Fish assemblages along the coasts of Tunisia:
a baseline study to assess the effectiveness of future Marine Protected Areas

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Abstract

The present study investigated coastal fish assemblages, using Underwater Visual Census (UVC) transects, that can be used as a baseline, at 3 locations in Tunisia (southern Mediterranean basin) where 3 MPAs will be established, before the implementation of protection measures. At each location, we used a sampling design where fish censuses were performed in two types of zone: zones that will be inside MPAs, and zones that will remain outside. On the whole, 49 taxa belonging to 19 families were censused. Our findings provided evidence of overfishing throughout the sampled areas, especially in terms of dominance of small- and medium-sized individuals of commercially relevant species. Our analyses, moreover, did not show any significant difference between fish assemblages (considering both density and biomass of whole assemblages, the different trophic categories and size distribution of commercial species) between future protected and unprotected zones. Overall, results suggest that: 1) current fish assemblages at the three studied locations are likely to be seriously impacted by fishing activities, and 2) these data could be used as a reliable baseline to assess the effectiveness of protection measures within the MPAs that will be established in the future. Our study is the first in Tunisia, and along the North African coasts, that has assessed distribution patterns of coastal fish assemblages by means of UVC, using a formal spatially replicated sampling design for resource management.

Keywords: Underwater Visual Census (UVC), Marine Protected Areas, Southern Mediterranean, Tunisia.

Introduction

Tunisia is located in the south-central Mediterranean Sea. It includes about 1670 km of coastline. It is considered as a crossroad between the eastern and western Mediterranean as it lies biogeographically in the Strait of Sicily, known for its high biodiversity, especially in terms of fish diversity (Bianchi *et al*., 2012). As in the rest of the Mediterranean (Sala *et al*., 2012 and references therein), professional (artisanal and industrial) and recreational fishing, along with a number of illegal practices, are seriously threatening coastal fish assemblages in Tunisia (Coll *et al*., 2010; CAR/ASP - PNUE/PAM, 2014; Halouani *et al*., 2015). In this context, Marine Protected Areas (MPAs) that include fully protected zones (also referred to as no-take zones or marine reserves) are important tools for conservation and management (PISCO & UNS, 2016). Worldwide, MPAs with fully protected zones have been clearly demonstrated to be effective for protecting fish assemblages (Di Franco *et al*., 2009; Guidetti *et al*., 2014, Mellin *et al*., 2016; PISCO & UNS, 2016; Bergseth *et al*., 2017). In the Mediterra-

nean Sea, recent studies provided significant evidence that well-managed and well-enforced MPAs trigger clear ecological responses (particularly from large predatory fishes; Guidetti *et al*., 2014; Giakoumi *et al*., 2017) and provide fishery benefits (Di Franco *et al*., 2016).

In most MPAs worldwide, scientists monitor the effectiveness of MPAs by assessing fish assemblages using Underwater Visual Census (UVC) methods after the establishment of the MPA, often comparing data collected under protected and fished conditions (e.g. Sala *et al*., 2012; Edgar *et al*., 2014; Aburto-Oropeza *et al*., 2015; Caldwell *et al*., 2016). Some authors have highlighted the importance of having time reference data, to be able to compare patterns before and after implementation of the MPA. This can be done by formally adopting the so-called 'Before vs After Control Impact' experimental design in the specific context of MPA studies (e.g. Guidetti, 2002; Pelletier *et al*., 2008). The point is that comparing fish assemblage patterns only after MPA implementation by sampling at protected and fished control sites, might be subject to interference the 'reserve effect' (i.e. the response to protection, especially in terms of increased

abundance, size and biomass of fish as a consequence of protection measures) because, without 'before' data, uncontrolled factors, e.g. habitat and seascape complexity (Garcìa-Charton *et al.*, 2000; Guidetti, 2002; Huntington *et al.*, 2010), may mask the effects of protection.

In this perspective, the present study has been undertaken to assess the status of coastal fish assemblages at three locations in Tunisia that will host MPAs in the near future (CAR/ASP - PNUE/PAM, 2015, but see also: http://www.apal.nat.tn/site_web/contenu/creation_et_gestion_des_amcp.html). The aim is to describe the status of these fish assemblages and use these data as 'before data' to test the effectiveness of MPAs once they are established and protection measures are implemented. To the best of our knowledge, this is the first study carried out in Tunisia, and along the coasts of North Africa, that has assessed distribution patterns of coastal fish assemblages by means of UVC, and that has used a formal spatially replicated sampling design.

Methods

Sampling locations

UVC sampling was performed at three locations, referred to as Tabarka, Cap Negro-Cap Serrat and Kuriat Islands. Each location encompassed 4 sites that will be protected (i.e. that will be included within an MPA), and 2 adjacent sites (controls) that will remain open to fishing. Tabarka is situated on the west coast of Tunisia and the MPA will cover 327.855 ha, down to 40-m depth; Cap Negro-Cap Serrat is located in the north, and the MPA will cover 1 300 ha, down to 45-m depth; Kuriat islands, situated off the east coast, will be the site of an MPA covering 19 674 ha, down to 40-m depth (Fig. 1).

Sampling design and data collection

Six sampling sites were surveyed at each location (4 sites that will in the future be protected and 2 that will remain unprotected), using the visual census transect method (see Harmelin-Vivien *et al.*, 1985) performed on rocky reefs from 10 to 20 meters depth. All sampling sites have similar characteristics in terms of habitat type, with rocky bottoms covering ~70%, and *Posidonia* meadows and sand covering the remaining ~30% of the substrate. One sampling survey per year was conducted (from 2014 to 2016 at Tabarka and Kuriat Islands, and in 2014 and 2016 at Cap Negro-Cap Serrat) during the warm season (from August to September) and under similar weather and sea conditions. The same person performed all fish counts at all sites, diving in one direction at constant speed, and performing three types of transects in terms of length and width: (1) transect A: 25 m x 5 m for necto-benthic fishes
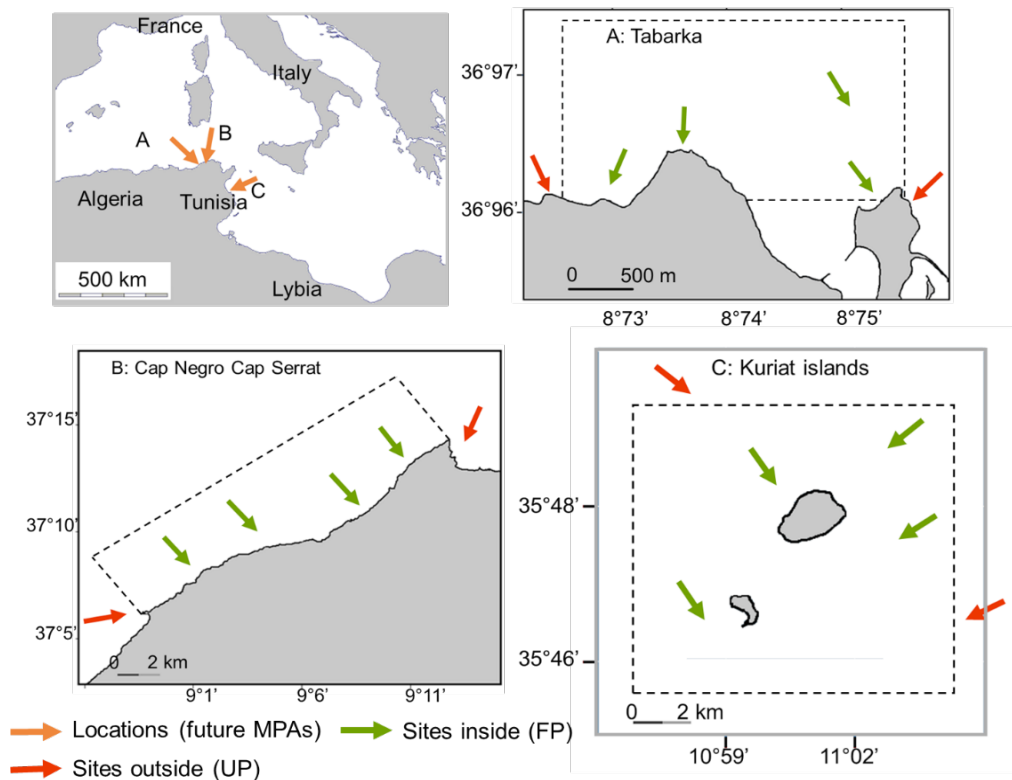

Fig. 1: Locations where MPAs will be established along the Tunisian coast. Location of future protected sites (FP) and those outside (that will remain unprotected) (UP) (separated with dotted lines indicating borders of future MPAs as they are proposed in management plans).

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(e.g. sea bream), (2) transect B: 35 m x 10 m for large mobile high-level predators (e.g. grouper), and (3) transect C: 10 m x 1 m for crypto-benthic fishes (e.g. Gobidae) (Prato *et al.*, 2017 for further methodological details) (see Suppl. mat. 1 for the species list). Three replicates of each transect type were performed at each site and in each sampling year for a total of 144 replicates conducted in this study. At each transect, each species encountered was identified and its abundance recorded. Fish size (total length) was recorded within 5 cm size classes for large sized fishes (species maximum size > 50 cm), 2 cm size classes for other necto-benthic fish species and 1 cm for small crypto-benthic fishes (following Prato *et al.*, 2017). Based on density and size data, fish biomass was estimated using length-weight relationships (Froese & Pauly, 2017).

Data analyses

Total fish density and biomass (pooling all species censused and calculated for all transect types together) were expressed as number of individuals or grams per square meter. Species richness was expressed as number of fish taxa per transect. Fish species were also characterized and pooled, in terms of density and biomass, according with their trophic category (see Bell & Harmelin-Vivien, 1983; Sala, 2004; Guidetti & Sala, 2007): large predators, small piscivores, invertivores 1 (major predators of sea urchins), invertivores 2 (with diet seldom including sea urchins), planktivores and herbivores (see Supp. Mat. 1 for further details). Then, for commercially relevant species (see table in Supp. Mat. 2), each recorded fish was assigned to one of three size classes, i.e. small, medium and large, corresponding to the lower, intermediate and upper 33% range of sizes reported in the literature (Froese & Pauly, 2017), and size-class frequencies were calculated for each location (see Supp. Mat. 2 for the total number of individuals per species used to build frequency distributions).

Overall fish assemblage structure (based on density and biomass data) was analysed using multivariate statistical techniques. Specifically, two "taxon x samples" matrices of species density and biomass (n = 49 taxa, n = 144 samples) were analysed. Univariate techniques were used for: (1) species richness (one matrix n = 1 variable, n = 144 samples), (2) total density and total biomass (two other matrices: n = 1 variable, n = 144 samples), and, (3) density and biomass per trophic category (12 matrices: n = 1 variable, n = 144 samples). Univariate and multivariate analyses were performed using a four-way permutational analysis of variance (PERMANOVA, Anderson, 2001). For all Permanovas, the following factors have been taken into account: factor "Protection" (P) (2 levels, Future Protected (FP) and Unprotected (UP)) was considered as fixed; factor "Location (Lo)" (3 levels: Kuriat, Cap Negro-Cap Serrat, Tabarka) and factor "Site" (Si), (2 to 4 levels) nested in each level of P, and factor "Time (Ti)" (2 to 3 levels), were both considered as random. We used MonteCarlo permutations whenever the number of possible permutations was < 200. The PRIMER 7 package implemented with PERMANOVA+ was used to perform the analyses.

Results

Multivariate analyses

Overall, fish assemblages comprised 49 taxa belonging to 19 families: 48 taxa were found at Tabarka, 45 at Kuriat islands and 34 at Cap Negro-Cap Serrat. Sparidae and Labridae were strongly represented families in terms of number of species (see Table in Supp. Mat. 1).

Multivariate analyses performed on density data show that fish assemblage structure changed significantly between sites that will be protected and those that will remain outside MPAs (factor 'P' significant; Table 1). Assemblage structures in terms of both density and biomass also changed significantly over time, but with changes that were not the same at the spatial scales of locations and sites (interaction 'TixLoxSi(P)' significant; Table 1).

Univariate analyses

Mean species richness ranged from 8.2 ± 0.7 taxa in UP Kuriat to 14.2 ± 1.4 taxa in UP Tabarka (Fig. 2-a). Mean fish density (pooling all species) ranged from 0.7 ± 0.1 ind/m^2 in UP Kuriat to 1.5 ± 0.3 ind/m^2 in UP Cap Negro Cap Serrat (Fig. 2-b). Mean fish biomass (again pooling all species) ranged from 11.9 ± 2.9 in UP Kuriat to 50.1 ± 7.9 gr/m^2 in UP Tabarka (Fig. 2-c).

Table 1. PERMANOVA (multivariate analysis) on square root transformed data of fish density and biomass. Ti: Time; Lo: Location; Si: Site; P: Protection. *p <0.05; **p < 0.01; ***p < 0.001.

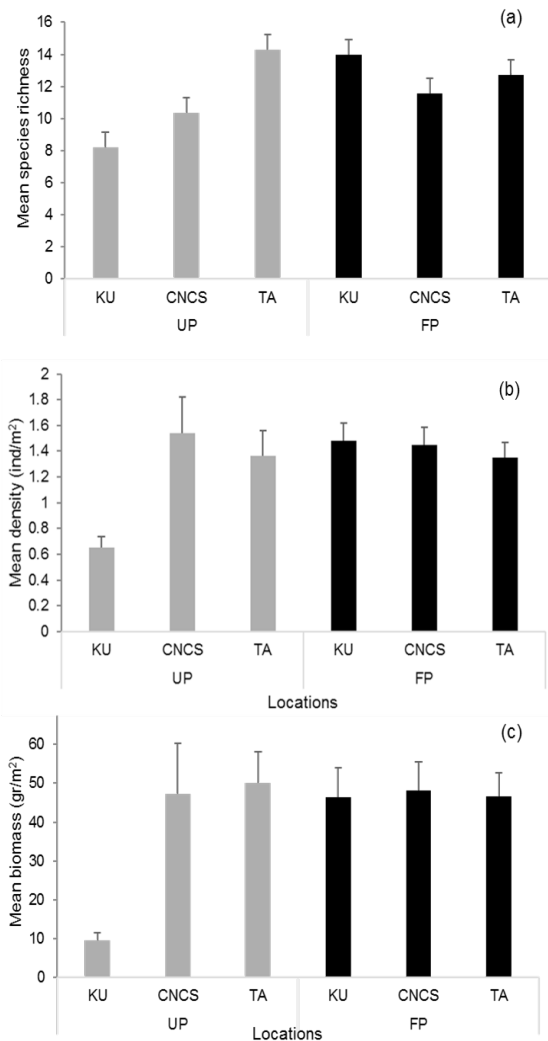| Source	df	Density MS	Pseudo-F	Biomass MS	Pseudo-F
Ti	2	10405	5.00***	13488	5.43***
Lo	2	7504.7	1.25	11354	1.65*
P	1	12003	2.16*	8628.8	1.43
Si(P)	5	4527.8	2.09	4391	1.71*
TixLo	3	4141	2.01*	4415.5	1.97**
TixP	2	2731.4	1.31	4065.9	1.63
LoxP	2	3862.1	1.04	5873.8	1.25
TixSi(P)	10	2239.4	2.02***	2621.2	1.58***
LoxSi(P)	6	3380.2	1.61*	3701.1	1.64*
TixLoxP	3	2316.2	1.12	2733.8	1.22
TixLoxSi(P)	8	2101.4	1.89***	2260.2	1.36*
Res	99	1106.6		1657.3	
Total	143				

Fig. 2: Mean species richness (a), mean density (b) and mean biomass (c) (±standard error) per location (KU: Kuriat islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka) and protection level (UP: Unprotected, FP: Future Protected).

Univariate analyses showed that: 1) none of the three variables (species richness, total density and biomass of fish) significantly differed between UP and FP (factor 'P' was never significant; Table 2), 2) species richness was significantly variable over sampling times (factor 'Ti' significant); 3) fish density displayed a variability over sampling times that differed at both the spatial scales of locations and sites (interaction 'TixLoxSi(P)' significant); 4) fish biomass changed over time (factor 'Ti' significant) and was significantly variable at the scale of locations (factor 'Lo' significant).

Trophic category density and biomass

Density per trophic category displayed different patterns (Fig. 3, Table 3). Density patterns of herbivore fishes did not change for any factor considered here. Large predator and invertivore 1 densities showed a significant temporal variability ('Ti' significant). Small predator density was not consistent over time between locations (interaction 'TiXLo' significant). Finally, mean densities of invertivore 2 fishes changed over time at both the spatial scales of locations and sites (interaction 'TiXLoXSi(P)' significant), while density of planktivores changed over time at the scale of locations (interaction 'TiXLo' significant).

Patterns of biomass also changed, depending on the trophic category (Fig. 4, Table 4). Biomass patterns of herbivores and invertivores 1 did not change for any factor considered here. Biomass of large predator fishes showed a significant variability over time ('Ti' significant). Small predator biomass was not consistent between times and locations (interaction 'TiXLo' significant). Mean biomass of herbivores was not consistent either, in the spatial (locations and sites) and temporal scales (interaction 'TiXLoXSi(P)' significant). Finally, biomass of invertivores 2 changed over time, but differently for sites

Table 2. PERMANOVA (univariate analysis) on species richness, total density and total biomass of fish. Ti: Time; Lo: Location; Si: Site; P: Protection. *p < 0.05; **p < 0.01; ***p < 0.001.

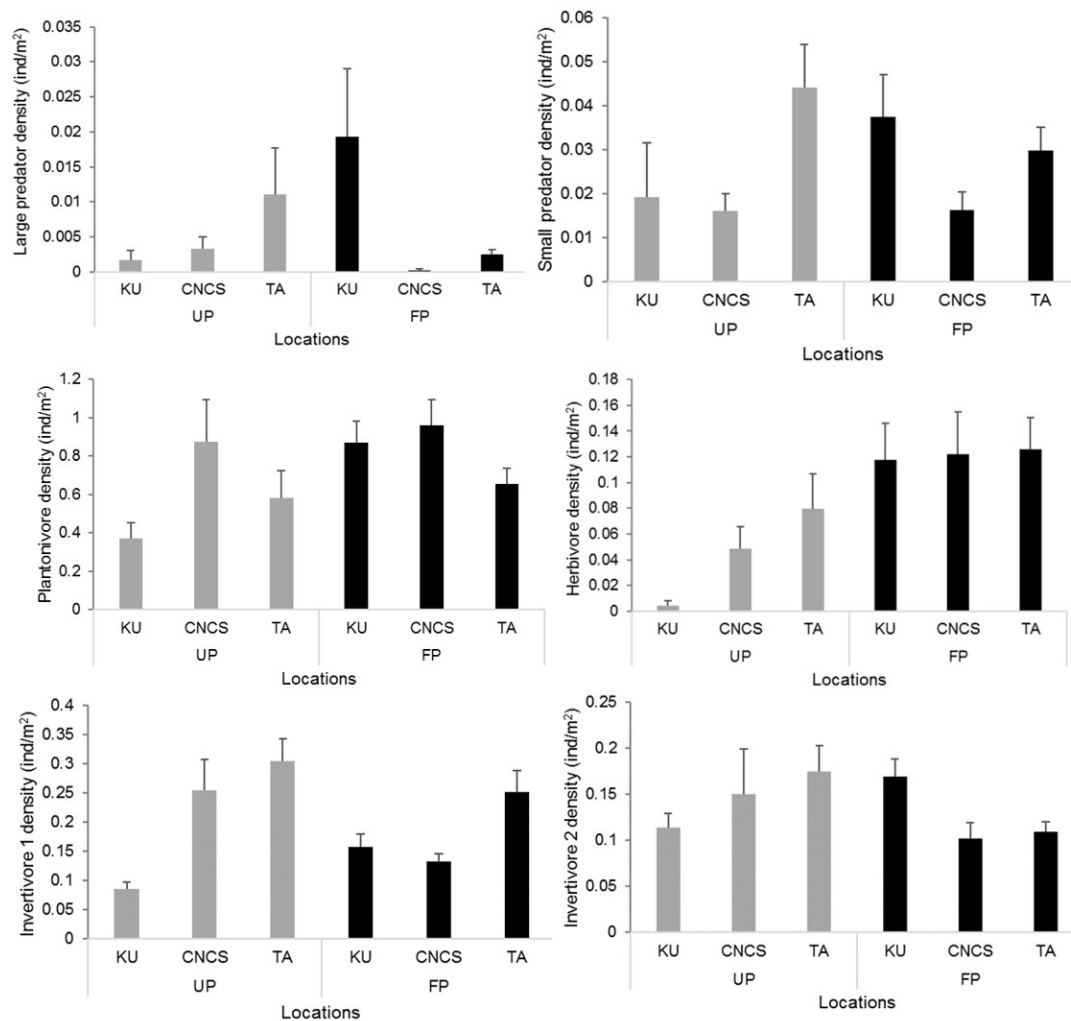| Source	df	Species richness		Density		Biomass	
		MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Ti	2	394.25	21.59***	9546.8	13.46***	11532	10.326***
Lo	2	221.54	4.43	1415.7	0.74	8621.9	3.9498**
P	1	287.76	1.95	6112.3	2.77	5629.4	1.9601
Si(P)	5	178.62	1.41	1428.5	1.94	948.87	0.83053
TixLo	3	150.75	0.51	1532.4	1.63	1443.7	1.4839
TixP	2	86.99	0.79	1316.2	1.85	2748.6	2.4612
LoxP	2	123.76	2.94	931.1	1.03	5348.9	2.1407
TixSi(P)	10	86.24	2.09	761.65	1.932*	1166.8	1.4275
LoxSi(P)	6	153.41	1.01	1632.2	1.71	936.74	0.95839
TixLoxP	3	108.46	1.79	231.28	0.24	1951.3	2.0056
TixLoxSi(P)	8	85.40	1.85	959.02	2.43**	979.65	1.1985
Res	99	49.72		394.22		817.41	
Total	143						

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Fig. 3: Mean density (±standard error) per trophic category at the sampling locations (KU: Kuriat Islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka) and per protection level (UP: Unprotected, FP: Future Protected).

Table 3. PERMANOVA (univariate analysis) on density data per trophic category. Ti: Time; Lo: Location; Si: Site; P: protection. *p <0.05; **p < 0.01; ***p < 0.001.

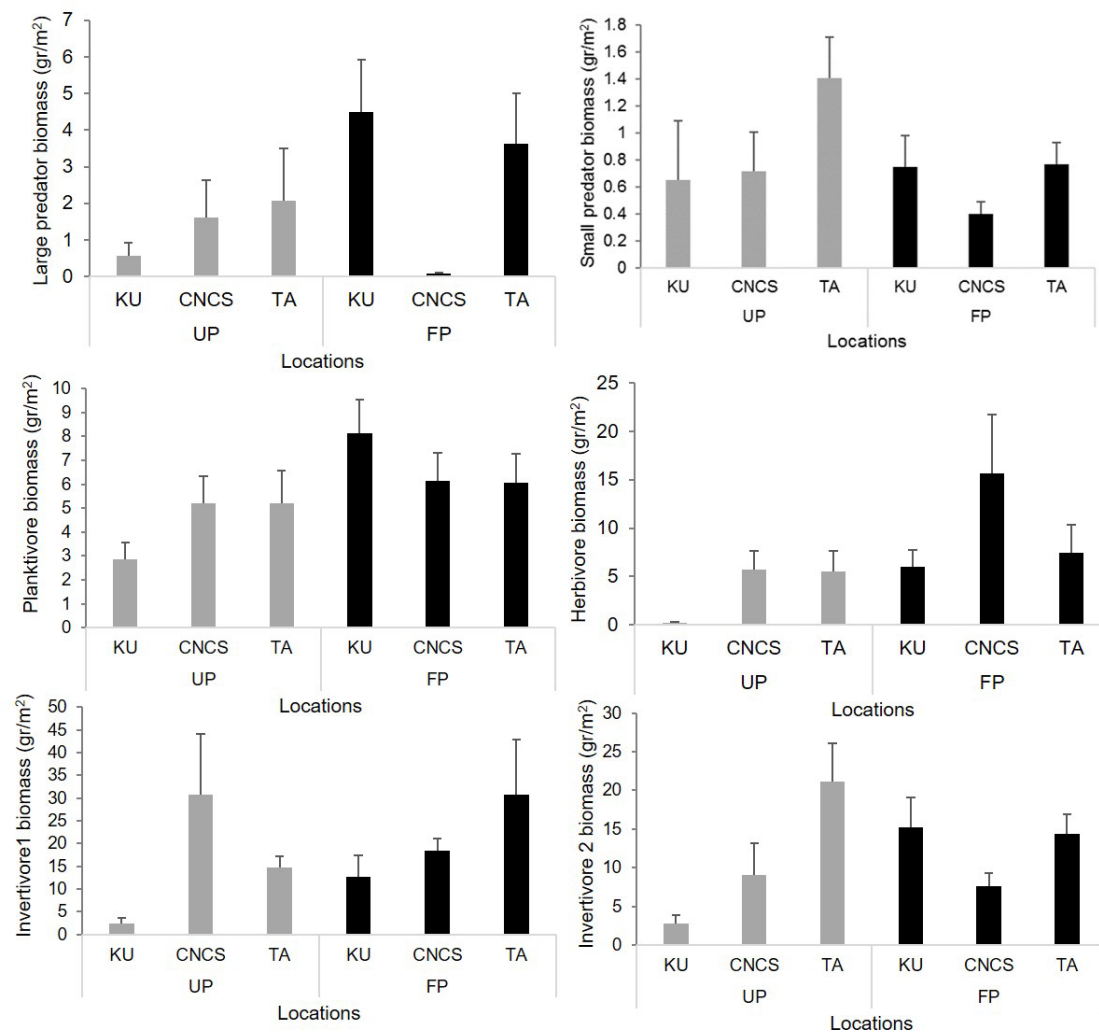| Density		Large predator		Small predator		Planktivore		Herbivore		Invertivore 1		Invertivore 2	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Ti	2	9958	0.00*	0.01	6.55*	1.70	5.76*	9954	0.02	0.17	6.15*	0.09	10.81**
Lo	2	0.00	0.92	7,8785E-06	0.09	1.04	0.68	0.03	0.64	0.13	3.07	0.00	1.16
P	1	5,6519E-08	0.63	0.00	0.67	1.63	2.32	0.10	3.98	0.06	3.97	0.00	1.05
Si(P)	5	0.00	1.36	0.00	0.88	0.44	1.48	0.00	0.84	0.02	0.79	0.01	1.47
TixLo	3	0.00	1.01	0.00	8.94**	1.10	8.38**	0.01	1.11	0.01	0.48	0.00	0.19
TixP	2	2,4098E-06	0.00	0.00	0.76	0.45	1.55	0.02	2.88	0.00	0.04	0.00	0.17
LoxP	2	0.00	1.12	0.00	1.19	0.21	0.59	0.00	0.34	0.05	1.29	0.01	1.98
TixSi(P)	10	0.00	0.60	0.00	1.65	0.30	1.28	0.00	0.33	0.03	1.64	0.00	1.18
LoxSi(P)	6	0.00	0.94	0.00	0.92	0.56	4.39*	0.05	3.52	0.03	1.53	0.01	0.79
TixLoxP	3	0.00	0.86	0.00	0.83	0.02	0.21	0.00	0.44	0.02	0.88	0.00	0.14
TixLoxSi(P)	8	0.00	0.36	0.00	0.49	0.12	0.53	0.01	0.84	0.02	1.42	0.01	2.41*
Res	99	0.00		0.00		0.23		0.01		0.01		0.00	
Total	143												

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Fig. 4: Mean biomass (±standard error) per trophic category at the sampling locations (KU: Kuriat Islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka) and per protection level (UP: Unprotected, FP: Future Protected).

Table 4. PERMANOVA (univariate analysis) on biomass data per trophic category. Ti: Time; Lo: Location; Si: Site; P: protection.
*p <0.05; **p < 0.01; ***p < 0.001.

Biomass		Large predator		Small predator		Planktivore		Herbivore		Invertivore 1		Invertivore 2	
Source	df	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F	MS	Pseudo-F
Ti	2	620.92	4.20*	4.55	2.38*	135.7	2.21	369.98	2.51	2159.8	1.52	4049.7	53.69***
Lo	2	348.03	1.20	1.21	0.22	3.261	0.62	376.76	0.89	1601.4	0.99	440.13	2.62
P	1	188.36	0.58	2.52	0.73	140.39	3.31	517.01	1.15	457.57	0.81	235.55	0.60
Si(P)	5	367.81	2.55	2.03	1.02	32.69	0.51	177.08	1.24	1182.6	0.84	126.71	1.93
TixLo	3	227.73	1.50	8.40	11.43**	65.21	1.15	34.65	0.06	1201.5	0.68	95.65	0.69
TixP	2	216.16	1.46	4.22	2.20	32.08	0.52	422.76	2.87	932.43	0.65	380.28	5.04*
LoxP	2	424.44	1.32	1.20	0.74	30.04	2.66	75.58	0.48	1997.5	1.12	639.65	1.50
TixSi(P)	10	140.1	0.72	2.04	1.77	65.48	1.78	137	0.66	1372.9	0.82	56.01	0.29
LoxSi(P)	6	180.27	1.20	0.03	0.04	31.73	0.55	990.29	1.93	2194.7	1.24	122.59	0.89
TixLoxP	3	246.18	1.63	2.46	3.34	2.10	0.03	258.09	0.51	1171.7	0.66	378.13	2.73
TixLoxSi(P)	8	149.08	0.77	0.71	0.62	57.36	1.56	516.91	2.49*	1758.5	1.05	135.93	0.71
Res	99	193.59		1.15		36.69		207.3		1662.1		191.44	
Total	143												

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that will be protected compared to sites that will remain outside MPAs (interaction 'TiXP' significant).

Size-class frequency distribution

Overall, small and- medium -sized individuals dominated and large-sized fishes were fairly rare (Fig. 5). Large-sized *Epinephelus marginatus*, *Dentex dentex*, *Sparus aurata* and *Serranus cabrilla* were censused only in UP, at Cap Negro-Cap Serrat and Tabarka. Large-sized *Epinephelus costae* and *Coris julis* were only recorded in FP at Tabarka. Large-sized individuals belonging to other species, such as *Sciaena umbra*, *Diplodus sargus*, *Diplodus vulgaris*, *Diplodus annularis*, *Diplodus puntazzo* and *Mullus surmuletus*, were recorded in both UP and FP conditions.

Discussion

The taxa composition of the assemblages censused at the three locations investigated in Tunisia showed that fishes belonging to Sparidae, Labridae and Serranidae families were the most strongly represented in terms of number of species, a classic pattern for the western Mediterranean fish assemblage (e.g. García-Charton & Pérez-Ruzafa, 2001; Seytre & Francour, 2014). Fishes belonging to Sparidae and Labridae families were also the most strongly represented at the three studied locations in terms of both density (minimum 59% of total density) and biomass (minimum 71% of total biomass). It is worth noting the presence of vulnerable and endangered species, such as the grouper *Mycteroperca rubra* and *Epinephelus marginatus*, and the common guitarfish *Rhinobatos rhinobatos* [see IUCN red list of threatened species, (IUCN, 2017)].

Fish assemblage structure, both in terms of density and biomass (see multivariate results), was quite variable over time and space. It differed slightly between sites that will be protected and sites that will remain outside MPAs. The observed patterns can be attributed to factors that are clearly not dependent on protection (not yet in place in the studied locations), such as habitat type distributions, slope, algal cover, bottom rugosity or seascape complexity, that have not been taken into account in the present study (see Garcia-Charton et al., 2000). Thus, this finding shows that other factors could contribute to differences in fish assemblage density and has, therefore, implications for future monitoring. This result stresses once more the usefulness of adopting proper sampling designs, such as, in this case, the crucial importance of 'before data' in the framework of BACI (before-after/control-impact) designs, to properly test hypotheses related to MPA effectiveness (Guidetti, 2002).

Mean values of total fish density assessed in this study are far lower than those assessed in many well-protected MPAs and are, on the other hand, comparable with the values reported from unprotected rocky reefs, open to fishing in the Mediterranean (e.g. Harmelin-Vivien et al.,

2008; Guidetti *et al*., 2014; La Mesa *et al*., 2017). Concerning the total fish biomass, the values observed in the present study range between ~11 and 50 gr/m^2, with an overall average around 40 gr/m^2. These values are lower than those reported from many well-managed MPAs in the Mediterranean (e.g. Tavolara, Cabo de Palos, Torre Guaceto, Medes Island, Carry-le-Rouet, Banyuls-sur-Mer) where values range between ~65 and 120 gr/m^2 (Harmelin-Vivien *et al*., 2008, Guidetti *et al*., 2014). The fish biomass values observed in this study in Tunisia are in any case relatively high, in comparison with other Mediterranean sites open to fishing, where average values range from ~5 to 30 gr/m^2 (Guidetti *et al*., 2014).

With regard to the fish biomass, it is widely accepted that this variable is the most relevant (much more important than density) as a basis for drawing conclusions regarding the effects of protection in MPAs (McClanahan & Mangi, 2000; Harmelin Vivien *et al*., 2008; Guidetti & Sala, 2007). Biomass integrates information regarding the abundance and size of fish. This is of paramount importance, considering that fishing usually targets large individuals of commercial species (Sandin *et al*., 2008). In our data set, it is important to highlight the presence of a few large-sized fishes (e.g. *Dasyatis pastinaca* and *Rhinobatos rhinobato*s). However, given that they are not very abundant, they did not significantly contribute to average values of total fish biomass in our assessment. From this perspective, most of the fish biomass estimated at the different locations in Tunisia is attributable to invertivore (~53%), planktivore (~10%) and herbivore (~11%) fishes, while the contribution of large predators was negligible, i.e. no more than 9%, versus ~38% at Cabo de Palos (Spain), Tavolara (Italy) and Scandola (France) (Prato *et al*., 2017).

As far as size of fishes is concerned, fish size at the studied locations was quite variable (with no obvious differences between sites that will be protected and sites that will remain outside MPAs in the future), and fish assemblages were generally dominated by small- and medium-sized fishes. Previous studies have shown that it is the large individuals of commercially relevant species that are chiefly removed by fishing as they have the highest market value (Pauly *et al*., 1998). The fact that large individuals are missing is thus widely considered a symptom of overfishing and of the community-wide impact of fisheries (Pauly *et al*., 1998; Guidetti & Sala, 2007).

The evidence from the present study commented on above suggests that fish assemblages at the studied Tunisian locations are likely to be impacted by fishing, which is capable of removing a remarkably large fraction of the fish biomass, in particular that of large-sized predatory fishes such as *Epinephelus marginatus*, *Epinephelus costae* and *Dentex dentex*. Meanwhile, the creation of MPAs at these locations is ongoing, in order to protect the biodiversity and enhance sustainable economic activities (CAR/ASP - PNUE/PAM, 2015). Like other well-enforced Mediterranean MPAs (Guidetti *et al*., 2014), we may expect that the future MPAs in Tunisia, if well-en-
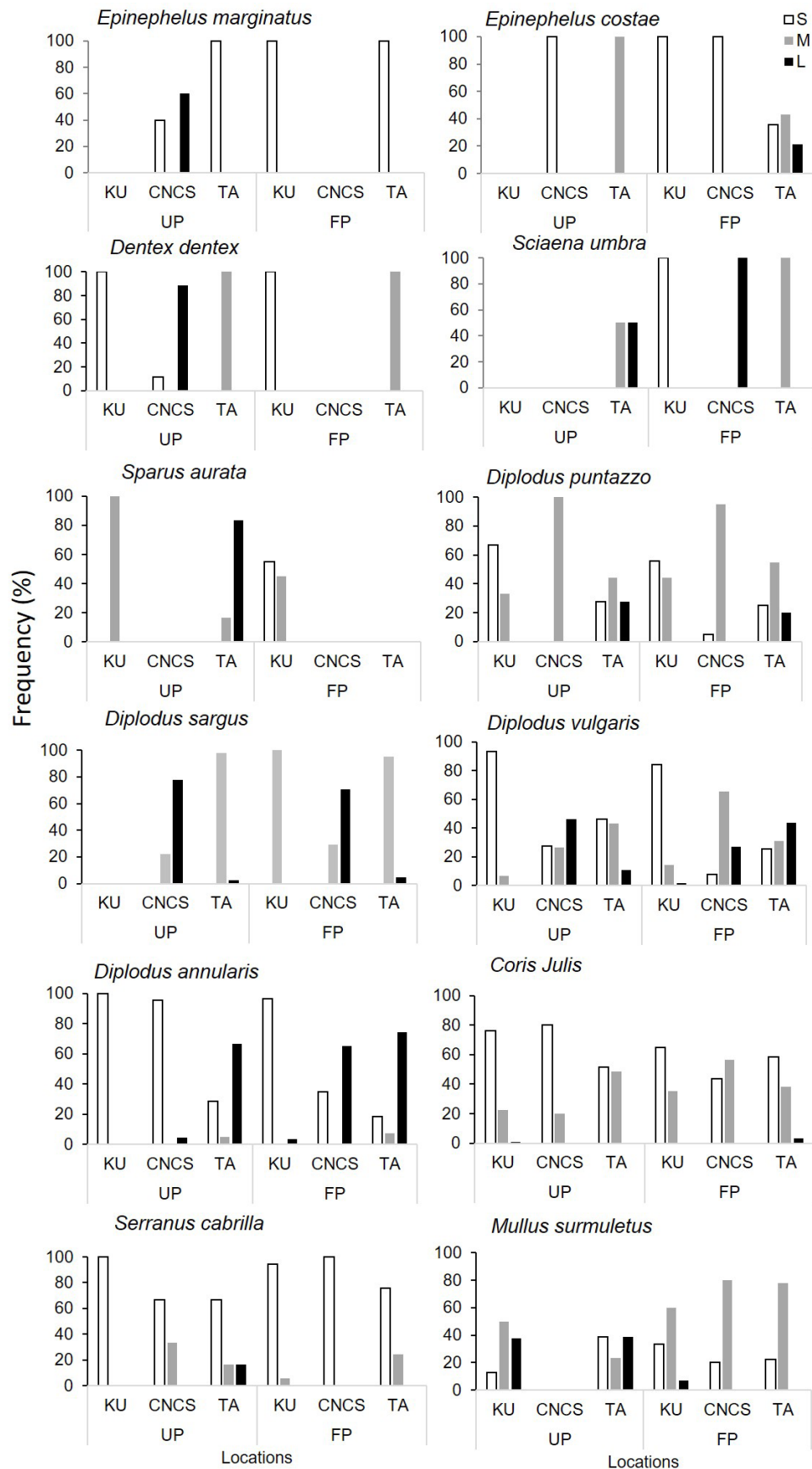
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Fig. 5: Size-class (S: small, M: medium and L: large) frequency distribution (%) of relevant target fishes in Unprotected (UP) and Future Protected (FP) zones at the three studied locations (KU: Kuriat Islands, CNCS: Cap Negro-Cap Serrat, TA: Tabarka), (Number of individuals used to calculate percentages is given in Supp. Mat. 2).

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forced, could provide benefits with regard to fish assemblages, and in the long-term for fisheries.

The present study is the first carried out in Tunisia (and, to the best of our knowledge, the first performed along the southern coasts of the Mediterranean Sea) that has reported quantitative data and assessed distribution patterns of coastal fish assemblages using the appropriate underwater fish visual census method (UVC; Harmelin-Vivien *et al*., 1985; Prato *et al*., 2017), and adopting a formal spatio-temporally replicated sampling design (Guidetti, 2002; Pelletier *et al*., 2008; Bonaldo *et al*., 2017).

From a methodological viewpoint, the UVC transect technique is widely accepted as a method that gathers quantitative data using a formal and appropriate sampling design, and offers a suitable basis for drawing reliable conclusions regarding the effects of protection within MPAs (Guidetti, 2002; Caldwell *et al*., 2016). This study satisfies both criteria, and could set a precedent for other studies that, it is to be hoped, will be carried out in Tunisia and in other countries in the southern and eastern Mediterranean in the future. This is important considering that a number of surveys and meta-analyses have reported that numerous studies have been carried out on the effects of Mediterranean MPAs, but almost all of them concern MPAs in Spain, France and Italy, fewer in Greece and Turkey, while the rest of the Mediterranean (more than half of its coasts) has been virtually ignored (Giakoumi *et al*., 2017 and references therein).

In conclusion, this study can be considered as an important baseline for future assessments of the health status of fish assemblages along the coasts of Tunisia, and the effects of protection measures that will be introduced after the implementation of the three planned MPAs. In addition, this study could trigger investigations in other North African Mediterranean countries and in the eastern Mediterranean that will provide a basis for a more exhaustive assessment of the effects of MPAs in the region as a whole. In Tunisia and in other south-eastern Mediterranean countries, it is of crucial importance, in addition to monitoring fish assemblages, that the proposed zoning of MPAs is applied and that restrictions, especially in no-take zones, are enforced in order to enable fish assemblages to recover. Otherwise, the expected benefits for fish assemblages, overall biodiversity and ecosystems, along with a number of positive effects for society (e.g. with regard to sustainable economic activities such as artisanal fishing and diving), will not be forthcoming (PISCO and UNS, 2016). In this framework, monitoring, using appropriate methods for collecting data with proper sampling designs, is a very important resource management tool.

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