Ecological and fishery responses to the populations management of the brown meagre (*Sciaena umbra;* Linnaeus, 1758) in the Bonifacio Strait Natural Reserve (NW Mediterranean, France)

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Abstract

Both spearfishing and traditional fishery target the brown meagre (*Sciaena umbra*, Linnaeus, 1758). With the current state of overexploitation, MPAs were created as tools for both conserve biodiversity and manage fisheries as sustainable activities. In the Bonifacio Strait Natural Reserve, mean biomasses recorded *in situ* and catches records of artisanal fishery since 1995, have been used to study the temporal evolution of the brown meagre populations in a north western Mediterranean Marine Protected Area. The increase of biomasses found in the whole of the area is higher in regulated zones than in fished areas. Spearfishing seems to have an important impact on these populations and its prohibition positively affect their development. In the other hand, artisanal fishery does not seem to have a great impact on this species because of the close biomasses evaluated in zones where it could be practiced and in areas where it is forbidden, and the continuous increase of catches observed in traditional nets. With this increase of the average biomasses and the mean catches shown over time, firstly, limited spearfishing pressure permits to enhance brown meagre stocks in MPAs; secondly, the artisanal fishery seems to take advantage of spillover and larvae exportation and it has to be incorporated into the management of MPAs as a sustainable activity, in order to maintain this traditional Mediterranean heritage. Moreover, the abundance of *Sciaena umbra* could be used as an indicator of fishing pressure exerted on fishes stocks.

Keywords: Catch per unit effort - Biomass - Visual census – Artisanal fishery – Spear fishing – Conservation – MPA management

1. Introduction

Nowadays, due to pollution and overexploitation, some species became rare, others are endangered (Abdulla et al., 2008; FAO, 2008). The world fisheries still critically increase in the last years. The FAO (2008) reported that the total world fishing production in 2006 were about 92 million of global

capture fisheries production (marine and inland waters). The overall review of the state of marine fishery resources indicates in 2007 that 19 percent of the stocks were overexploited, 8 percent were depleted and 1 percent was recovering from depletion. This severe overexploitation is a critical factor of actual biodiversity crises as defined by the scientific community. The increasing anthropogenic pressure is affecting the richness and the complexity natural world with the acceleration of its declining rate. However, capture fisheries are responsible for a significant share of the food supply for human consumption. They provide jobs and incomes for millions of people worldwide and have an important role in the economy of many countries (FAO, 2008).

In the Mediterranean Sea, the fishing fleet can be described as an “artisanal” or “coastal” activity. Artisanal fishery consists of small-scale boats, working closed to the coast, using traditional methods (Miniconi, 1994; Colloca et al., 2004). It represents a fleet consisted of small-capital exploitation with often fishermen’s property. The 12 million of people that it employed catch about 30 million tonnes of fish per year for human consumption, as opposite to the only 0.5 million of industrial fishery jobs equally catching the same amount of resource; it also induces less discharge of oil; furthermore, fish and other sea life discarded are much less important (Jacquet & Pauly, 2008). It contains a large number of little ships based on a multitude of modest ports, some of artisanal vessels are mechanized but most used traditional fishing gear, such as small nets, traps, lines, spears and hand-collection methods. There are many variations from an area to another, in term of fishing activities, mostly because of social, economical and historical contexts of these countries (Farrugio et al., 1993).

Another important fishing activity still increased each year, the recreational fishery. It encompasses angling and spearfishing. Recent studies take into account the impact of this type of leisure on fish stocks. It could have an important impact on the populations of rocky benthic fish (Lloret et al., 2008a), coastal fish communities (Lloret et al., 2008b) and on the most sedentary species in the *Posidonia oceanica* meadows (Cardona et al., 2007). According to Coll et al. (2004), this type of

fishing is really selective and productive. They have ever demonstrated that spearfishing affects the mean density and size of *Sciaena umbra*.

Regarding these destructions, a general awareness allowed the creation of Marine Protected Area (MPAs) as a tool for conserving and managing marine and coastal ecosystem (Roberts and Polunin, 1991; Francour et al., 2001; Roberts et al., 2001; Claudet et al., 2008; Garcia-Charton et al., 2008; Harmelin-Vivien et al., 2008). In MPAs, the will to conserve biodiversity was applied by limitation of individuals caught and fishing gear, instauration of closed seasons and temporary area closure (Francour et al., 2001; Cooke and Cowx, 2006; Worm et al., 2009). However, there is a recent global awareness of the importance to maintain the artisanal fishing activity, traditionally rooted in coastal populations, which supplies locally employment (FAO, 2008; Seytre and Francour, 2008; Worm et al., 2009; Guidetti et al., 2010) in order to include local people in marine reserves. This important fact takes part in the principal actions on the BSNR. There is an agreement between fishermen and the administrators of the BSNR, with the exception of such local zones, artisanal fishermen can practice their activity all over the reserve and an annual partnership allow the study of the fish stock evolution per year instated since 1992 in Lavezzi Islands Marine Reserve (Culioli, 1994), and extended to the whole of the BSNR in 2000.

This study accounts for the evolution of the population density of *Sciaena umbra* counted by the non-destructive Underwater Visual Census method (UVC) and evaluated through the catches from artisanal fishing activities. Changes on brown meagre biomasses could be expected within the BSNR due to fishing regulations. The aims of the present paper were: (1) to bring to light the benefits on brown meagre populations brought to the boundary zones due to the edge effect; (2) to underline the impact of spearfishing prohibition and the consequences that it exercised on catches from artisanal fishing; (4) to show that the creation of different protection levels could enhance artisanal fishery, in order to sustain this local activity.

2. Materials and methods

2.1. Study area.

This study was carried out in the Bonifacio Strait Natural Reserve (BSNR), located in the North-Western part of the Mediterranean Sea, between South Corsica, France, and North Sardinia, Italy (Fig. 1). Its marine surface is about 80 000 ha and includes rocky and sandy bottoms and beds of *Posidonia oceanica.* The BSNR was created in 1999 and is currently managed by the Corsican Environment Office (France). It encompassed two existing reserves: the Lavezzi Islands Natural Reserve and the Cerbical Islands Natural Reserve, both created in 1982. Its creation is the result of a long process including the Fishery Cantonment of Bonifacio, the two existing reserves and different areas included into measures of protection.

The BSNR is characterized by several controlled perimeters, with four Zones of Reinforced Protection (ZRP) including 12,000 ha and five No-Take Zones (NTZ) representing a surface about 1,200 ha. In Zones of Reinforced Protection (ZRP), spearfishing and recreational coast angling are forbidden but artisanal fishing can be practiced for fishermen having a particular license delivered by the senior Corse government official. In No-Take Zones (NTZ), all fishing methods and scuba diving activities are prohibited. The rest of the area not included in these two types of protection are fishing zones or Free Exploited Zones (FEZ), recreational and professional fisheries are authorized but also regulated. Into the whole of the BSNR, the use of nets with a mesh size smaller than 62 mm (corresponding to 9 nodes for 25 cm long) was prohibited by the Bonifacio Jurisdiction and then written into the decree of the creation of the BSNR. For spearfishing activities, minimum landing sizes were attributed for certain species and the totally number of fishes daily caught do not have to exceed 8 per fishermen. More details are available about the legislation on the website http://www.parcmarin.com/.

2.2. Artisanal Fishery

Fishermen mainly used trammel nets and boats that were often smaller than 12 meters (Culioli, 1994; Miniconi, 1994). Other fishing activities are also practised within the BSNR such as long lines fishing, rarely traps, and collection of sea urchins. The Bonifacio Jurisdiction contain on average 35 licences a year. Trammel nets are generally set for 24h at depths ranging from 20 to 60 meters, and mesh size used for fish varies from 7 to 9 nodes for 25 cm long.

In the context of the decline of traditional fisheries into the Mediterranean Sea, it seems to be important and of top priority to associate the artisanal fishermen at the benefits of the protection induced by the creation of MPAs for a sustainable development of the local fishery activity. The Lavezzi Islands Natural Reserve started a partnership in 1992 between fishermen and scientists that was extended at the whole of the BSNR in 1999. The collaboration between the managers of the BSNR and the fishers of the Bonifacio Jurisdiction permits different scientific studies led by the BSNR, mostly on marine organisms as the urchins, the spiny lobster and on fishes exploited communities. The important relations built between fishermen and scientists induced on-board recorded for each year, by the administrators of the BSNR and to bring to light the evolution of catches from artisanal fishing. With this study concerning the exploitation of fishes stocks from artisanal fishery, the ichthyologic marine fauna of the Bonifacio Strait was evaluated by Under Visual Census method since 1992. These long term studies permit to the managers of the BSNR to have a reliable evaluation of the health of the ichthyologic littoral communities.

2.3. The species.

The brown meagre, *Sciaena umbra* (Linnaeus, 1758), is a symbolic species of the management of a Mediterranean Marine Protected Area (MPA), and thus an emblematic species of the Bonifacio Strait Natural Reserve (BSNR). Really searched by divers, it is also particularly targeted by spearfishing and artisanal fishing activities, representing a high economical and gastronomic value

(Miniconi, 1994).Very popular for the gustative qualities of its flesh (Harmelin, 1991) it can be considered as endangered by the human predation, the brown meagre is an easy prey for spearfishers, mostly because of its calm diurnal behaviour (Chauvet, 1991) and its easily accessible shelters. It thus was really impacted by the recent development of this leisure. Due to artisanal, semi-industrial and recreational fishing, the stock of brown meagre in the Northern Mediterranean Sea has been considerably reduced and the North African stock seems to be currently over-exploited including this species into news propositions for protection measures (Fischer et al. 1987; Chauvet, 1991). Currently, it has been censused, in some MPAs, exclusively within the reserve, were fishing is prohibited (Garcia-Rubies and Zabala,, 1990; Francour et al., 2001; Rius, 2007).

Chao (1986) and Fischer et al. (1987) described the brown meagre as a body rather short and deep fish, strongly arched with a mouth inferior, nearly horizontal. Its colour varied from dark brown to dark black with metallic or gilt reflects and individuals have a common size from 20 to 35 cm. It is distributed along Eastern Atlantic coasts from the English Channel to the South of Senegal, and throughout Mediterranean Sea, Black Sea and Sea of Azov. It is currently observed in inshore waters from 20 to 180 meters, on rocky and sandy bottoms. It can enter in estuaries and it has a nocturnally activity. It feeds on small fishes and crustaceans. Its spawning period begins from March until August. Chauvet (1991) reported a gregarious fish presenting a calm behaviour and it can be observed immovable above the bottom mostly because of its remarkable buoyancy control. Both sexes increase rapidly in length until attaining sexual maturity at about three years of age, after which females reached a higher asymptotic length than males (La Mesa et al., 2008). Written on the Appendix 3 of the Bern and Barcelona Conventions, *Sciaena umbra* also takes part of the red list of vulnerable species in France. Into the Bonifacio Strait Natural Reserve (BSNR), it is protected by the prefectural order of the 1st October 2004, limiting the minimum size of catch at 30 cm for spearfishermen.

2.4. Data Collection.

Surveys were conducted, first by Underwater Visual Census (UVC) method from 1995 to 2007 (Culioli, 1995), second by accounts on traditional fishing catches using trammel nets (Culioli, 1994; Mouillot et al., 2002; Mouillot et al., 2007; Mouillot et al., 2008;) between 2004 and 2008.

Underwater Visual census data: Starting in 1992 in the Lavezzi Islands Natural Reserve, the Underwater Visual Census (UVC) method described by Camus et al. (1987) and Bouchereau et al. (1989) consists on a counting of 21 targets species, during 7-8 minutes on a fixed point delimited by a fictive rope creating a 10.75 meters diameter circle.

2132 fixed points (detailed in the Table 2) were listed between 1995 and 2007 on 18 different stations within the BSNR detailed in the Table 1.

The total weight of each individual was estimated using size class correspondences: P corresponding to little individuals, M corresponding to middle individuals and G for large.

Fishing data: From 2004 to 2008, during warm period (between April and September), individuals caught by professional fishermen were randomly on-boat recorded by scientists with the consent of fishermen. 913 fishing landings (detailed in the Table 2), each representing a net, were sampled from the boats in 7 ports (Porto-Vecchio, La Chiappa, Santa Giulia, Sant'Amanza, Piantarella, Bonifacio, Pianotolli-Caldarello). All individuals caught were measured and their total weight was estimated using size class correspondence. Other collected information as the fishing area and the depth, the duration of hauled, the type of gear employed, their mesh size, the number of pieces of net per fishing sets were listed. Unit efforts (UE) were evaluated representing the number of pieces of 50 meters of nets per fishing day (24 hours). Thus Catch Per Unit Effort (CPUE) was computed, expressed the totally catches in grams during a fishing event: per 50 meters of nets and per 24h ($g\ p^{-1}\ d^{-1}$).

Data analysis. The brown meagre, was extracted from the global data: means of biomasses and CPUE were estimated for both Underwater Visual Census and Fishing data. The average biomass,

expressed in grams/are, was calculated for each fixed point evaluated in the Underwater Visual Census data. As far as fishing data were concerned, CPUE, in grams/unit effort, were evaluated. The CPUE represents the wet weight (grams) per number of pieces of 50 meters of fishing net per day. Data were analysed by analysis of variance (ANOVA) performed using Statistica 5.5. Significant differences were identified using Least Significant Difference (LSD) test.

3. Results

3.1. Biomasses underwater visual censused, trend between 1995 and 2007

Biomasses were evaluated on 1292 fixed points between 1995 and 2007. 208 of these samples were recorded in the FEZ, 219 in the ZRP created in 1999, 452 in the ZRP created in 1982, 232 in the NTZ created in 1999 and 181 in the NTZ created in 1982 (Table 3).

In the whole of the BSNR, there is a global significant trend to the increase of the average biomass of brown meagre, in the exception of FEZ, between 1995 and 2005.

The Fig. 2 shows that in FEZ, where all fishing methods can be used, the mean biomass was multiplied by 3 in ten years after the creation of the BSNR, increasing from 26 to 76 grams per are between 1995 and 2005. However, these results are not significant (p = 0.59*)* but they revealed a trend to a positive evolution on brown meager stocks. The detailed evolution of mean biomass for FEZ is 26 in 1995, 54 in 2000, 71 in 2002 and 76 grams/are in 2005.

Fig. 3 displays that in ZRP_82 (for zones of reinforced protection created in 1982), the biomasses evaluated evolved from 247 to 2573 grams per are between 1995 and 2007. In NTZ_82 (for no take zones created in 1982), the biomasses increase from 256 to 2455 grams per are between 1995 and 2004. Then, the average biomass was multiplied by 10 approximately in 12 and 9 years respectively. The increase of brown meager biomass in these protected zones is really significant with respectively p about 0.00012 and 0.007.

In ZPR and NTZ created in 1999 (ZPR_99 and NTZ_99), the mean biomass significantly increased from 17 to 1885 grams per are for ZPR_99; and from 558 to 2303 grams per are between 2000 and 2005 for NTZ_99. The significantly *p* corresponding are 0.00019 for the ZPR_99 and 0.032 for the NTZ_99. Then, the biomasses were respectively multiplied by 110 and 4 in 5 years.

In the Fig. 4, the comparison of the mean biomasses calculated for all of the years sampled for each level of protection presents a significant difference, showing the impact of the protection on stocks for spearfishing, and the relative low disturbance from artisanal fishery. The ANOVA revealed 3 groups significantly different from the others. The group 1 represents the FEZ with a mean biomass closed to 46 g/are and the ZRP_99 with an average biomass equal to 624 g/are. The group 2 includes the ZRP_99, the NTZ_82 and the ZRP_99 respectively having 624, 912 and 1147 g/are. The 3 regrouped the NTZ_82, the ZRP_82 and the NTZ_99 with 912, 1147 and 1540 g/are.

The *p* for this comparison of levels of protection is highly significant, reached 3, 6.10^{-7}.

3.2. Biomasses evaluated from fishing data, trend between 2004 and 2008

The number of fishing vessels exploiting the BSNR did not really change since 1995. It was on average closed to 35 for the Bonifacio Jurisdiction. In the same way, the average length of nets used was approximately constant (from 440 to 470 meters of one net). On average, 22 fishermen were sampled a year, representing a ratio of 63 per cent of their total number. Artisanal fishing vessels were spread around 7 little ports from the South Est to the South West of the BSNR. 538 fishery landings were recorded: 154 in 2004, 91 in 2005, 166 in 2006 and 127 in 2008. The fishing season in the BSNR principally occurs from spring to the beginning of august, with a peak in summer, mostly because of the important request from restorers in summer touristic period. During the winter, the fishing activity is low and mainly axed on the collect of urchins. Trammel nets are the fishing gear the most used in this area (87 % of Corsican fishermen used this type of gear, Miniconi, 1994).

The Fig. 5 displays that the mean biomasses of brown meagre caught by artisanal fishermen tend to increase each year. They were multiplied by 11.5 (an increase of 75.7 g biomass per 50 meters of net and per day between 2004 and 2008) in 4 years rising from 7.22 to 82.85 grams per unit effort with some fluctuations each year: 51 for 2005 and 36 g/unit effort for 2006. The corresponding *p* is significant ($p = 0.002$).

4. Discussion

4.1. Effects of protection applied

It is commonly established that there is positive effects of protection in MPAs in term of size, and abundance on fishes. Higher densities, size, biomasses or abundance were recorded in most fish assemblages from samples collected on sites within marine reserves than for samples from non-reserve sites (Bell, 1983; Garcia-Rubies and Zabala, 1990; Roberts and Polunin, 1991; Harmelin and Ruitton, 2007; Rius, 2007; Pérez-Ruzafa et *al*., 2008; Cadiou et *al*., 2009; Forcada et al., 2009; Stobart et al., 2009). These results come to the same conclusion that there are two principal factors affecting the structure of fish population, the first is the "edge-effect" through spillover and larvae exportation (García-Rubies and Zabala, 1990; Russ and Alcala, 1996; Rius, 2007; Forcada et al., 2008; Francini-Filho and Moura, 2008; Goñi et al., 2008; Harmelin-Vivien et al., 2008; Forcada et al., 2009) and the second is the depth (see also Bell, 1983; García-Rubies and Zabala, 1990; Ashworth and Ormond, 2005). In 1991, Roberts and Polunin listed different studies explaining these effects. They underlined that cessation of fishing within an area increases the average sizes of targeted species and this reduced mortality rates should result in an increase in abundance of a stock. More recently, in 2007, Rius noted larger individuals in the Ses Negres MPA than outside the reserve only with three years monitoring. Stobart et al. (2009), demonstrated an augmentation on fish abundance, biomass and average body size during a period of 8 to 16 years after fishing ceased

without reach a stable state and still increases since the institution of protection. These increases were higher inside the non-fished area than in the border fished zones and there is a clear evidence of spillover of fish from the reserve to the adjacent fishery zones. García-Rubies et al. (1990), Pérez-Ruzafa et al. (2008), Cadiou et al. (2009) and Forcada et al. (2009), have revealed the exploited population of fishes significantly responded to the protection with higher biomass inside the protected zones and higher catches into border zones. The brown meagre is a sensitive species of the protection instituted by the BSNR. Harmelin and Ruitton (2007), demonstrating an increase of the brown meagre populations in the Port Cros National Park and an extension of their spatial distribution. Our study confirms this trend for the brown meagre with higher biomasses in zones where fishing activities are regulated. The average biomass and mean CPUE, for both UVC and Fishing data, still increase since the creation of the two pre existing reserves (Lavezzi and Cerbical Natural Reserves) and the BSNR. This augmentation relates the importance of fishing pressure exerted on the populations of *S. umbra* and the positive effect provided by the regulation of fishing activities in these areas.

The comparison of the three types of protection (FEZ, ZRP and NTZ) shows that there is a significant positive impact in the creation of protected zones (ZRP and NTZ, both created in 1982 and 1999) because of their higher brown meagre's biomasses (23 times upper) that those founded in FEZ. The FEZ seem to have significant lower biomasses than protected zones, but they also still slowly increase each year, although spearfishing can be practised in these areas. These zones adjacent to protected areas (ZRP and NTZ) benefit from the increase of brown meagre biomasses thanks to exportation effects from boundary protected zones (according to Forcada et al., 2008; Forcada et al. 2009; and Stobart et al., 2009). The augmentation of *Sciaena umbra* into the BSNR could be due to: (1) protection of brainers stocks (with higher survival rate permitting individuals to reach their sexual maturity); (2) emigration of individuals from protected areas to the closed non

protected area, thus a recolonisation of fished areas (with an increase of CPUE for fishermen); (3) protection of zones of recruitment and larvae exportation.

The boundary zones are transitional zones between protected areas and fished zones, in which spillover increases with the years of protection (Stobart et al., 2009). In NTZ, an increase of the number of individuals could be expected through a limitation of fishing pressure inducing an augmentation of the reproduction rate as well as a higher survival rate. The boundary zones of NTZ, including ZRP and FEZ, benefit on the adult fish spillover and the export of fish eggs through water currents. The spearfishermen (in FEZ) and especially the artisanal fishermen (in FEZ and ZRP) take advantages of this edge effect in term of grow of catches. In this way, maintain "no take zones" where populations can spawn and grow inducing spillover effects and larvae export, seems to have profits for both marine environment, with increase of populations, and for artisanal fishermen, with higher catches without disturbed the recur of fishes stocks.

4.2. Spear fishing pressure

In the Mediterranean Sea, the recreational fishing is far from negligible compared to artisanal fishing (Cadiou et al., 2009). Cooke and Cowx (2004) estimated that the potential contribution of recreational fish harvest around the world may represent approximately 12 percent of the global fish harvest. This activity is now highly developed and pursued by large numbers of people. It is first for pleasure, but also a source of incomes and a supplement of food (Cooke and Cowx, 2006). Jouvenel & Pollard (2001) related that the differences observed between two target-fish (*Sparus aurata* and *Dichentrarchus labrax*) densities and sizes inside and outside a marine reserve area are most probably largely a consequence of mortality due to fishing pressure. Coll et al. (2004) demonstrated that sport fishing and especially spearfishing affect the mean density and size decrease of *Sciaena umbra*. Lloret et al. (2008a) evaluated the total biomass extracted annually by spearfishing in the Cape Creus MPA about 20 tonnes, representing 40 % of the biomass extracted annually by artisanal

fishing (about 50 tonnes). In this sense, spearfishing activities could be considered as competitive with artisanal fishery, both targeted the same resources (see also Lloret et al., 2008b). Morales-Nin et *al*. (2005) underlined that *Epinephelus marginatus* and *Sciaena umbra* are species mainly caught by spearfishers. The dusky grouper *Epinephelus marginatus* is also an emblematic species of the protection applied in MPAs, really impacted by sport fishing activities, and still growing on the Lavezzi Islands Natural Reserve (Culioli & Quignard, 1999) since the prohibition of spearfishing in this area. In this way, as the dusky grouper, an increase of brown meagre stocks could be expected in the BSNR, due to the prohibition of spearfishing activities.

In comparison with Harmelin-Vivien et al. (2008), describing higher fish abundance (1.3 times upper) and biomass (4.7 times upper), in six Mediterranean MPA, with decreasing gradients of fish abundance and biomass across MPA boundaries to fished area induced by export of adults fishes from MPAs to adjacent non-reserve sites; our results show that the average biomass observed only for the brown meagre in zones protected from spearfishing (including ZRP_99, ZRP_82, NTZ_99 and NTZ_82) is 23 times upper than in fished areas (FEZ).

The mean biomass of brown meagre evaluated by UVC method in the ZRP_99 was multiplied by more than 100 between 2000 and 2005, demonstrating the negative impact of spearfishing on this species, and the importance of its prohibition in order to maintain the populations. The comparison between the different levels of protection was significant, excluded the FEZ, where spearfishing can be practiced from the protected areas (ZRP and NTZ). The spearfishing targeting brown meagre adults, mostly just before or at the beginning of their sexual maturity, destroy the brainers stocks. Even if the average biomass into FEZ is lower than in other zones, there is a global low increase. Concerning the spearfishing pressure, 16.5 % of the total surface of the BSNR are protected. The limit size of catches imposed by the legislation (see the presentation of the study area) equals to 30 cm enables the protection of the brainer stock of brown meagre, the sexual maturity being reached at 21 cm for males and at 23 cm for females (Chakroun-Marzouk & Ktari, 2003). However, the low

biomasses observed into the FEZ could not only signify that the brown meagre are less represented, but could be due to a modification on their behaviour (as it was also suggested by Jouvenel & Pollard, 2001, for two spearfishing target-fish species). Effectively, the pressure exerted by spearfishing activity on this species could make it join higher depth (more than 20 meters); they would thus be less observed.

In the BSNR, more than 500 hours of diving permitted to constitute an important data currently knows as one of the most important on the ichthyologic Mediterranean fauna.

The important increase of brown meagre populations within the ZRP (for both created in 1999 and 1982) can be attributed to the one prohibition of spearfishing activities in these zones.

Control spearfishing, really affecting brown meagre's populations, could be a positive tool in order to conserve fishes stocks, as brown meagre; in the other hand, the spearfishing activity was also mostly anchored since older generations and has not to be banned because besides the potential negative effects on coastal fauna, it has positive economic effects on the local economy, since spearfishermen spend a fairly large sum on goods and services directly related to their fishing activities (Lloret et *al*., 2008a; Lloret et *al*., 2008b).

4.3. The sustainability of artisanal fishery in the BSNR

The traditional fishery is characterized by its small size fleet usually practiced by one fisherman, the owner. Most of small fishing vessels are multipurpose and use different types of gear depending on time, season and opportunity (FAO, 2008). The artisanal fishery in Corsica presents an important seasonality, mostly because of the important request of the restorers in summer tourist period. The fishing season usually starts in spring and extends until the beginning of autumn, with an important peak during summer principally access on the lobster and a low activity during the rest of year.

The total number of artisanal fishermen did not significantly change since the beginning of the sample; the fishing effort (mean number of fishermen fishing per day) was approximately constant

also. Certain environmental factors as the weather, the sea conditions, could influence the annual CPUE. Moses et *al.*, 2002 explained that the pattern of seasonal fluctuations in artisanal fisheries catches and CPUE can be attributable to seasonal changes in the hydro climatic conditions. But with these fluctuations, an increase of catches from artisanal fishery in zones close to protected areas could be expected due to direct or indirect reserve effects (see also Abesamis et *al*., 2006; Stelzenmüller et *al*., 2007; Stelzenmüller et *al*., 2008). Russ and Alcala (1996), had interview some fishers fished close to the reserve of the Apo Island explaining that their catch had least doubled after 10 years of protection. Abesamis et *al*. (2006) confirmed this trend with higher CPUE near the Apo Reserve. Mouillot et *al*. (2008) revealed an increase of 25% in the total fish biomass caught by local fishermen inside the BSNR over a period of 10 years (1992 – 2003). This increase also occurs in the whole of the BSNR between 2004 and 2008, fishermen working in FEZ and ZRP but not in NTZ, the average CPUE was multiplied by 11.5 in 4 years with protection. These augmentations are due to gear restrictions and closed areas organized by the BSNR legislation (see also Worm et *al*., 2009). The individuals caught did not seem to be targeted by any mesh size, and the catches sampled were equally distributed over June in August. For the Underwater Visual Census data, the ANOVA regrouped the protected areas (including ZRP and NTZ for both created in 1999 and 2002) into two groups, different from the FEZ. The biomass into ZRP is only 1.4 times upper than in NTZ (for both created in 99 and 82). The closed biomasses founded in these two types of zones which only differed by the practice or not of the artisanal fishery can lead to the conclusion that this activity does not seem to have a negative impact on brown meagre populations because of their continuous increase; these results are in agreement with those occurs by Boudouresque et *al*. 2004 into the Port Cros National Park. Moreover, the mesh sizes smaller than 62 mm being prohibited into the whole of the BSNR, the impact of artisanal fishery on the fishes populations of little sizes has been thus limited.

Then, in Marine Protected Areas, artisanal fishing could be practiced with the intention of conservation (according to Mouillot et *al*., 2007; Worm et *al*., 2009) through catch restrictions, gear modifications and closed areas. In this way, Cadiou et *al*. (2009) described the sustainability of artisanal fishing within the Port Cros National Park (France) using a renewable resource maintaining the social and cultural network and contributing to the local economy without having a negative notable impact on the environment, and its compatibility with the conservation of ecosystem possible with the prohibition of recreational fishing, the banning of trawling and the fishing gears used, among others factors. The local benefits for artisanal fishermen could be due to spillover from protected zones (NTZ and ZRP) to fished zones (FEZ). In this way, Russ and Alcala (1996) already showed the exportation of adult fish from reserve to the adjacent non reserve sites. Kaunda-Arara and Rose (2004), Abesamis et *al*. (2006) explained that the higher CPUE found near the reserve area may result from spillover to the reserve. Goni et *al.* (2008) and Stelzenmüller et *al*. (2008) shown a higher concentration of fishing effort near Fishery Closure boundaries, interpreted as spillover benefits to adjacent fisheries; artisanal fisheries could take advantage on the protection instituted within the BSNR and coastal MPAs can be effective management tool for artisanal fishermen. In this way, fishermen take advantages of the management measures applied within the BSNR since 1999 (mostly because of the spearfishing prohibition) with these high increases of CPUE (as it was already shown Mouillot et *al*., 2007).

It thus seems to be important to integrate this local activity in MPA in order to maintain this tradition (Higgins et *al.*, 2008; Worm et *al*., 2009; Guidetti et *al*., 2010) and to ameliorate the knowledge of the state of fishes stocks (Seytre and Francour, 2008). The partnership associating C$ Corsican fishermen and the managers of the BSNR, first collaboration into a protected Mediterranean space, initiated in 1992 and still being a priority of the BSNR actions, contribute to the knowledge of the artisanal fishing activity and then of the marine environment into the Bonifacio Strait.

4.4. Indicator species as a tool for management

Claudet et *al*. (2006) defined an indicator as a metric that should be sensitive to the effect studied, and from their results, relevant indicators could be at the species level, for example for *Serranus cabrilla* and *Coris julis*. In this sense, the brown meagre, presenting increases of their populations size with limiting fishing activities, but also having an important value for fishermen, could be used as a tool, a biotic indicator to measure the fishing pressure exerted and the state of exploited fishes the BSNR (see also Harmelin et *al*., 1995; Harmelin and Ruitton, 2007; Mouillot et *al*. 2002) and the effectiveness of protection applied.

But, more than an indicator of spearfishing pressure, the brown meagre could be used by the managers as a bio geographic indicator. Indeed, as a species with a Southern affinity, Northern populations can be facilitated by environmental shifts induced by climatic changes. It is an interesting species to be studied in zones where the human impact is limited.

However, the increase of brown meagre could also be influenced by the water temperature. *S. umbra* is a typical species of warmer waters, and could have a higher abundance in zones with higher temperatures. Without any significant increase, the global sea temperature trends to be higher into the Mediterranean Sea and could influence the augmentation of this species (Forcada et *al*. 2009).

4.5. The importance of enforcement

The continuous increase of brown meagre biomasses does not seem to reach any equilibrium and still occurs in the whole of the BSNR (see also Stobart et *al*. 2009). However, the results show a biomass close to 900 g/are for NTZ created in 1982, after 13 years of protection whereas after 6 years of protection for NTZ created in 1999, this biomass tends to reach 1540 g/are. There was an important increase of *S. umbra* for all the zones from 1999. The creation of the BSNR, even if some zones were ever protected, engendered the implantation of an active supervision by the managers,

first necessary action for the ecosystem development (Byers and Noonburg, 2007). This supervision permits a decrease of illegal fisheries and the respect of protection applied. *S. umbra* significantly responded to protection in term of biomass only on high-enforcement reserves (Guidetti et *al*., 2008). Seytre and Francour (2008) suggested that the lack of statistical difference between *Posidonia oceanica* fish assemblages inside and outside the Cape Roux MPA (France) may be because of poaching occurred due to the lack of permanent surveillance (see also, Francour et *al*., 2001). In the BSNR, the enforcement is characterized by an active surveillance, applied all over the protected area, exerted by reserve personnel, coast guards or other marine police forces. These active continuous patrols make the poaching decreasing.

4.6. The management of brown meagre populations

Fishing activities of any kind, whether commercial or recreational, have the potential to affect negatively fish, fisheries and aquatic habitats (Cooke and Cowx, 2006). However this negative effect varies with the type of fishery. Two groups of factors influence the abundance, availability and the sustainable management/development of coastal resources ecosystems: natural fluctuations in the geophysical and hydro climatic forces, and the impact of human activities on the chemical and biological regimes of the coastal environments (Moses et *al*., 2002). Without acting on the first one, the study and the management of the second one with effective fishing regulation (see also Morales-Nin et *al*., 2005) are necessary in the implantation of a sustainable development of the continuity of the human activities including fisheries and leisure activities. While in some areas, fisheries and conservation may be seen as incompatible activities, it is widely recognized that both are fundamental elements of sustainable development (FAO 2008, Worm et *al*., 2009). This study clearly underlines the reserve effect exerted on *S. umbra* populations. Listed as an endangered species (Fisher et *al*. 1987; Chauvet, 1991) observed more and more often exclusively within protected areas (Garcia-Rubies and Zabala, 1990; Rius, 2007), it is however in augmentation in the

BSNR. It was demonstrated by counting from Underwater Visual Census method (with increasing biomasses) but also confirmed with the increases of CPUE into the fishermen nets. The one prohibition of spearfishing produced this edge effect showing the important impact of this leisure on brown meagre stocks, but also on artisanal fisheries. The managers of the BSNR have to preserve marine resources and the cultural patrimony that the artisanal fishery represents too. These regular studies and data collections are necessary and justify the importance of the collaboration and its sustainability between fishermen and managers.

The recreational fishing activity and the artisanal fishery have not been banned inside the BSNR but only excluded from certain protected zones. The benefits generated by the NTZ for boundaries areas could permit to maintain these two activities without which enter in the competition.

Conclusion

Many species highly targeted by fishing activities of any kind saw their populations decreasing (FAO, 2008). The brown meagre both targeted by spearfishing and artisanal fishing had decreased in the last years. The professional fishing of this species, not really occurring in the North of the Mediterranean Sea, is, in the other hand intense in the South part of this one (Harmelin, 1991).The caught of little individuals, not having attained their sexual maturity, could have a negative impact on its stocks (Culioli, 1994). In the context of the will to conserve biodiversity and the current increase of the creation of MPAs, these populations took back their growth in the BSNR thanks to the implantation of protected zones from fishing (according to the results shown by Harmelin et Ruitton, 2007). Our study shows a significant globally increase of the average biomass of brown meagre into the whole of the BSNR, with the negative impact of spearfishing exerted on this species, limited in this area due to its restriction and a maintain of artisanal fisheries with higher catches for this sustainable activity. *Sciaena umbra*, as the dusky grouper (*Epinephelus marginatus*) should not be prohibited from spearfishing?

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Tables and Figures

Table 1. Stations evaluated by Underwater Visual Census method and their respective protection

Station	Curent level of protection	History of protection
Est Bonifacio	NTZ	NTZ since 1982
West Bonifacio	ZRP	ZRP since 1999 - FEZ before 1999
Bruzzi	NTZ	NTZ since 1999 - ZRP between 1994 and 1999
Calasciumara	FEZ	FEZ since 1999
BonifacioCantonment	NTZ	NTZ since 1982
Capofeno	FEZ	FEZ since 1999
Cerbicale	ZRP	ZRP since 1999 - FEZ between 1999
Grand olmeto	FEZ	FEZ since 1999
Est Lavezzi	ZRP	ZRP since 1982
North Lavezzi	ZRP	ZRP since 1982
West Lavezzi	ZRP	ZRP since 1982
South Lavezzi	ZRP	ZRP since 1982
Moines	NTZ	NTZ since 1999 - ZRP between 1994 and 1999
Olmeto	ZRP	ZRP since 1999 - FEZ before 1999
Pyramide	NTZ	NTZ since 1999 - ZRP before 1999
Sant'Amanza	FEZ	FEZ since 1999
Toro	ZRP	ZRP since 1999 - FEZ before 1999
Tour Lavezzi	ZRP	ZRP since 1982

Table 2. Data collection during the 13 years

Years	Number of fix points sampled	Number of fishing logbooks listed
1995	300	0
2000	310	0
2001	30	0
2002	270	0
2003	30	0
2004	61	154
2005	171	91
2006	180	166
2007	30	0
2008	0	127

Table 3. Mean biomasses of *Sciaena umbra* depending on the level of protection and the year.

Sector	Year	N (number of fixe points sampled)	Mean Biomass (g/are)	Standard error
FEZ	1995	90	25,8	16,7
FEZ	2000	30	54,1	27,4
FEZ	2002	58	70,8	43,5
FEZ	2005	30	76,0	39,6
ZRP_99	2000	95	17,1	12,4
ZRP_99	2002	62	292,8	134,8
ZRP_99	2005	62	1884,5	656,5
ZRP_82	1995	150	246,7	72,6
ZRP_82	2000	31	1336,9	591,1
ZRP_82	2001	30	1555,2	794,8
ZRP_82	2002	60	1081,8	309,9
ZRP_82	2003	30	797,0	386,3
ZRP_82	2004	31	2051,0	495,7
ZRP_82	2006	90	1539,2	404,0
ZRP_82	2007	30	2572,8	670,9
NTZ_99	2000	93	558,4	161,1
NTZ_99	2002	60	1233,5	485,9
NTZ_99	2005	79	2303,1	725,4
NTZ_82	1995	60	257,7	124,9
NTZ_82	2000	61	611,5	324,2
NTZ_82	2002	30	1290,7	580,8
NTZ_82	2004	30	2454,6	948,2
FEZ	all years	208	45,97899246	13,9
ZRP_99	all years	219	623,8264771	196,3
ZRP_82	all years	452	1147,092407	133,3
NTZ_99	all years	232	1539,73291	254,2
NTZ_82	all years	181	912,2817383	223,2

Table 4. Mean CPUE of *Sciaena umbra* from artisanal fishery depending on the year.

Year / Sector	N (number of logbooks listed)	Mean CPUE (g/unit effort)	Standard error
2004	154	7,2	2,1
2005	91	51,1	16,4
2006	166	36,1	11,0
2008	127	82,9	23,7

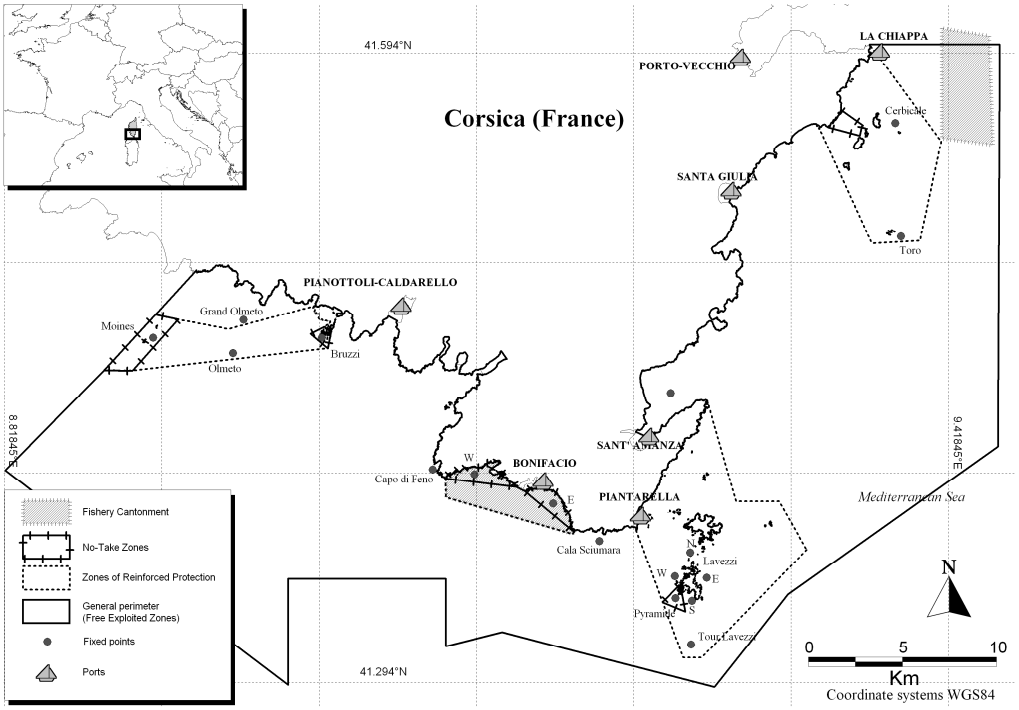

Figure. 1. Map of the study area: the Bonifacio Strait Natural Reserve (BSNR) in south Corsica, France.

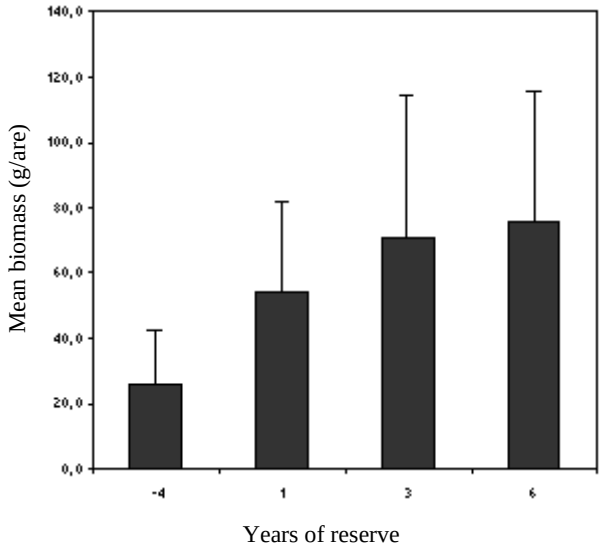

Figure 2. Trends in mean biomass of *Sciaena umbra* as function of time (years) since protection within FEZ area of the BSNR. Errors bars = standard error.

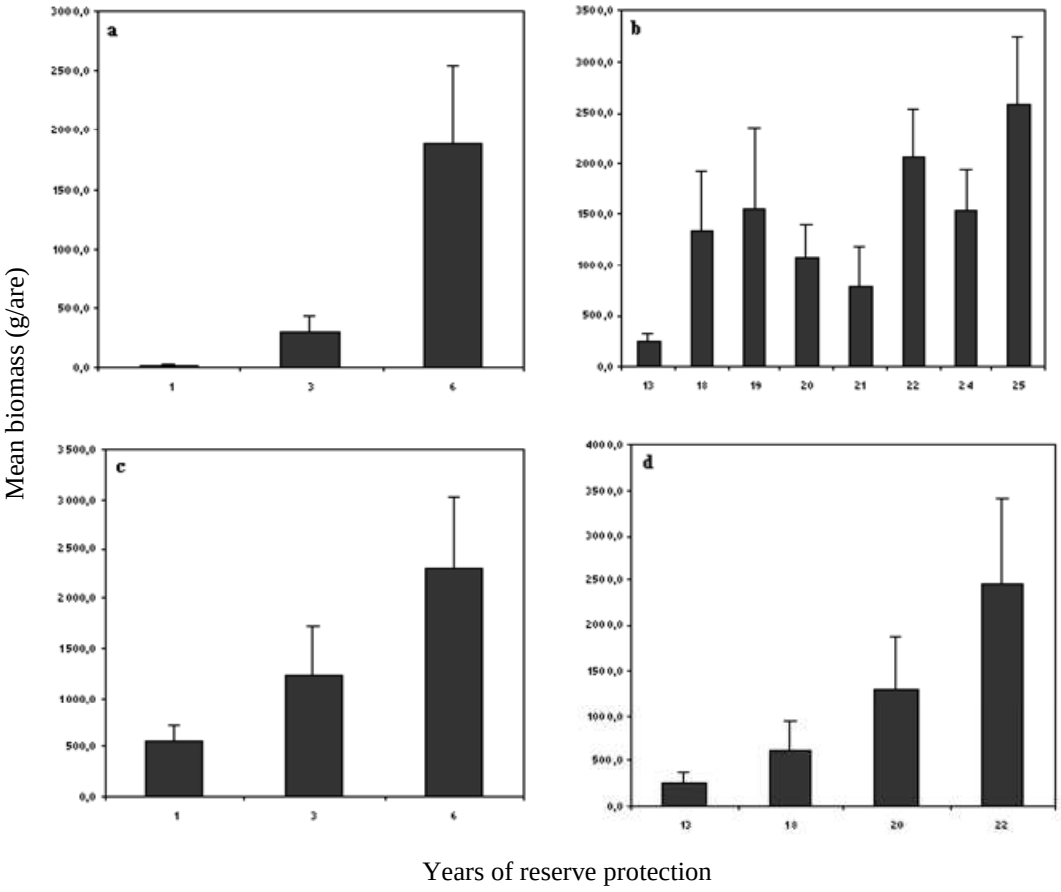

Figure 3. Trends in mean biomass of *Sciaena umbra* as function of time (years) since protection within: (a) ZRP_99, (b) ZRP_82, (c) NTZ_99, (d) NTZ_82; of the BSNR. Errors bars = standard error.

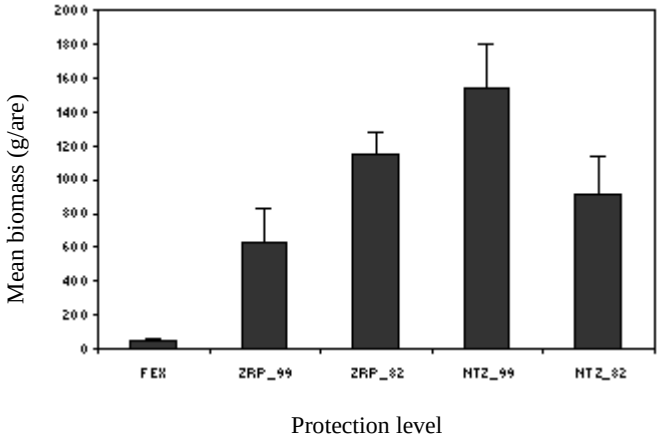

Figure 4. Comparison of the average biomass (g/are) of *Sciaena umbra* counted between 1995 and 2005 within the different zones of the BSNR. Errors bars = standard error.

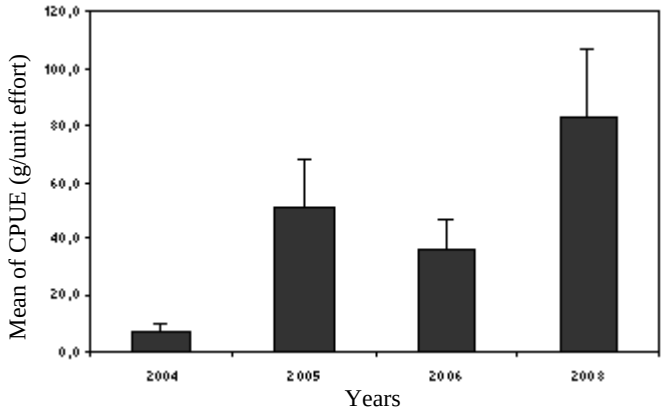

Figure 5. Mean of the catches (g/unit effort) of *Sciaena umbra* per year through on-boat recorded from the artisanal fleet. Errors bars = standard error.