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

Daniela Bănaru, Laurence Ledireach, Guillaume Crest, Melissa Tenaille, Mireille Harmelin-Vivien

Cybium 2022, 46(1): 19-28. https://doi.org/10.26028/cybium/2022-461-003

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

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

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

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

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

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

Abstract. –

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

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

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

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

INTRODUCTION

The surmullet *Mullus surmuletus* Linnaeus, 1758 (Osteichthyes, Perciformes, Mullidae) is a teleost fish species commonly found in the Mediterranean, the Black Sea and the East Atlantic (Hureau, 1986). This bentho-demersal species occurs from shallow waters down to 400 m, being more abundant between 50 and 200 m depth (Hureau, 1986, Tserpes *et al*., 2002). *M. surmuletus* juveniles settle in shallow coastal habitats and disperse in deeper waters when growing, while adults undergo seasonal migrations toward deep habitats for reproduction (Garcia-Rubies and Macpherson, 1995; Machias *et al*., 1998). *M. surmuletus* is a major target species in the Mediterranean Sea, exploited by various artisanal small fisheries using trawls and nets. However, the General Fisheries Commission for the Mediterranean-GFCM stock assessment in the French Mediterranean area is performed only for the red mullet *M. barbatus*, a related species considered as over-exploited (Biseau, 2020). No biomass data are available for the populations of the south-eastern coast of France, the scientific MEDITS trawling campaigns covering only the Gulf of Lion and the east coast of Corsica (Ifremer, 2021; https://campagnes.flotteoceanographique.fr). These two sympatric Mullidae species are among the 15 most important species in the French Mediterranean Sea in terms of landings and value (Demaneche *et al*. 2009). FAO fishery databases reported 292 tonnes of catches for *M. barbatus* and 90 tonnes for *M. surmuletus* along the entire French Mediterranean coast in 2018 (www.fao.org). They represent together the third most important species groups in terms of annual average landings in 2008-2018 of the fleet of gillnetters [6-12m[of the Var region (south-eastern coast of France). Their landings represent 6% of the average annual value in Euros and 3% (25 tonnes) of the average annual volume landed by the Var fleet (https://sih.ifremer.fr/; Sock, 2020). In addition, fisheries landings in the south-east of France are probably largely underestimated due to the absence of auctions and direct sales at ports and to restaurants (CRPMEM PACA, 2016).

By selecting individuals of a certain size and exploiting specific areas, fisheries may affect mean body length, population demography, sex-ratio and reproduction (Froese *et al*., 2016). The gonado-somatic index and gonadal development are generally related to body length, with higher values in larger individuals (Michaletz, 1998). Fisheries regulation of fishing effort, nets and mesh size, etc) is shown to have positive effects on mean body length, population structure and reproduction indices (Roberts and Polunin, 1991; Lloret and Planes, 2003; Boudouresque *et al*., 2021). It is thusessential to study species life-history traits in order to understand how fish populations are impacted by fisheries, and whether the existing fishery regulations would allow their sustainable exploitation (King and McFarlane, 2003).

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

MATERIAL AND METHODS

Sampling and study zones

Sampling was done in the Var region, on the south-eastern coast of France (North-Western Mediterranean Sea), at four sites located in a fisheries regulated zone, the adjacent marine area (AMA) of Port-Cros National Park (PCNP), and at four sites located in non-regulated zones to the west and east of this area (Fig. 1). The AMA in the central part of Var encompasses Hyères Bay and Lavandou Bay, with Port-Cros Island fishing regulated since 1963, Porquerolles island fishing regulated since 2007 and Le Levant Island which is a military zone with limited access for any activity. In this oldest marine protected area in Europe, regulations governing sites, fishing gear, catches, fish size, etc. are applied to both professional and recreational fishing (Boudouresque *et al*., 2005; Robert, 2013; Astruc *et al*., 2018; Barcelo *et al*., 2018). In addition to the regulations implemented by the PCNP, there are also regulations imposed by the local *Prud'homies* for access to some areas on certain dates with a limit on the number of authorized vessels or regulations on the duration of setting the nets and their mesh and length. These coasts are influenced by the Northern Current flowing in an east-west direction along the continental slope (Millot, 1999). Sampling was done with professional fishermen partners using bottom-set trammel nets between 15 and 30 m depth. Sampling was performed at the West and AMA sites in autumn 2019 (October to December) and at all sites in spring 2020 (April to June). A total number of 263 individuals were analyzed (Table 1).

Sample treatment

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

Data analysis

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

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 (± 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

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

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

Gonado-somatic index

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

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

Gonadal development stages

The gonadal development stages increased with size for both females (Fig. 7A) and males (Fig. 7B), but there were no significant differences between females and males ($p > 0.05$). For females, stage I dominated in the 14 cm size class, stage II in 20 cm, stage III between 22 and 28 cm, while stage V showed its highest percentage in the 30 cm size class (Fig. 7A). For males stage II dominated in size class between 14 and 18 cm, III between 20 and 22 cm, IV in 24 cm, stage V in 26 cm, while stages III and IV were equally represented in 30 cm size class (Fig. 7B). For females, gonadal development stage III dominated in all zones, while stage VI was observed only in the AMA and West zones (Fig. 8A). For males, stage II dominated in all zones (Fig. 8B). For both females and males individuals in stage V were more numerous in the AMA. However, differences in gonadal development stage between zones were not significant ($p > 0.05$) and were related only to differences in the individual size for both females and males ($F = 44.20$; $p < 0.0001$ and respectively $F = 9.16$; $p = 0.004$).

Lower gonadal development stages dominated in autumn for both females (II and III) ($F = 50.12$; $p < 0.0001$) (Fig. 8C) and males (II and III) ($F = 7.00$; $p = 0.010$) (Fig. 8D). Significant seasonal differences, independent of size, were also observed for both females ($F = 70.63$; $p < 0.0001$) and males ($F = 18.21$; $p < 0.0001$). However, development stages in males seemed to be in advance compared to females in autumn, as stage IV and V were observed for males, while stage I were still present in females. More advanced gonadal development stages occurred in spring, with stages IV, V and VI observed in similar percentages in both sexes.

DISCUSSION

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

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

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

Differences in the relationship between length and weight may be related to environmental and trophic factors as well as reproduction and stage of maturity (Pauly, 1984; Cherif *et al*., 2007). The study area is impacted by the oligotrophic Northern Mediterranean current (Millot, 1999) and is probably less productive than other marine coastal areas (Diaz *et al*., 2001). Moreover, trophic conditions and diet may influence the relative body condition. Condition factors compare the well-being of fish based on the assumption that heavier fish of a given length are in better condition (Froese, 2006). Fish condition is relevant because it influences growth, reproduction and survival (Lambert and Dutil, 1997; Shulman and Love, 1999). In this study relative body condition did not differ significantly between sexes, in accordance with the results published by Lloret and Planes (2003). However, body condition was positively correlated with gonad mass and gonado-somatic index, confirming the influence of body condition on reproductive success.

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

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

In the south-east of France, the percentage of females increased with size and size classes > 27 cm were sometimes exclusively composed of females, as recently observed by Kousteni *et al*. (2019) in the Aegean Sea. This was also observed by Reñones *et al.* (1995) in Mallorca, where individuals > 23 cm presented very low proportions of males. Females largely dominated in all zones and in both seasons. A sex-ratio in favour of females in *M. surmuletus* was recorded in previous studies in the Eastern Channel and the North Sea (Mahé *et al*., 2005), but also in the Mediterranean Sea (Kousteni *et al*., 2019 and references therein), Morocco (Lamrini, 2010) and Spain (Reñones *et al*., 1995). This might be attributed to differences in spatial distribution between sexes. Coastal areas, probably more productive, could be more favourable for feeding for females preparing for reproduction. The high proportions of females in our samples might thus be due to the females coming close to the coast for feeding, before and after reproduction, which takes place in deeper waters (Machias *et al*., 1998). The observed imbalance in the relative proportions of sexes in our samples suggested that males and females displayed different spatial behaviour, with males living offshore most of the time (Machias *et al*. 1998). In our study, the sex-ratio was less unbalanced in the AMA (2:1) than in the West and East areas (3:1). Marine protected areas are known to have positive effects on population demography and sex-ratio compared to fisheries non-regulated areas (Grüss *et al*., 2014; Boudouresque *et al*., 2021). The sex-ratio of the Var *M. surmuletus* population differed from those of the Gulf of Lion, where males generally dominated and the sex-ratio females-males reached 1:8 in 2011. However, annual variations were observed in the Gulf of Lion, with the sex-ratio females-males varying from 1:2 in 2019 to 1:1 in 2020.

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

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

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

Acknowledgments. -

This study was funded by the EMFF (European Fund for Maritime Fisheries Affairs), within the framework of the PACHA program. This study was performed in collaboration with professional fishermen and Port-Cros National Park. Thanks are due to Port-Cros National Park, Toulon fishing *Prud'homies*, Giens, Salins and Lavandou sections, and Stéphanie Joubert from the Var Departmental Maritime Fisheries Committee.

Thanks are addressed to the association Planète Mer and the CDPMEM Var, within the framework of the PELA-Méd program (Fishermen Engaged for the Future of the Mediterranean), who contributed to this study by providing samples from the West and East zones of the PCNP AMA.

D. Bănaru benefited from leave within the ANR CONTAMPUMP project (no ANR-19-CE34-0001). Thanks are also addressed to Michael Paul for English proofreading and to the two reviewers who helped us to improve the manuscript.

REFERENCES

ARSLAN M. & İŞMEN A., 2013. - Age, growth and reproduction of *Mullus surmuletus* (Linnaeus, 1758) in Saros Bay (Northern Aegean Sea). *J. Black Sea / Medit. Environ.,* 19(2): 217-233.

ASTRUCH P., BOUDOURESQUE C.-F., ROUANET É., LE DIREACH L., BONHOMME P., *et al*. 2018. - A quantitative and functional assessment of fish assemblages of the Port-Cros Archipelago (Port-Cros National Park, north-western Mediterranean Sea). *Sci. Rep. Port-Cros Natl. Park*, 32: 17-82.

BARCELO A., BERNARDI P., BUZAUD C., CREUSEFOND M., DESPINOY P., GABRIEL J., HILY G., MAZZELLA C., MILLIER L., CRESP G., RIDOLFI J., COUPEZ L., CROSSETTI G., RENOUX S. & PRODROMIDES M., 2018. – Mode de gouvernance pour la gestion concertée du coeur marin de l'île de Porquerolles, au sein du Parc national de Port-Cros (Provence, France) : retour des acteurs sur 10 années de pratique. *Sci. Rep. Port-Cros Natl. Park*, 32: 83-111.

BAUTISTA-VEGA A., 2007. - Etude des réseaux trophiques aboutissant aux rougets méditerranéens (*Mullus barbatus* et *M. surmuletus*) par l'utilisation des isotopes stables. Thèse Doctorat Sciences de l'Environnement marin, Université de la Méditerranée Aix-Marseille 2, 156 p.

BAUTISTA-VEGA A.A., LETOURNEUR Y., HARMELIN-VIVIEN M. & SALEN-PICARD C., 2008. -Difference in diet and size-related trophic level in two sympatric fish species, the red mullets *Mullus barbatus* and *Mullus surmuletus*, in the Gulf of Lions (north-west Mediterranean Sea). *J. Fish Biol*., 73: 2402-2420. https://doi.org/10.1111/j.1095-8649.2008.02093.

BENSAHLA-TALET L., BENSAHLA-TALET A. & ZITOUNI B., 2014. - Croissance relative pour quatre poissons (téléostéens : Sparidae, Mullidae) pêchés dans la baie d'Oran, Algérie (Méditerranée ouest). *In* : Troisième colloque international sur la biodiversité et écosystèmes littoraux (Chouikhi A., Boutiba Z., Mouffok S., Bouderbala M. éds.), Université d'Oran publ., Algérie, p 399-407.

BOUDOURESQUE C.F., CADIOU G. & LE DIRÉACH L., 2005. - Marine protected areas: a tool for coastal areas management. *In*: Strategic management of marine ecosystems (Levner E., Linkov I. & Proth J.M. eds.), Springer publ., Dordrecht: 29-52.

BOUDOURESQUE C.-F., DOMINICI J.-M., DURIEZ O., ASTRUCH P., LE DIRÉACH L, MÉDAIL F., SALA E., SCHOHN T. & VICENTE N., 2021. - A terrestrial and marine nature reserve in the NW Mediterranean, Scàndula (Corsica): Biodiversity and lessons from 46 years of management. *Sci. Rep. Port-Cros Natl. Park*, 35: 43-181.

BISEAU A., 2020. - Diagnostic halieutiques française 2019 sur les ressources halieutiques débarquées par la pêche française (métropolitaine). Rapport Ifremer, RBE, janvier 2020, 30 p. https://wwz.ifremer.fr/peche.

CAMPILLO A., 1992. - Les pêcheries françaises de Méditerranée : synthèse des connaissances. Institut Français de Recherche pour l'Exploitation de la Mer publ., France, 206 p.

CHERIF M., GHARBI H., JARBOUI O., M'RABET R. & MISSAOUI H., 2007. - Le rouget de roche (*Mullus surmuletus*) des côtes nord tunisiennes : reproduction, sexualité et croissance. *Bull. Instit. Nat. Sci. Technol. mer Salammbô*, 34: 9-19.

CRPMEM PACA, 2016. - Etat des lieux et caractérisation de la pêche maritime professionnelle et des élevages marins en PACA. Amélioration de la connaissance sur la petite pêche artisanale et la pisciculture marine locale. Projet E-CaPE – Données 2014 Rapport, 103 p.

DEMANECHE S., MERRIEN C., BERTHOU P. & LESPAGNOL P., 2009. - Rapport R3 Méditerranée continentale, échantillonnage des marées au débarquement. Méthode d'élévation et évaluation des captures et de l'effort de pêche des flottilles de la façade Méditerranée continentale sur la période 2007-2008. Programme P6 AESYPECHE "Approche écosystémique de l'halieutique" Projet Système d'Informations Halieutiques SIH, IFREMER, France, 54 p.

DIAZ F., RAIMBAULT P., BOUDJELLAL B., GARCIA N., MOUTIN T., 2001. - Early spring phosphorus limitation of primary productivity in a NW Mediterranean coastal zone (Gulf of Lions). *Mar. Ecol. Prog. Ser.*, 211: 51-62. https://doi.org/10.3354/meps211051.

FROESE B.R., 2006. - Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. *J. Appl. Ichthyol.*, 22: 241-253.

FROESE R., WINKER H., GASCUEL D., SUMAILA U.R. & PAULY D., 2016. - Minimizing the impact of fishing. *Fish Fish.*, 17: 785-802.

GARCIA-RUBIES A. & MACPHERSON E., 1995. - Substrate use and temporal pattern of recruitment in juvenile fishes of the Mediterranean littoral. *Mar. Biol.*, 124: 35-42.

GÖKHAN G., AYDIN I. & METIN C., 2007. - Length-weight relationships of 7 fish species from the North Aegean Sea, Turkey. *Intern. J. Nat. Engin. Sci.*, 1: 51-52.

GRÜSS A., ROBINSON J., HEPPELL S.S., HEPPELL S.A. & SEMMENS B.X., 2014. - Conservation and fisheries effects of spawning aggregation marine protected areas:

What we know, where we should go, and what we need to get there, *ICES J. Mar. Sci.*, 71(7): 1515-1534. https://doi.org/10.1093/icesjms/fsu038.

HUREAU J.C., 1986. - Mullidae. *In* : Fishes of the North-eastern Atlantic and the Mediterranean (Whitehead P.J.P., Bauchot M.L., Hureau J.C., Nielsen J, & Tortonese E. éds). Les Presses de l'Unesco publ., Paris, p 877-882.

IFREMER, 2021. - Indices de populations et de communautés issus des campagnes de surveillance halieutique de l'Ifremer. Accessible à l'adresse suivante : http://www.ifremer.fr/SIH-indices-campagnes. Consulté pour la dernière fois le 10 mai 2021.

JUKIC S. & PICCINETTI C., 1981. - Quantitative and qualitative characteristics of demersal resources in the Adriatic Sea with some population dynamics estimates. *FAO Fisheries Reports*, 253 p, agris.fao.org.

KARAKULAK F.S., ERK H. & BILGIN B., 2006. - Length–weight relationships for 47 coastal fish species from the northern Aegean Sea, Turkey. *J. Appl. Ichthyol*., 22(4): 274-278.

KING J.R. & MCFARLANE G.A., 2003. - Marine fish life history strategies: applications to fishery management. *Fish. Manag. Ecol*., 10: 249-264. https://doi.org/10.1046/j.1365-2400.2003.00359.x

KOUSTENI V., ANASTASOPOULOU A. & MYTILINEOU C., 2019. - Life-history traits of the striped red mullet *Mullus surmuletus* (Linnaeus, 1758) in the south Aegean Sea (eastern Mediterranean). *J. Mar. Biol. Assoc. U.K*., 99(6): 1417-1427.

LAMBERT Y. & DUTIL J.D., 1997. - Can simple condition indices be used to monitor and quantify seasonal changes in the energy reserves of Atlantic cod (*Gadus morhua*)? *Can. J. Fish. Aquat. Sci*., 54(1): 104-112.

LAMRINI A., 2010. - Croissance et reproduction du rouget barbet de roche (*Mullus surmuletus* L. 1758) dans la baie de M'diq (Maroc). *Rapp. Comm. Intern. Explor. Sci. Mer Médit*., 39: 565.

LE CREN E.D., 1951. - The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *J. Anim. Ecol*., 20: 201-219.

LLORET J. & PLANES S., 2003. - Condition, feeding and reproductive potential of white seabream *Diplodus sargus* as indicators of habitat quality and the effect of reserve protection in the northwestern Mediterranean. *Mar. Ecol. Prog. Ser.*, 248: 197-208.

MACHIAS A., SOMARAKIS S. & TSIMENIDES N., 1998. - Bathymetric distribution and movements of red mullet (*Mullus surmuletus*). *Mar. Ecol. Prog. Ser.*, 166: 247-257.

MAHÉ K., DESTOMBES A., COPPIN F., KOUBI P., VAZ S., LE ROY D., CARPENTIER A., 2005. - Le rouget barbet de roche *Mullus surmuletus* (L. 1758) en Manche orientale et mer du Nord. Rapport de Contrat IFREMER/CRPMEM Nord-Pas6de-Calais, 187 pp.

MICHALETZ P.H., 1998. - Effect of body size on fecundity, the gonadosomatic index, egg size, and timing of spawning of gizzard shad. *J. Freshw. Ecol*., 13(3): 307-315.

MILLOT C., 1999 - Circulation in the western Mediterranean sea. *J. Mar. Syst.*, 20: 423-442.

MEHANNA S.F., 2009. - Growth, mortality and spawning stock biomass of the striped red mullet *Mullus surmuletus*, in the Egyptian Mediterranean waters. *Medit. Mar. Sci*., 10: 5-17.

MORALES-NIN B., 1991. - Parametros biologicos del salmonete de roca *Mullus surmuletus* (L. 1758), en Mallorca. *Bol. Inst. Esp. Oceanogr.*, 7: 139-147.

MULLEN A.J., 1994. - Effects of movement on stock assessment in a restricted-range fishery. *Can. J. Fish. Aquat. Sci*., 51: 2027-2033.

N'DA K., DÉNIEL C. & YAO K., 2006. - Growth of striped red mullet *Mullus surmuletus* in the northern area of the Bay of Biscay. *Cybium*, 30: 57-63.

NIKOLSKY G.V., 1963. - Ecology of fishes. Academic press, London, 352 pp.

PAPACONSTANTINOU C., TSIMINIDES N. & DAOULAS C.H., 1981. - Age, growth and reproduction of red mullet (*Mullus surmuletus* Linnaeus, 1758) in the Gulf of Seronikos and Thermaikos. *Thalassographica*, 1: 39-66.

PAULY D., 1984. - Some Simple Methods for the Assessment of Tropical Fish Stocks. *FAO Fish. Tech. Rep*. Rome, FAO, 234, 52 pp.

REÑONES O., MASSUTI E. & MORALES-NIN B., 1995. - Life history of the red mullet *Mullus surmuletus* from the bottom trawl fishery off the Island of Majorca (North-West Méditerranean). *Mar. Biol.*, 123: 411-419.

RICKER W.E., 1975. - Computation and interpretation of biological statistics of fish populations. *J. Fish. Res. Board. Can.*, 191: 1-382.

ROBERT P., 2013. – Évolution de la gouvernance : l’exemple de la pêche dans les eaux du Parc national de Port-Cros. *Sci. Rep. Port-Cros Natl. Park*, 27: 319-324.

ROBERTS C.M. & POLUNIN N.V.C., 1991. - Are marine reserves effective in management of reef fisheries? *Rev. Fish. Biol. Fish.*, 1: 65-91.

ROCHET M. J., 1998. - Short-term effects of fishing on life history traits of fishes. *ICES J. Mar. Sci.*, 55: 371-391.

SHULMAN G.E. & LOVE R.M., 1999. - The biochemical ecology of marine fishes. *In*: Advances in marine ecology (Southward A.J., Tayler P.A., Young C.M. eds.), 36: 1-351. Academic Press, London.

SOCK L., 2020. - Exploitation et Gestion des ressources halieutiques par la pêche aux petits métiers dans le Var (en Méditerranée française) sur la période 2008-2018. Rapport Master 2 Economie de l'énergie et des ressources naturelles. Mémoire professionnel. Aix-Marseille Université, 114 p.

TSERPES G., FIORENTINO F., LEVI D., CAU A., MURENU M., ZAMBONI A. & PAPACONSTANTINOU C., 2002. - Distribution of *Mullus barbatus* and *M. surmuletus* (Osteichthyes: Perciformes) in the Mediterranean continental shelf: implications for management. *Sci. Mar.*, 66: 39-54.

UNDERWOOD A.J., 1997. - Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press, London, 504 p.

WINEMILLER K. O., 2005. - Life history strategies, population regulation, and implications for fisheries management. *Can. J. Fish. Aquat. Sci*., 62(4): 872-885. https://doi.org/10.1139/f05-040.

WOOTTON R.J. 1998. - Ecology of Teleost Fishes. London: Kluwer Academic, 386 p.

https://campagnes.flotteoceanographique.fr

www.fao.org

www.ifremer.fr

https://sih.ifremer.fr/

Figures and tables legends

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

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

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

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

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

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

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

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

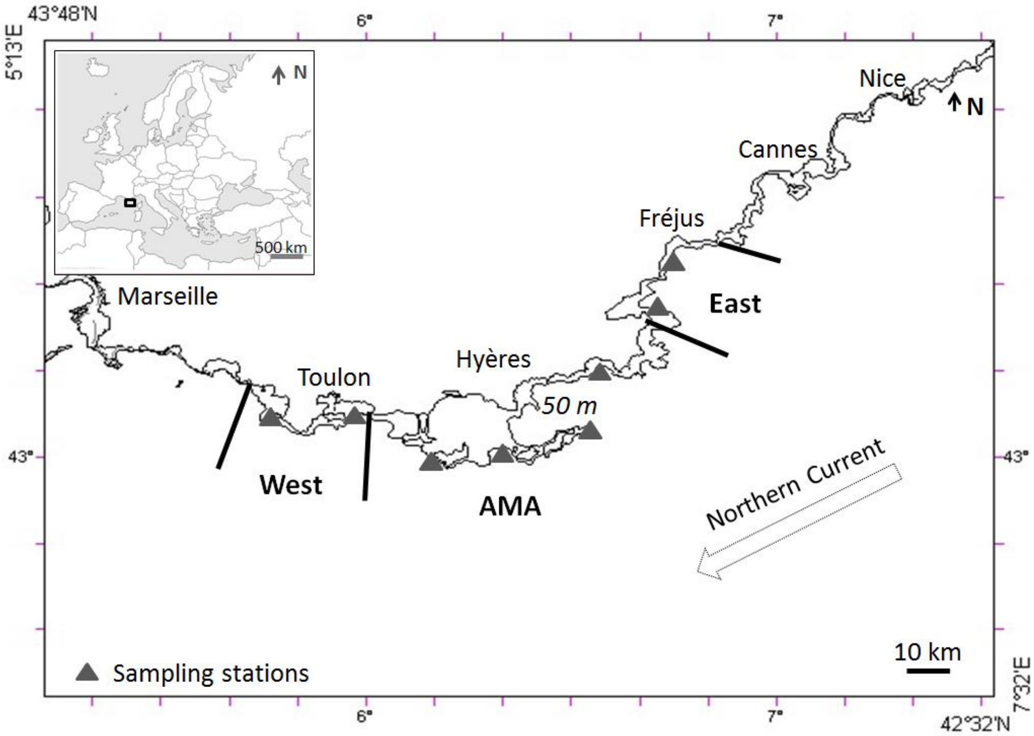
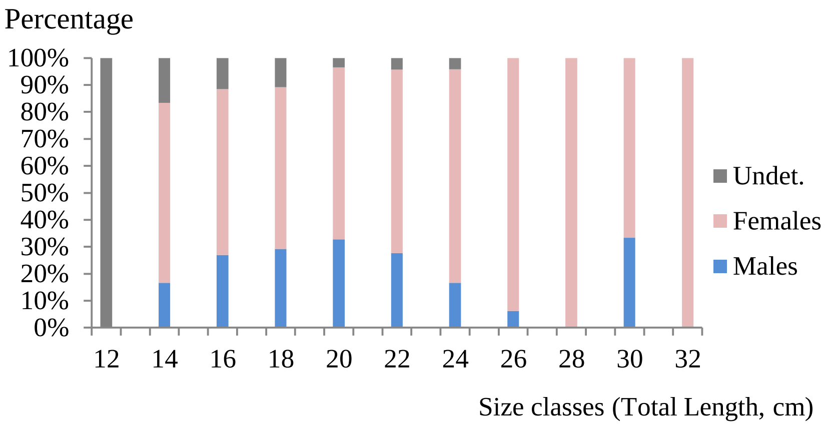
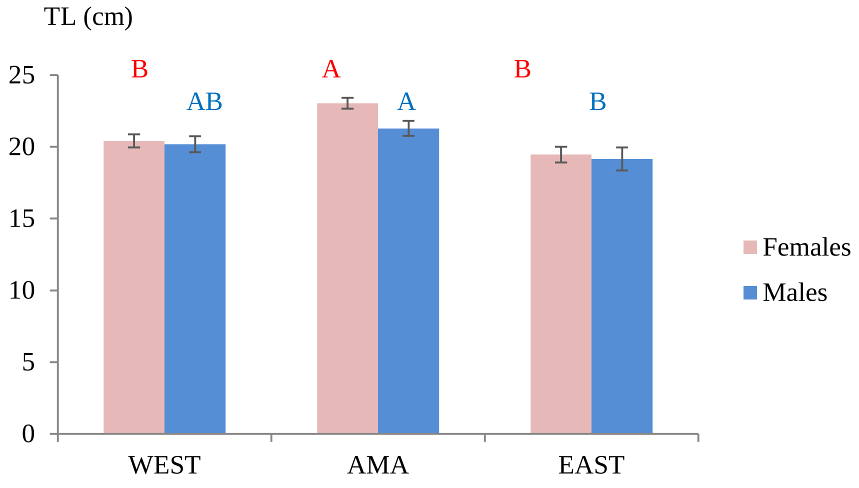

43°48'N
5°13'E
6°
7°
43°
7°32'E
42°32'N
N
500 km
Nice
Cannes
Fréjus
Marseille
East
Hyères
Toulon
50 m
West
AMA
Northern Current
10 km
Sampling stations

Figure 1



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

Figure 2



N = *69 - 24* *85 - 30* *25 - 12*

Figure 3

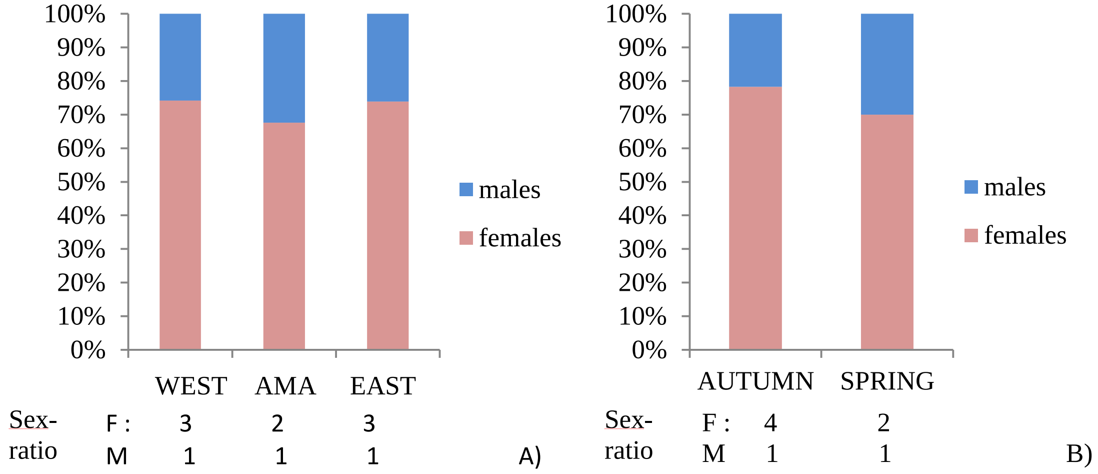

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
WEST
AMA
EAST
males
females
Sex-ratio
F : 3 2 3
M 1 1 1
A)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AUTUMN
SPRING
males
females
Sex-ratio
F : 4 2
M 1 1
B)

Figure 4

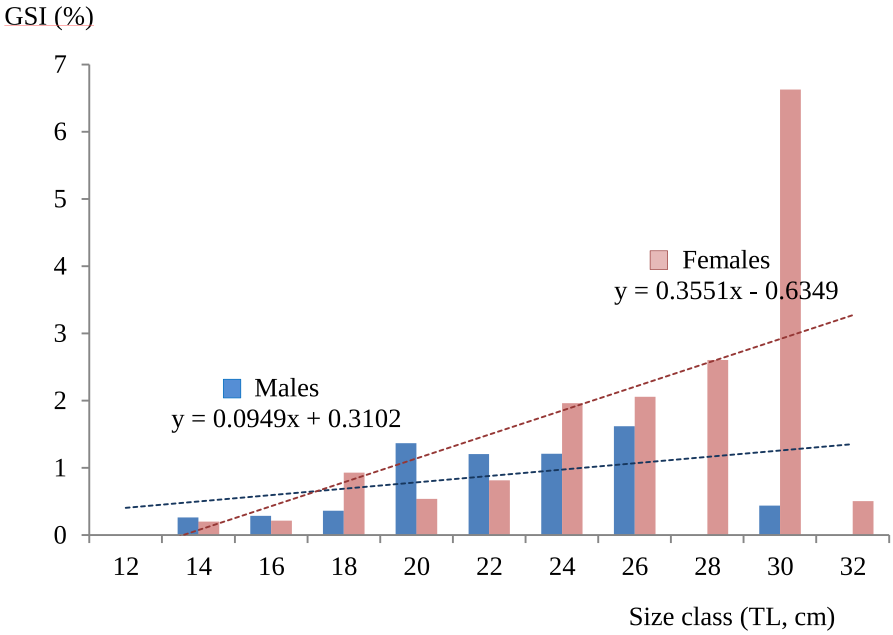

GSI (%)
7
6
5
4
3
2
1
0
Females
y = 0.3551x - 0.6349
Males
y = 0.0949x + 0.3102
12
14
16
18
20
22
24
26
28
30
32
Size class (TL, cm)

Figure 5

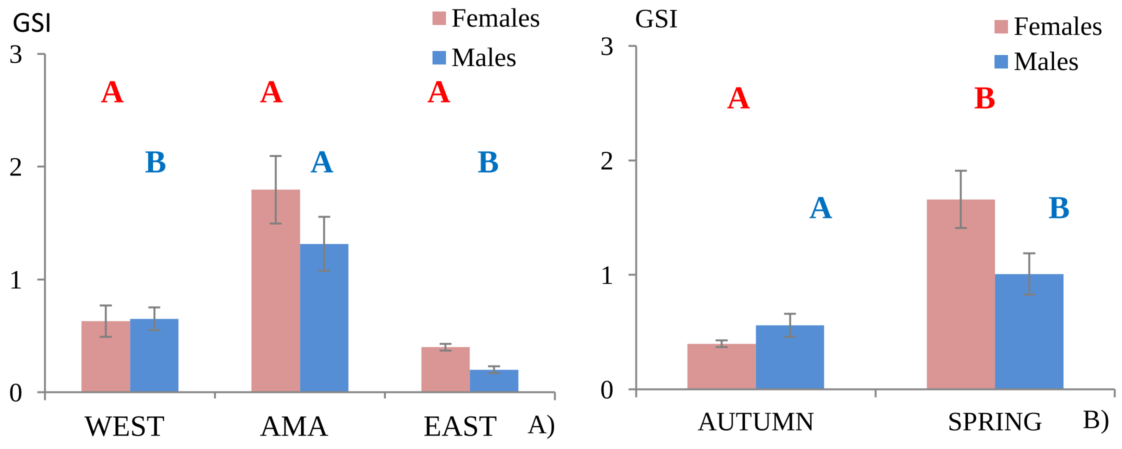

GSI
3
2
1
0
Females
Males
A
A
A
B
A
B
WEST
AMA
EAST
A)
GSI
3
2
1
0
Females
Males
A
B
A
B
AUTUMN
SPRING
B)

Figure 6

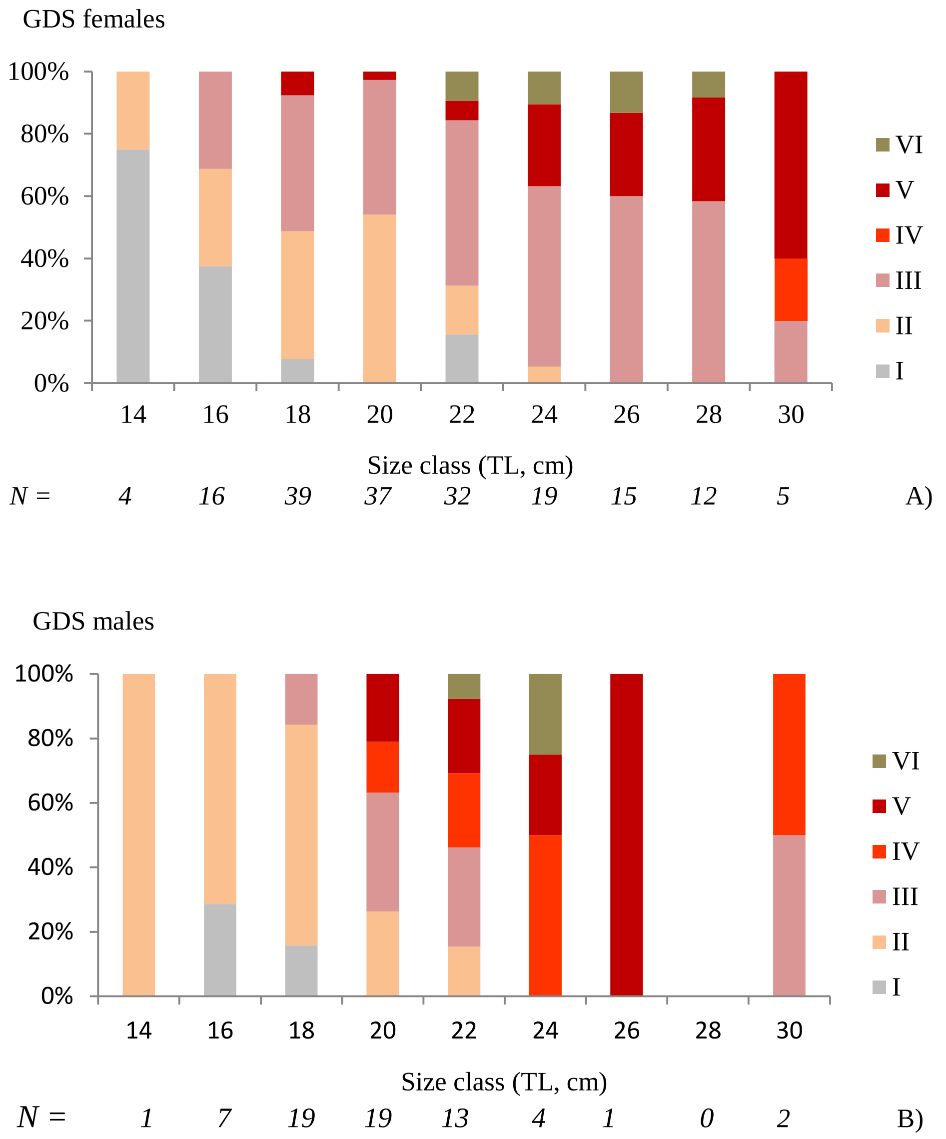

GDS females
100%
80%
60%
40%
20%
0%
14
16
18
20
22
24
26
28
30
Size class (TL, cm)
VI
V
IV
III
II
I
N = 4 16 39 37 32 19 15 12 5
A)
GDS males
100%
80%
60%
40%
20%
0%
14
16
18
20
22
24
26
28
30
Size class (TL, cm)
VI
V
IV
III
II
I
N = 1 7 19 19 13 4 1 0 2
B)

Figure 7

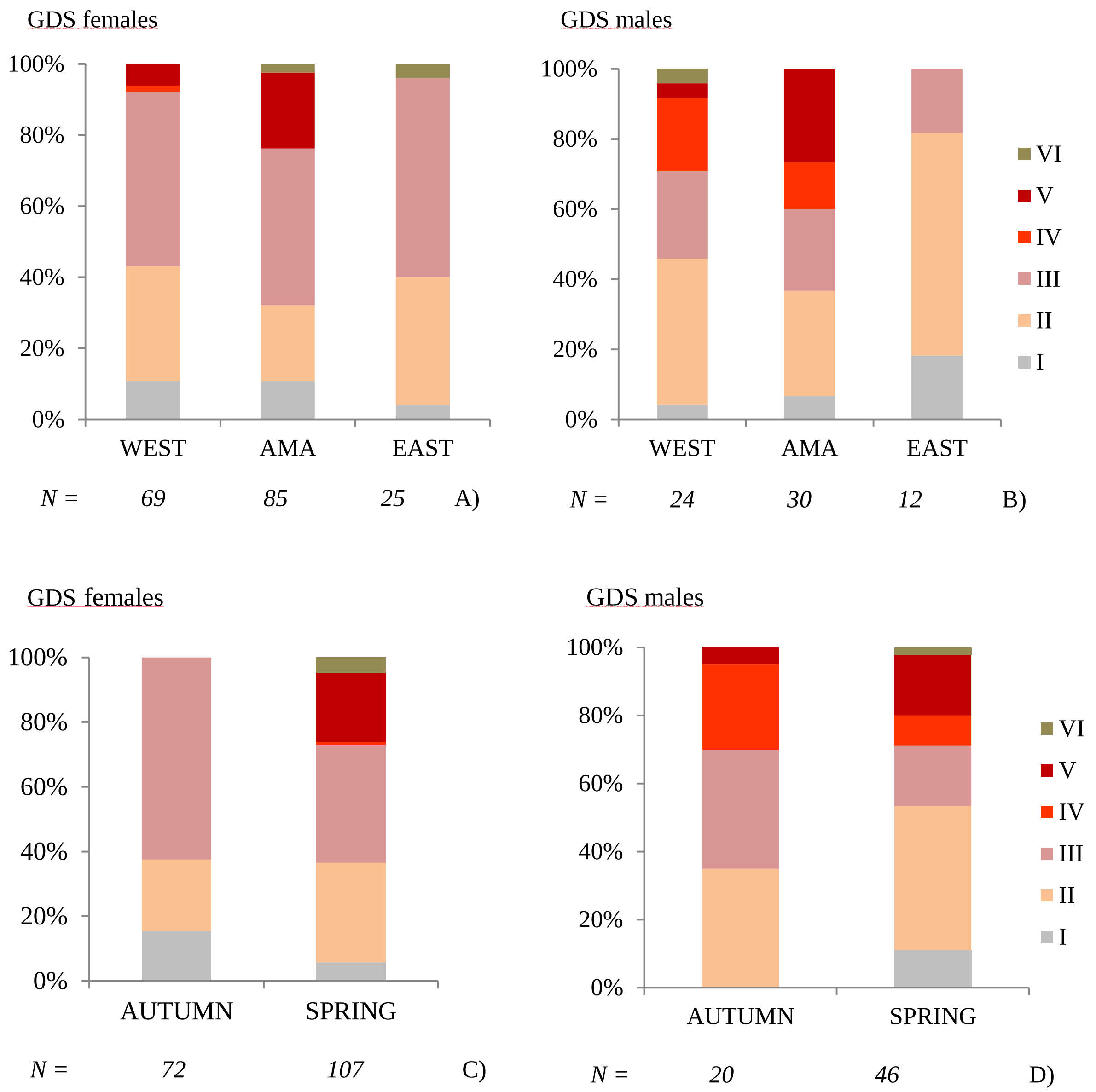

GDS females
100%
80%
60%
40%
20%
0%
WEST
AMA
EAST
N = 69 85 25
A)
GDS males
100%
80%
60%
40%
20%
0%
WEST
AMA
EAST
N = 24 30 12
B)
VI
V
IV
III
II
I
GDS females
100%
80%
60%
40%
20%
0%
AUTUMN
SPRING
N = 72 107
C)
GDS males
100%
80%
60%
40%
20%
0%
AUTUMN
SPRING
N = 20 46
D)
VI
V
IV
III
II
I

Figure 8

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

Table 2. – Mean (± SE) relative body condition (Kn) by sex, zone and season.

Table 1

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

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