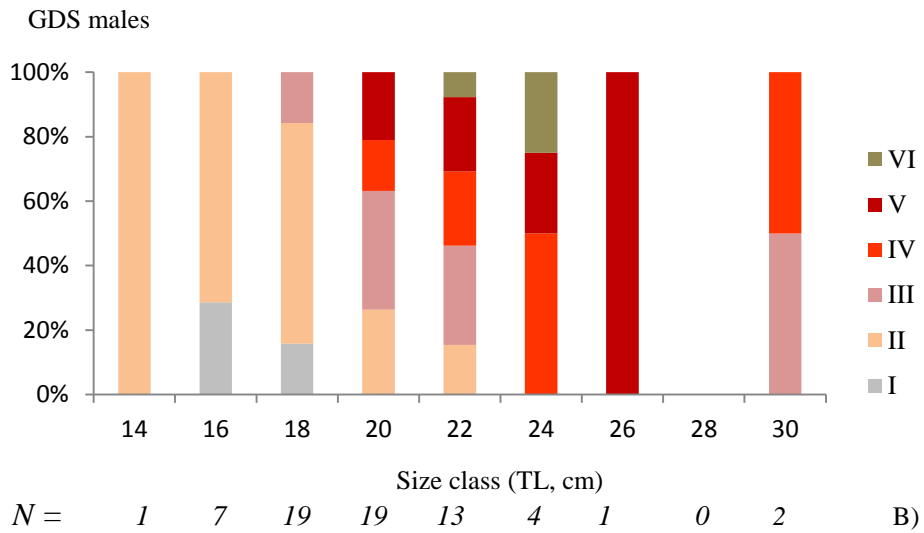
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545 Figure 6

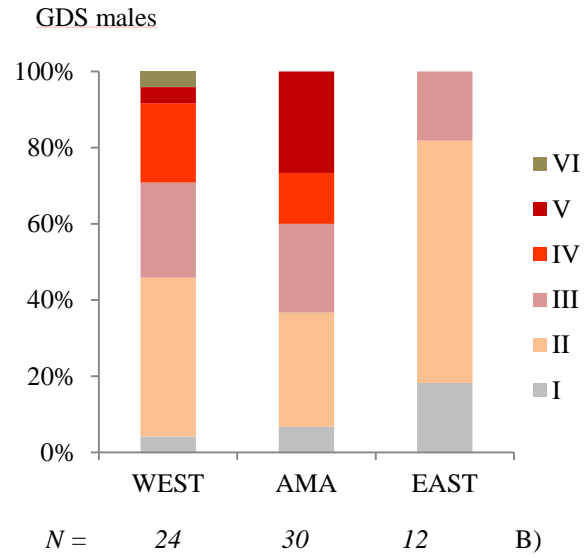
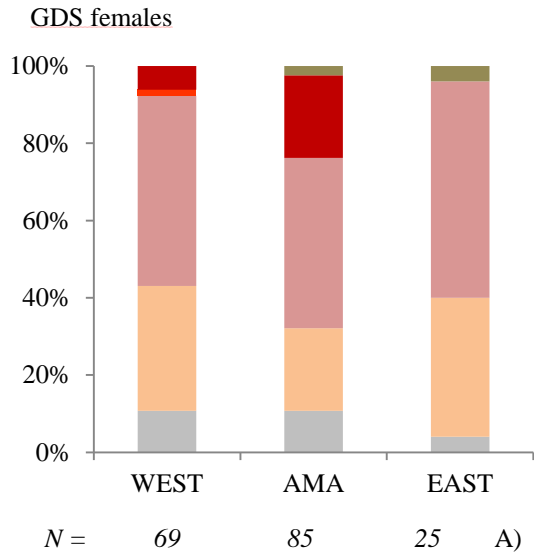


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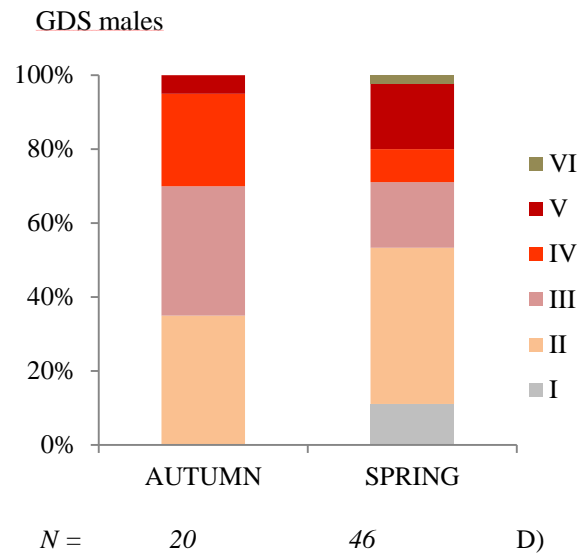
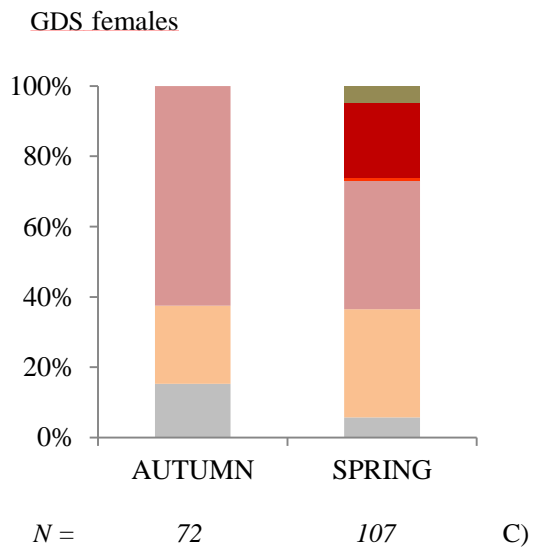


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548 Figure 7



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	± 0.01	1.00	± 0.01	-	-
Males		1.05	± 0.03	0.99	± 0.02	-	-
Females	Spring	0.96	± 0.01	1.06	± 0.02	0.99	± 0.01
Males		0.92	± 0.02	1.01	± 0.02	1.00	± 0.02

559

560