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# Effects of reserve protection level on the vulnerable fish species *Sciaena umbra* and implications for fishing management and policy



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## ABSTRACT

The brown meagre *Sciaena umbra*, an iconic demersal fish species in Mediterranean coastal habitats, is particularly vulnerable to fishing pressure and presents a worrying population decline. Fish numbers and sizes were surveyed by visual census at Scandola (Corsica) in and outside reserve zones subject to increasing levels of protection, including unprotected zones (UP) where all fishing activities are permitted, buffer zones (BZ) subject to partial protection and a totally protected no-take integral reserve zone (IR). The numerical abundance, individual size and biomass of the brown meagre were found to increase with levels of reserve protection. The abundance of the larger size classes and the numbers of fish per shoal were significantly lower in unprotected zones. A comparison with similar censuses performed in 1983 showed a significant increase of *S. umbra* abundance in IR, but no difference in UP. That increasing levels of protection resulted in increased abundance and biomass of the brown meagre suggested a prominent role of fishing, particularly spearfishing, activities in the persistence of its low abundance in the unprotected zones. As a consequence, protective action for the brown meagre (including a ban on both spearfishing and recreational hook-and-line fishing) has been introduced in France since January 2014.

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## 1. Introduction

Fishing has long been the cause of depletion of fish populations in the Mediterranean Sea, as in much of the rest of the world's oceans (Papaconstantinou and Farrugio, 2000; Pauly, 2008; Tsikliras et al., 2013), inducing changes in the trophic levels of communities and the functioning of coastal ecosystems (Pinnegar et al., 2003; Sala et al., 2012). Those fish species

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that are most vulnerable to such depletion are generally larger, longer-lived and of higher trophic levels (Jennings et al., 1999), all being parameters which characterize the brown meagre *Sciaena umbra* Linnaeus 1758.

Because of particularly attractive features (beauty, calm swimming, aggregative behaviour, accessibility, excellent flesh, large otoliths collected for souvenirs), the brown meagre has soon become both an iconic species and a highly desirable target, when spearfishing started to develop in the Mediterranean Sea. Less well known than the dusky grouper (*Epinephelus marginatus* (Lowe 1834)), another iconic fish species occurring in this same area, the brown meagre is also a vulnerable fish particularly in the north-western Mediterranean, where these two species are both naturally less abundant than on the southern coasts (Harmelin, 1991, 2013). The brown meagre benefits from protection measures inside marine protected areas (MPAs) (Harmelin and Ruitton, 2007), but is frequently targeted outside these areas by small-scale professional and recreational fishers, especially by spearfishing (Morales-Nin et al., 2005; Lloret et al., 2008; Font et al., 2012).

The brown meagre occurs in the Eastern Atlantic, from the Bay of Biscay to Senegal, and in the Mediterranean and the Black Seas (Chao and Trewavas, 1990). This gonochoristic species reaches sexual maturity at 3–4 years (~25 cm for males and ~30 cm for females) and reproduces in summer, probably forming spawning aggregations (Fiorentino et al., 2001; Ragonese et al., 2002; Grau et al., 2009). *Sciaena umbra* is a slow-growing and long-lived species, which can live for up to 30 years and exceed 50 cm in total length (Ragonese et al., 2004; La Mesa et al., 2008; Morat, 2009). Dieuzeide et al. (1955) report a maximum length of 75 cm on the Algerian coasts, but individuals larger than 60 cm have become very scarce nowadays. It feeds actively during the night, preying mainly on crustaceans and incidentally on polychaetes, along with benthic fish in the case of the largest individuals (Fabi et al., 2006; Derbal and Kara, 2007; Engin and Seyhan, 2009). During the day, it seeks shelter on rocky substrates among boulders, in crevices or under overhangs, and also in *Posidonia oceanica* seagrass beds, swimming slowly in small shoals.

Due to its biological and behavioural characteristics, and the reduction of its populations along the north-western coasts of the Mediterranean Sea, *S. umbra* is listed in Annexe III (Protected Fauna Species) of the Barcelona and Bern Conventions, and is classified as a vulnerable fish species by the IUCN (Abdul Malak et al., 2011; Bizsel et al., 2011). Although *S. umbra* has never been especially targeted by Mediterranean small-scale fisheries, the decrease of catches is a long-standing trend in France, as indicated by historical sources (Gourret, 1894). Based on FAO catch statistics, Bizsel et al. (2011) report a decline of approximately 70% of the population of the brown meagre in the Mediterranean Sea between 1980 and 2005. However, this species does not benefit from any specific protection outside of MPAs. In coastal zones with favourable habitats, the presence of *S. umbra* is considered as an indication of high environmental quality and fish community richness (Mouillot et al., 2002; Garcia-Rubies et al., 2013). Monitoring its population characteristics in both protected (Harmelin and Marinopoulos, 1993; Francour, 1994; Harmelin, 2013) and unprotected areas exposed to all types of fishing reveals trends over time and attests to the fact that the brown meagre can be a useful bioindicator of professional and recreational fishing pressures (Harmelin and Ruitton, 2007).

The present study was undertaken to assess the brown meagre populations at Scandola in the Regional Natural Park of Corsica (north-western Mediterranean Sea) at a series of sites subject to different reserve protection levels, from totally protected areas to unprotected areas where all fishing activities are allowed, in order to assess the effects of differing fishing pressures on this species. Various studies have been made on the fish communities of *Posidonia oceanica* seagrass beds and rocky reefs in the Scandola MPA in the past (e.g. Harmelin-Vivien, 1984; Miniconi et al., 1990; Francour, 1991, 2000), but no particular attention was devoted to *S. umbra* populations. In this present work, we tested (1) whether the density, size-structure and total biomass of *S. umbra* populations differed with differing levels of reserve protection status; and (2) whether the abundance of brown meagre among zones of contrasting protection status has changed over the past 29 years. The ultimate goal was to provide scientific data for the improvement of protection of this highly vulnerable species.

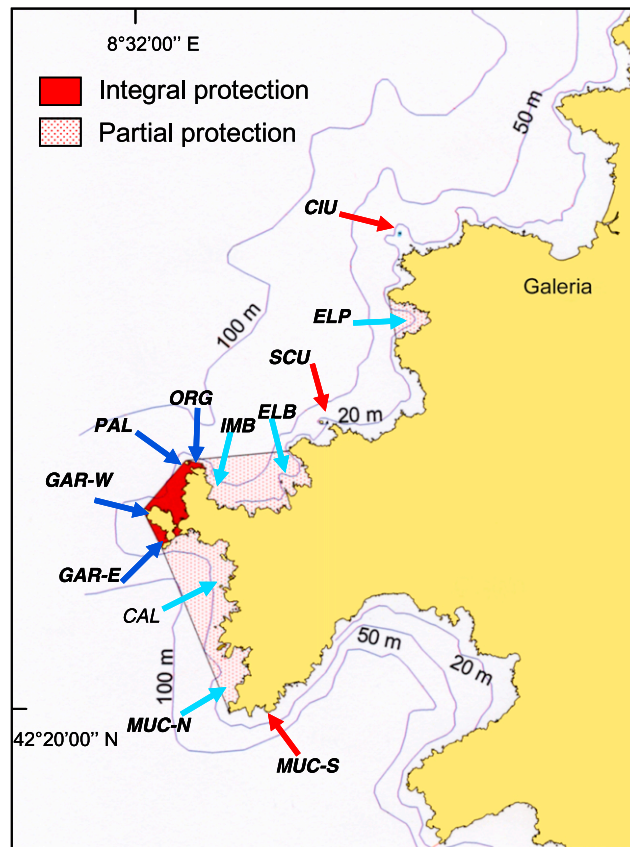
## 2. Methods

### 2.1. Study area

Founded in 1975 at a site recognized as World Heritage by UNESCO, the Marine Reserve of Scandola (590 ha) is one of the oldest Mediterranean MPAs and benefits from well-enforced protection measures (Gabrié et al., 2012). It includes a no-take area or integral reserve (IR: 72 ha), where most human activities (including fishing, diving, and boat anchoring) are prohibited, and partially protected areas or buffer zones (BZ: 518 ha), where professional fishing activities only are allowed under certain conditions (i.e. using small boats with low-powered engines and traditional fishing methods). In unprotected zones (UP) outside the MPA, all types of professional and recreational fishing are allowed, including spearfishing. The brown meagre was surveyed at Scandola during July–August 2012 (25/07/12–03/08/12), at 12 sites subject to the three differing protective management levels (Fig. 1). Four sites were located inside the integral reserve, five sites in the buffer zones, and three sites in unprotected zones (Table 1).

### 2.2. Data collection

Fish surveys were conducted by underwater visual censuses from the surface down to 35 m depth in habitats similarly available in the three zones, i.e. *P. oceanica* seagrass beds, rocky reefs, or a mixture of these two habitats. Censuses



**Fig. 1.** Locations of sites investigated for the *Sciaena umbra* survey at Scandola (Corsica) according to protection level. Site codes are indicated in Table 1. Dark blue arrows: sites in no-take totally protected zone (IR); light blue arrows: sites in partially protected zones (BZ); red arrows: sites in unprotected fished zones (UP).

**Table 1**

Number of transects per site and protection status at Scandola, and number of *Sciaena umbra* observed. Total numbers of transects and fish per protection level are indicated in *italics*.

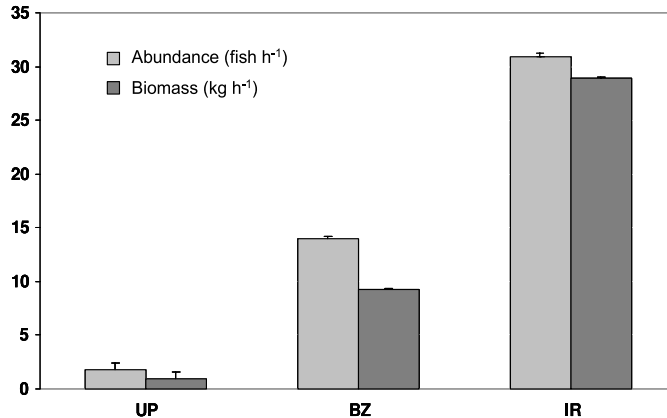
Protection level	Site	Site code	Nb transects	Nb <i>S. umbra</i>
Integral reserve (IR)	Gargalu-W	Gar-W	50	114
	Gargalu-E	Gar-E	83	80
	Les Orgues	Org	13	27
	Palazzu	Pal	24	216
<i>Total IR</i>			<i>170</i>	<i>437</i>
Buffer zone (BZ)	Muchilina-N	Muc-N	4	18
	Cala di Ponte	Cal	49	56
	Imbuttu-Ficaccia	Imb	60	121
	Elbu-Dromadaire	Elb	41	29
	Elpa Nera	Elp	59	24
<i>Total BZ</i>			<i>213</i>	<i>248</i>
Unprotected zone (UP)	Muchilina-S	Muc-S	46	21
	Sculietti	Scu	47	1
	Ciuttone	Ciu	56	0
<i>Total UP</i>			<i>149</i>	<i>22</i>

were performed by well trained scientists following the standardized method used in other Mediterranean MPAs for the assessment of *S. umbra* populations (Harmelin and Marinopoulos, 1993; Harmelin and Ruitton, 2007). Brown meagre individuals observed were recorded over 5 min intervals at a constant depth along 15 m wide and 50 m long transects, leading to a mean surveyed surface area of 750 m<sup>2</sup> per transect. The number of transect surveys carried out per site was determined by the overall site size.

**Table 2**

Percentage of occurrence (% O), mean  $\pm$  SD abundance (fish 750 m<sup>-2</sup>) and mean biomass (g 750 m<sup>-2</sup>) of *Sciaena umbra* per transect according to protection level at Scandola. Results of Kruskal–Wallis post-hoc tests (KW) are given, different letters indicating significant differences of means ( $p < 0.05$ ). IR = integral reserve, BZ = partially protected buffer zone, UP = unprotected area.

Protection level	% O	Abundance (fish 750 m <sup>-2</sup> )	KW	Biomass (g 750 m <sup>-2</sup> )	KW
IR	21	2.57 $\pm$ 7.38	a	2409.3 $\pm$ 7707.1	a
BZ	18	1.16 $\pm$ 3.94	ab	769.0 $\pm$ 2543.5	ab
UP	4	0.15 $\pm$ 1.26	b	82.7 $\pm$ 659.8	b



**Fig. 2.** Mean ( $\pm$  SE) abundance and biomass of *Sciaena umbra* at Scandola according to protection level. IR = integral reserve, BZ = partially protected buffer zone, UP = unprotected zone.

The size (total length, TL in cm) of each brown meagre observed was estimated (with an accuracy of 1 cm for fish  $\leq 20$  cm TL and 2 cm for fish  $> 20$  cm TL) and recorded, along with the depth of encounter and habitat type. Underwater photos and videos were used to assist in the assessment of the size of *S. umbra* shoals, which exceeded 30 individuals at some protected sites. The estimated weight of each fish ( $W$  in g) was obtained using the length–weight equation established for the brown meagre near Calvi (NW Corsica), close to Scandola:  $\text{Log}W = 2.62 \text{Log}TL - 3.74$  (Culioli, 1986), as geographical variations in growth have been recorded (Grau et al., 2009). To track long-term effects of reserve protection on the *S. umbra* population at Scandola, we compared our recent data with earlier data obtained from comparable visual surveys of fish communities on 50 m long transects performed at the same sites in 1983, eight years after the establishment of the MPA (MHV and JGH, unpublished data).

### 2.3. Data analysis

Differences in mean fish density, mean fish size and mean fish biomass according to protection level were tested by one way non-parametric Kruskal–Wallis ANOVAs, as the data were not normalized, followed by appropriate post-hoc tests where differences were significant. The influence of depth and habitat type on the abundance and size of the brown meagre was tested using linear regressions. Differences in mean density at each site between 1983 and 2012 were tested by non-parametric Man–Whitney U tests.

## 3. Results

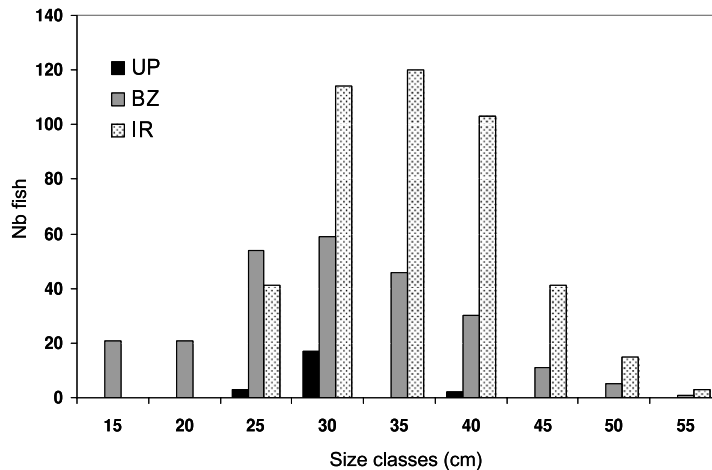
### 3.1. Effects of protection level on abundance and biomass

A total of 532 transect surveys were undertaken, 32% in IR, 40% in BZ and 28% in UP (Table 1). Of the total number of *S. umbra* recorded (707), 62% were observed in IR, 35% in BZ and only 3% in UP. The percentage of occurrence in the transects, and mean abundance and mean estimated biomass of the brown meagre all increased with increasing protection level (Table 2). Mean abundance and biomass were significantly higher in IR than in UP (Kruskal–Wallis  $H > 22.1$ ,  $p < 0.001$  for both), while those parameters recorded in BZ were intermediate, but did not differ significantly from either of the other two. The mean abundance of *S. umbra* was higher by a multiple of 7.9 from UP to BZ, and by 17.4 from UP to IR. For estimated biomass, differences were still higher, with mean *S. umbra* biomass being higher by a multiple of 9.3 in BZ and 29.3 in IR, compared to UP, testifying to the beneficial effect of reserve protection for this vulnerable species (Fig. 2).

**Table 3**

Mean  $\pm$  SD individual size (TL cm), mean individual weight ( $W$  g) and mean size of shoals (fish number per shoal) of *Sciaena umbra* at Scandola according to protection level. Results of Kruskal–Wallis post-hoc tests (KW) are given, different letters indicating significant differences of means ( $p < 0.05$ ). IR = integral reserve, BZ = partially protected buffer zone, UP = unprotected area.

Protection level	Fish length (TL cm)	KW	Fish weight ( $W$ g)	KW	Shoal size (fish shoal <sup>-1</sup> )	KW
IR	34.9 $\pm$ 4.1	a	937.3 $\pm$ 453.1	a	12.1 $\pm$ 12.0	a
BZ	29.1 $\pm$ 7.7	b	660.9 $\pm$ 462.4	b	6.4 $\pm$ 7.3	b
UP	29.6 $\pm$ 3.7	b	560.4 $\pm$ 215.7	b	3.7 $\pm$ 5.6	b



**Fig. 3.** Size structure of *Sciaena umbra* population at Scandola according to reserve protection level (total length (TL) of fish recorded by UVC). IR = integral reserve, BZ = partially protected buffer zone, UP = unprotected zone.

### 3.2. Effects of protection level on population size-structure and behaviour

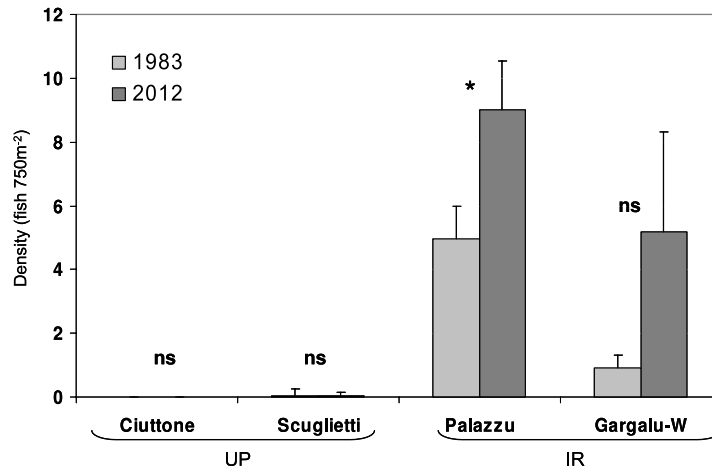
Individual mean size ( $H = 84.6$ ,  $p < 0.001$ ) and estimated weight ( $H = 84.7$ ,  $p < 0.001$ ) of *S. umbra* were both significantly higher in IR than in BZ and UP (Table 3). The shoal size was also significantly larger in IR, with mean shoals comprising 12 individuals in IR compared to fewer than 4 in UP ( $H = 12.9$ ,  $p = 0.002$ ). The size structure of the brown meagre population also differed with protection level, with a higher abundance of larger individuals in IR and of smaller ones in BZ (Fig. 3). However, the median size was generally fairly similar whatever the protection status, being 30 cm in both the UP and BZ zones and 35 cm in the IR zone. Larger individuals (TL > 40 cm) were more frequent in the IR zone (13.5%) than in the BZ zone (6.5%), and were absent from the UP zone. The smallest individuals (TL < 25 cm) were recorded only in the BZ zone, where suitable habitats for juvenile and young adult brown meagre were more abundant. In addition, the behaviour of *S. umbra* differed notably with the protection status of the sites. In IR and BZ, the brown meagre swam slowly in large shoals without any fear of divers, while the individuals seen in UP rapidly sought shelter.

### 3.3. Effects of depth and habitat

No correlation was found between the abundance of *S. umbra* and depth of transects ( $R^2 = 0.004$ ,  $p = 0.588$ ). The brown meagre was observed in various habitats: *P. oceanica* seagrass beds, boulder zones, rocky substrates with overhangs and crevices, or a mix of these habitat types. While rocky areas and large boulders were more frequently found in deeper water than the seagrass beds, no correlation was found between the numbers ( $R^2 = 0.020$ ,  $p = 0.205$ ) and mean sizes ( $R^2 = 0.0040$ ,  $p = 0.579$ ) of individuals and habitat types. No correlation was found between fish size and depth in IR ( $R^2 = 0.005$ ,  $p = 0.135$ ) and UP ( $R^2 = 0.125$ ,  $p = 0.106$ ), while a slight but significant increase of *S. umbra* size with depth was observed in BZ ( $R^2 = 0.050$ ,  $p = 0.0003$ ).

### 3.4. Long-term change

In 1983, as in 2012, the abundance of *S. umbra* was significantly higher in IR than in UP (Fig. 4). At the two sites located in UP, either no or only a very few brown meagre were observed in both 1983 and 2012 surveys, with no significant change in the intervening 29 years. By contrast, a conspicuous increase in *S. umbra* abundance was observed at the two survey sites located in IR. However, the mean density was not significantly different between years at one of these site (Gargalu-W) due to the high variance of the data linked to the uneven spatial distribution of this species, which aggregated in large groups at a few sites in 2012 ( $U = 212.3$ ,  $p = 0.533$ ). The total number of *S. umbra* was higher by a multiple of 1.8 at Palazzu (from



**Fig. 4.** Mean (+ SE) abundance of *Sciaena umbra* recorded at sites located in the integral reserve (IR) and unprotected zones (UP) of Scandola in 1983 and 2012.

119 to 216 fish) and of 5.7 at Gargalu-W (from 20 to 114 fish) after this 29 year period, indicating a continuous long term effect of protection on this fish species.

## 4. Discussion

### 4.1. Effects of protection, habitat and fish behaviour

The census of *Sciaena umbra* populations in unprotected (UP), partially protected (BZ) and totally protected (IR) zones at Scandola (Corsica, NW Mediterranean) demonstrated that the abundance and size of this iconic and vulnerable fish species conspicuously increased with reserve protection level and the duration of protection. An increase in fish abundance and biomass (linked to increased individual fish size) in well enforced totally protected MPAs is a general and well-documented pattern, particularly in the Mediterranean Sea (e.g. Francour, 1994; Harmelin-Vivien et al., 2008; Guidetti et al., 2010, 2014; Coll et al., 2013, among many others). Large individuals, particularly in the case of females, mean more productive reproducers, a higher production of good quality eggs and thus surviving larvae, and a greater reseeded of surrounding zones due to the “spillover effect” (Gell and Roberts, 2003). However, assessment of the effectiveness of partial protection is less well-documented and depends on the type of ecosystem, the species involved, and the types of fishing and other protective regulations (Francour, 1991; Mosquera et al., 2000; Harmelin-Vivien et al., 2008). It is generally concluded that partial protection is not adequate to restore community biodiversity and full ecosystem function in marine systems (Sciberras et al., 2013; Guidetti et al., 2014). However, it could be an effective means to enhance populations of species targeted by fisheries or particularly vulnerable species such as large predators (Mosquera et al., 2000; Prato et al., 2013; Hackradt et al., 2014). Partial protection is also more acceptable to professional fishermen operating under specific management rules than total protection (Guidetti and Claudet, 2010; Sciberras et al., 2013). At Scandola, we observed a higher abundance of *S. umbra* in partially protected zones than in unprotected ones, but at a lower level than in the integral reserve. These results thus indicated the possibility of a partial recovery of the brown meagre population with more appropriate regulation of ongoing professional fishing.

Large predatory fish such as the brown meagre and the dusky grouper benefit particularly from protection from fishing, with a higher abundance inside MPAs, but exhibit generally limited spillover (exportation of individuals outside these MPAs) due to their social behaviour and sometimes their habitat requirements (Garcia-Rubies et al., 2013; Hackradt et al., 2014). *Sciaena umbra* presents a daytime resting and a nocturnal foraging pattern of activity. During the day, it swims generally quietly in small shoals near rocky shelter or in *Posidonia* meadows, and disperses at night, probably to nearby areas to feed on macro-benthic invertebrates, and especially crustaceans, which may emerge more often at night (Harmelin, 1991; Fabi et al., 2006). This behavioural pattern is common among tropical nocturnal predators that feed on crustaceans, such as haemulids and lutjanids (Hitt et al., 2011). If the daytime site fidelity of the brown meagre seems to be corroborated by underwater observations, there is a lack of data on its nocturnal behaviour and the spatial extent of its nocturnal movements. The distribution of the brown meagre is highly aggregative, particularly in specific diurnal resting sites (Harmelin and Ruitton, 2007). This results in a high variability in the data recorded by visual censuses, as observed in the present study. We also observed that the number of individuals in shoals was larger in IR than in UP, indicating an effect of protection on the tendency of *S. umbra* to aggregate. Thus, appropriate monitoring of the brown meagre population would involve combining extensive observation along the coast to look for the expected extension of its spatial distribution due to increased protection, and regular monitoring of particular favourable sites to determine their carrying capacity (Harmelin and Ruitton, 2007; Harmelin, 2013). The expected seasonal displacement of individuals for breeding aggregation should also be better

documented, as little is known of the reproductive movements of the brown meagre (Fiorentino et al., 2001; Grau et al., 2009; Picciulin et al., 2013). Such movements could mitigate the effect of reserve protection if individuals leave MPAs seasonally, becoming again vulnerable to fishing.

#### 4.2. Impacts of professional and recreational fishing

The brown meagre, while not very abundant, is a regular and valuable target of artisanal fisheries in the north-western and central Mediterranean Sea (Morales-Nin et al., 2005; Cadiou et al., 2009). Its exploitation by professional fishermen is more intensive in Corsica, where it is more common than on the continental French coasts, but this does not result in sizeable catches there (Culioli, 1986; Rocklin et al., 2011). At Scandola, *S. umbra* ranks only 20th in biomass in the artisanal fishery catches, and is more frequently caught there during autumn (Le Diréach et al., 2011; Cottalorda et al., 2014). However, the brown meagre has long been considered a prized trophy fish by spearfishers (Harmelin, 1991, 2013; Font et al., 2012). Spearfishing is recognized as one of the most popular recreational fishing activities on the Mediterranean coasts (Coll et al., 2004; Morales-Nin et al., 2005; Lloret et al., 2008; Rocklin et al., 2011), and the brown meagre appears to be one of the most highly targeted species by fishers using this highly selective fishing method (Font et al., 2012). *Sciaena umbra* is ranked fifth in spearfishing catches in both the Balearic Islands (Coll et al., 2004) and in the Cap Creus MPA (Lloret et al., 2008) in those areas where this fishing practice is allowed. In the Bonifacio Strait Natural Reserve (South Corsica), the effect of spearfishing regulation on local fisheries was demonstrated by Rocklin et al. (2011): the closure of 15% of the MPA surface area to spearfishing resulted in a 60% increase in catches for artisanal fisheries eight years after its implementation. The brown meagre was one of the fish species which responded most positively to this spearfishing ban, indirectly demonstrating its high vulnerability to this type of fishing (Rocklin et al., 2011). At Scandola, *S. umbra* exhibited an 8 times higher abundance in partially protected areas where professional fishing was allowed, than in totally unprotected zones where all types of professional and recreational fishing, including spearfishing, were permitted. Thus, it could be reasonably hypothesized that the low density of *S. umbra* in UP and its lack of increase there since the foundation of the reserve was mainly due to intensive spearfishing and also other types of fishing in this region. Shoaling during the diurnal resting period is interpreted as a way to mitigate predation risk (Hitt et al., 2011). However, this pattern of behaviour, along with a calm attitude, makes the brown meagre highly vulnerable to spearfishing (Coll et al., 2004; Morales-Nin et al., 2005; Lloret et al., 2008; Rocklin et al., 2011; Font et al., 2012), as is also widely documented in the popular spearfishing literature.

#### 4.3. Importance of long term surveys

While we did not find any difference in *S. umbra* abundance in fished areas between 1983 and 2012, we recorded a conspicuous increase in its abundance in the no-take integral reserve. The few long term surveys conducted in Mediterranean MPAs, such as at Port-Cros (Harmelin and Ruitton, 2007; Harmelin, 2013), the Medes Islands (Garcia-Rubies et al., 2013) and Scandola (Francour, 1991, 2000), all indicate that the recovery of such fish populations is a long term process. Garcia-Rubies et al. (2013) demonstrated that the time required for full recovery of a fish population is highly dependent on the size and age that the species can reach, and depends also on its home range and patterns of behaviour. They estimated that the carrying capacity of the brown meagre biomass in the Medes Islands might only be attained after ~50 years of full protection. In Port-Cros, the abundance of *S. umbra* is still increasing after 50 years of protection, and this increase has been particularly conspicuous during the last 10 years (Harmelin, 2013). However, some professional fishing (using trammel nets) is allowed at Port-Cros, probably slowing the recovery process, although the brown meagre is not particularly targeted nor caught by local fishermen there (Cadiou et al., 2009). The time required for the brown meagre population to reach its carrying capacity at Scandola probably also exceeds half a century though any accurate estimation of this would require recurrent surveys. The slow recovery process of *S. umbra* populations may be related to its probably low reproductive and demographic dynamics. Unfortunately, knowledge of the brown meagre's recruitment intensity, which could provide precious information on the patterns of progression of its population growth, is virtually nil, as juveniles are highly cryptic and only very seldom observed (Francour and Le Direac'h, 1994).

#### 4.4. Implications for fisheries policy and management

On the basis of the factors evidenced in the present study and owing to the commitment of the Groupe d'Etude du Mérou ([www.gemlemerou.org](http://www.gemlemerou.org)), a temporary status of partial protection of the brown meagre *S. umbra*, including a ban on spearfishing and hook-and-line recreational fishing, has been adopted for the French Mediterranean coasts since January 2014 (Prefectoral orders n° 2013357-0002 for Corsica and n° 2013357-0007 for continental coast). However, this moratorium has been established for five years only and its renewal must be scientifically defended if the recovery of *S. umbra* populations in the north-western Mediterranean, as already observed for the dusky grouper (Harmelin, 2013), is to be hoped for. The lack of good historical records precludes a full understanding of the impact of human activities, introduced species and climate change in the Mediterranean, but they are a prerequisite for any accurate estimation of the carrying capacity of the marine ecosystems there (Coll et al., 2012; Sala et al., 2012).

## 5. Conclusion

In conclusion, we have shown that the vulnerable fish species *S. umbra* is particularly responsive to reserve protection level, and thus most likely to fishing pressure and practices. Abundant populations with a well-balanced size structure occur in no-take zones of MPAs, while these parameters are drastically reduced outside these zones in unprotected areas, where fewer and generally smaller and more timid individuals are encountered. Partial protection (no recreational fishing, adequate regulation of professional fishing), which is better accepted by professional fishers than total protection, might allow *S. umbra* to maintain relatively abundant and balanced populations, although at a lower level than in fully no-take zones. The banning of spearfishing, the most damaging and selective type of fishing activity for this species, and also recreational hook-and-line fishing, is a first step towards the replenishment of *S. umbra* populations along the north-western Mediterranean coasts of France and elsewhere. This study also shows the importance of recurrent monitoring surveys of such vulnerable fish species inside and outside MPAs in order to estimate the time needed for full population recovery, to assess the carrying capacity of coastal ecosystems, and to provide conservation managers with an assessment of the effects of their actions with regard to the effectiveness of fishing regulations.

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