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Comparative analysis between artisanal and recreational fisheries of *Dentex dentex* in a Marine Protected Area

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Abstract: The common dentex *Dentex dentex* (Linnaeus, 1758) is an iconic marine coastal fish in the Mediterranean Sea. This study was performed in the Bonifacio Strait Natural Reserve (BSNR), (NW Mediterranean Sea). The aims were to: (i) evaluate temporal variation of the artisanal fishing of common dentex (2000-2012); (ii) compare and quantify (2006-08-11-12) catch rates, fishing techniques, catch composition , for artisanal and recreational fisheries and determine the influence of management measures by both activities; (iii) and estimate the production of both artisanal and recreational fisheries. Fishery data were collected from different artisanal fishing surveys (onboard fishing vessels and landings) and recreational fishing surveys (roving-roving). The gears with the highest rates of exploitation were Longline (3554.28 g.100 hooks^{-1} ±SE) and Trolling (358.50 g.boat^{-1} h^{-1} ±SE), respectively, for artisanal and recreational fishing. This study showed that catches obtained by both activities were quantitatively higher in partially protected areas than outside them. Production estimations suggest that recreational fishery contributes significantly to fishing mortality and that it can magnify the negative effects of artisanal fisheries. It is now necessary to implement specific measures to contribute to the sustainable fishery management of common dentex.

Key words: Small-scale fisheries, IUCN red list, fisheries management, marine reserve.

Running head: Artisanal & recreational fishing of common dentex

Introduction

The Mediterranean Sea is a marine biodiversity hot spot under intense pressure, where ecological and human influences meet and strongly interact (Coll *et al.* 2010, Lejeusne *et al.* 2010). Among ecological factors, such as direct habitat modification, species tropicalization, and seawater acidification, fishing represents the activity having the greatest impact because it has driven most stocks to overexploitation (Quetglas *et al.* 2013).

To reduce such negative impacts, marine protected areas (MPAs) have been implemented as part of an ecosystem-based approach to coastal management (Albouy *et al.* 2010). Multiple-use MPAs have been widely implemented due to their potential to achieve conservation objectives while allowing human uses and minimizing conflicts, by including some degree of protection for commercial species and important habitats as well as promoting the use of local fisheries and a range of recreational activities (Lester *et al.* 2009, Rocklin *et al.* 2011, Horta e Costa *et al.* 2013). More generally, MPAs are increasingly used as a tool for fishery management (Rocklin *et al.* 2011). They have the potential to sustain the fisheries adjacent to protected areas while safeguarding species and habitats within them (Francour *et al.* 2001). The expected benefits of MPAs for fishes include an increase in abundance (net emigration of adults and juveniles across borders, termed ‘‘spillover”), biomass and fecundity (the increased production and exportation of pelagic eggs and larvae), as well as a potential benefit for biodiversity (Francour *et al.* 2001, Gell & Roberts 2003).

Artisanal fisheries or small-scale coastal fisheries are particularly important in the Mediterranean, where they constitute about 80% of the fishing fleet (European Commission 2004). Artisanal fishing is a complex system characterized by commercial fishers operating in small boats, exploiting areas near the coast, using a large number of gears and techniques, typically manned by a single fisherman or a pair of fishermen and targeting a high diversity of species (Colloca *et al.* 2004, Gomez *et al.* 2006, Lloret & Font 2013). In the Mediterranean, fish are heavily exploited by commercial fishing but recreational fishing is also intensive along the

Mediterranean coast (Seytre *et al.* 2013). Recreational fishing in the Mediterranean can be defined as follows: all non-commercial fishing carried out mainly for pleasure or sport, where the catch - the sale of which is illegal - is used for private consumption (Font *et al.* 2012). Recreational fishing has economic, social, and cultural roles; it has been recognized as one of the most common leisure activities and is now a thriving activity in Mediterranean coastal areas (Morales-Nin *et al.* 2005, Albouy *et al.* 2010, Font & Lloret 2011). In the Mediterranean, recreational fishing is particularly important because it represents more than 10% of the total production of all fishing (European Commission 2004).

Recreational and artisanal sectors often compete for limited coastal resources and the intensification of recreational fishing magnifies pressure on species already in an advanced state of exploitation (Diogo & Pereira 2013, Lloret & Font 2013). Commercial and recreational fishing can have similar demographic and ecological consequences on fished populations and may provoke serious ecological and economic damage (Coleman *et al.* 2004). Despite this similarity, generating a variety of impacts on marine ecosystems, much less research is performed on recreational fishing compared to commercial fishing, due in part to the difficulties involved in collecting data on recreational fishing (Font *et al.* 2012). There is an urgent need to evaluate the potential impact that the different types of fishing activities, alone and in combination, can have on the sustainability of coastal resources and on the general functioning of coastal ecosystems (Albouy *et al.* 2010).

The common dentex *Dentex dentex* (Linnaeus, 1758) is an iconic marine coastal fish in the Mediterranean Sea. It is a demersal sparid fish (0-200 m) that grows to a maximum length of 100 cm and weight of 13 kg, with a relatively long life span (more than 20 years) (Morales-Nin & Moranta 1997). As a high trophic level predator, it holds a key position in coastal marine food webs. The global commercial catch of common dentex has fluctuated over the last sixty years on a multidecadal time scale and declined significantly from a peak of ~7,000 tons in 1990 to less than 1,000 tons in 2005 (Abdul Malak *et al.* 2011, Marengo *et al.* 2014). *D. dentex* is now classified by the International Union for the Conservation of Nature (IUCN) as “vulnerable” on the Red List of Threatened Species in the Mediterranean Sea (Abdul Malak *et al.* 2011). Despite this status, there is no Minimum Landing Size (MLS) to safeguard the reproductive potential for this species. *D.dentex,* due to its large size, flesh quality, and high commercial value is of great economic interest for both artisanal and recreational fisheries (Morales-Nin & Moranta 1997, Loir *et al.* 2001). The main fishing gears used by artisanal fishing, specifically targeting the common dentex are: bottom long-lines, trammel nets and medium-large mesh gillnets (Morales-Nin & Moranta 1997, Sacchi & Dimech 2011). The most common methods used in recreational fishing for *D. dentex* are boat fishing, spearfishing, line and shore fishing (Morales-Nin *et al.* 2005, Font & Lloret 2011). There is an alteration and/or combined use of this gear, depending on the season, habitat and geographic area (Marengo *et al.* 2014). Despite its economic and ecological importance, data on this species regarding fishing gear, seasonality, fishing effort, catches and the yields of the artisanal and recreational sector are still limited.

The aims of this study were to: (i) characterize the artisanal fishing of common dentex in the Bonifacio Strait Natural Reserve (BSNR, Corsica, NW Mediterranean Sea) in terms of temporal variability; (ii) compare and quantify, over a four year period, the catch rates, fishing techniques, catch composition of the artisanal and recreational common dentex fisheries and determine the influence of management measures (protected areas) on the captures by both activities; (iii) and estimate the production of the common dentex for both artisanal and recreational fishing.

Materials and methods

Study area

This study was performed in the Bonifacio Strait Natural Reserve (BSNR), located in southern Corsica (France; Mediterranean Sea, Fig.1). Several activities take place in this MPA such as artisanal fishing (mainly trammel nets and longlines), recreational fishing (mainly longlines, hook fishing and spearfishing), diving and sailing.

It was created in September 1999 and encompasses the Lavezzi Islands Reserve created in 1982 (Mouillot *et al.* 2002). Its bottom substrate is predominantly covered by a mosaic habitat of rocks, sand and seagrass beds of *Posidonia oceanica* (L. Delile), and the maximum depth is 158 m. Its marine surface area of 79 640 ha includes four zones of Partially Protected Areas (PPA; 12 300 ha), where spearfishing is forbidden (artisanal fishing authorized), and six No-Take Zones (NTZ; 1130 ha) closed to all types of fishing activities (both artisanal and recreational) as well as diving (Mouillot *et al.* 2002). See http://www.rnbb.fr/ for more details about legislation.

Data collection

Fishery data were collected from different artisanal fishing surveys (from 2000 to 2012; except 2009) and recreational fishing surveys (2006, 2008, 2011, 2012) carried out in BSNR (see Table 1 for a summary of the survey details). Over the study period, 962 commercial boats (= fishing parties) and 459 recreational boats (= fishing parties) were sampled.

Artisanal fishing surveys: the fishing catches were collected by BSNR scientists onboard fishing vessels or on landing, only on retained fish (see Table 1), in collaboration with fishermen of the prud'homie of Bonifacio, from four main ports (Pianottoli, Bonifacio, Sant'Amanza, Porto-Vecchio) and three shelter ports (Piantarella, Santa Giulia, La Chiappa). All the common dentex caught were measured and their total weight was estimated using size class correspondences: Small: 0-40 cm = 0.3828 kg; Medium: 40-60 cm = 2.1053 kg; Large: 60-80 cm =5.4653 kg; (Marengo *et al.* 2013). The fishing area, the duration, the type, the characteristics of the gear that were deployed and the fishing effort were recorded. To standardize the data collected, Catch

Per Unit of Effort (CPUE) was expressed for nets, in grams by piece of net (50 m) (CPUE mass: $g.50m^{-1}$), and per number of individual caught by piece of net (50 m) (CPUE num: $ind.50m^{-1}$). In this study, the “Spiny Lobster net” is defined by duration of fishing operation of at least two days at a depth exceeding or equal to 50 m. The "Fish net" covers any type of net that does not correspond to the first definition. For longlines CPUE was expressed in grams per 100 hooks (CPUE mass: g.100 $hooks^{-1}$) and per number of individuals caught per 100 hooks (CPUE num: Ind.100 $hooks^{-1}$). Fishing yield data is expressed in grams per day per boat.

Recreational fishing surveys: Surveys covered the summer (tourist) season. During fishing activity, a study on boat fishing was conducted at sea using a boat and several interviewers in the BSNR (roving-roving). For each fishing set, the data collected included type of fishing gear, the date, the duration of each fishing operation and the catch (only on retained fish). Weight estimates for common dentex were obtained with a spring balance (accuracy ± 20g) or were derived using length-weight relationships published in FISHBASE [http://www.fishbase.org/], based on Morales-Nin and Moranta 1997. CPUE mass was recorded per gram per boat per hour of fishing ($g.boat^{-1}h^{-1}$) and CPUE num per number of individuals caught per boat per hour of fishing ($ind.boat^{-1}h^{-1}$).

Estimation of fishing effort and production

Artisanal fishing: The fishing effort was expressed as the mean number of active fishing boats per day, and the mean number of trips performed during the whole fishing season (Farrugio & Le Corre 1993). The BSNR annual production was estimated using this previous information combined with the mean daily biomass caught per boat (yields data) for the years 2006, 2008, 2011, 2012.

Recreational fishing: The BSNR annual production was estimated using several key assumptions; a heuristic approach was developed to estimate the fishing effort.

Information for the study was gleaned from a multiple approach based on fishing authorizations and roving-roving data, for more reliable assessments of the actual numbers of recreational anglers and their fishing effort and yields. The number of fishermen practicing in the RNBB was obtained from the number of declaration of intent of fishing made in 2013 within the BSNR. A new regulation (Arrété prefectoral n° 2013165-0001) requires all recreational fishermen to declare themselves to the managers. From this survey, the fishing effort was calculated based on: the number of fishermen, their profiles, the type of activity, the mean duration of fishing, the number of trips per year. The annual production value was estimated from the calculated average yield for Trolling (based on the study period 2006-2008-2011-2012) and the annual effort values, expressed as total catch per fisher and hour of fishing, and total number of fishing trips per fisher and year (2013), respectively.

Data analysis

Data-sets were not normally distributed; therefore assessments were tested for significance using non-parametric tests. Annual trends (2000–2012) in the fishing yields were assessed using the Mann-Kendall test to test whether there was a trend in the time series and the Pettitt's test allowed identifying whether a shift occurred. A smoothing method was also used (Moving average) on these data sets. For artisanal fishing, differences in the CPUE between the sectors (PPA, GP, Out) was analyzed using the Kruskal-Wallis H test analysis of variance, with the Dunn post-hoc test and the Bonferroni correction. For recreational fishing, differences in the CPUE between sectors (PPA, GP) were analyzed using the Mann-Whitney U test. Analyses were performed using XLSTAT software (with the Time package).

Results

Time series analyses

The trend analysis of the fishing yield for artisanal fishery (2000-2012) showed no significant temporal trends (Mann-Kendal test, p-value =0.86) and no shift was detected (Pettitt's test, p-value =0.212). However, by segmenting the time series a significant increasing trend was detected between 2000 and 2006 (Mann-Kendal test, p-value <0.05) while no significant temporal trend was detected between 2007 and 2012 (Mann-Kendal test, p-value >0.05). Furthermore, graphically, the moving average showed two main trends during these years. A first trend of increase between 2000 and 2006, with a yield in 2000 of 653.7 g day^{-1} $boat^{-1}$, reaching a peak exploitation in 2006 of 3750.2 g day^{-1} $boat^{-1}$. In the second phase, the results indicated a relatively stable yield (moving average), although highly variable with strong interannual fluctuations between 2007 and 2012. The yield varied from a minimum of 565.6 g day^{-1} $boat^{-1}$ in 2007 to a maximum of 4720.9 g day^{-1} boat in 2011 (Fig.2). The number of fishing vessels exploiting the MPA (an average of 13 boats per day) did not change between 2000 and 2012.

Catch composition

For artisanal fishing, the fishing method with the largest number of specimens caught was the Fish net (65% of catches) followed by the Longline (25% of catches) and the Spiny lobster net (10% of catches) (Fig.3A). For recreational fishing, the fishing method with the largest number of specimens caught was (bottom) Trolling (90% of catches), followed by Spearfishing (6% of catches) and boat Angling (4% of catches) (Fig.3A). As regards to size representativeness in the catch for artisanal fishing (Fig.3B), it can be noted that Spiny Lobster nets (SL) and Fish nets (FI) have a broad spectrum of capture: the three size classes were well represented (SL, S: 24%, M: 48%, L: 28%; FI, S: 32% M: 46% L: 22%), with a predominance of the Medium size class. Individuals caught using Longlines (LL) were essentially large specimens (LL, M: 22%, L:

78%). For recreational fishing, Trolling (TF= T in Fig.3B) was the gear that captured the most large individuals (TF, S: 11%, M: 17%, L: 72%). For Spearfishing (SF= S Fig.3B) and boat Angling (or handlining) BA= A Fig.3B), the only size class found in the sample was the category Medium (SF and BA; M: 100%).

Fishing gears

In the study area for both artisanal and recreational fishing, six types of fishing gear targeting the common dentex were identified (Table 2). For artisanal fishing, the Longline had the highest rates of exploitation (3554.28 g.100 hooks $^{-1}$) followed by the Fish net (69.53 g.50m of net $^{-1}$) and the Spiny Lobster net (31.49 g.50m of net $^{-1}$). Although these fishing gears were used in a wide range of depths, most of the effort was deployed between 48 and 68 m depth. For recreational fishing, Trolling reached the highest levels of exploitation (358.50 g.boat^{-1} h^{-1}). By comparison, Spearfishing and boat Angling had much lower levels of exploitation (68.02 g.boat^{-1} h^{-1} and 12.73 g.boat^{-1} h^{-1} respectively).

Differences between protection levels

For artisanal fishing, the result indicated that there were significant differences between the CPUE values according to zone (Out of reserve = OUT, General Perimeter = GP, Partial Protected Area = PPA) (Kruskal-Wallis test, $p < 0.0001$). The multiple pairwise comparisons using Dunn's procedure showed that the CPUE values within the OUT were significantly higher than within the GP, and CPUE values within the PPA were significantly higher than within the GP. The mean CPUE was 26.3 g.50m of net $^{-1}$(±SE 6.6) in the OUT zone, 17.4 g.50m of net $^{-1}$ (±SE 4.9) for GP and 98.6 g.50m of net $^{-1}$(±SE 17.4) for the PPA zone (Table 3).

For recreational fishing, data analysis showed that the CPUE values within the PPA were significantly higher than within the GP. The mean CPUE was 55.5 g.boat^{-1} h^{-1} (±SE 26.4) in the GP, and 355.1 g.boat^{-1} h^{-1} (±SE 87.1) in the PPA (Mann–Whitney test, $p = 0.014$) (Table 3).

Fishing Production

From the data collected, the estimated mean annual production (based on the study period) in BSNR was 5.8 and 3.4 tons for artisanal fisheries and for recreational fishing modalities considered in this study, respectively. Proportionally, recreational fishing represented 58% of the total captures of artisanal fisheries for this species. Recreational fishing amounts to 37% of the total catch (artisanal and recreational production combined) of the species in this MPA. The total annual fishing production estimated in the BSNR area for common dentex is 9.2 tons.

Discussion

The common dentex is considered as a trophy fish and it is therefore targeted by both artisanal and recreational fishing. Our time series results for artisanal fishing in the Bonifacio Strait Natural Reserve (BSNR) showed that despite strong intra and inter-annual variability two prominent periods (an increase from 2000-06 and relatively stable yield from 2007-12). Even if time series data of the present study started just after the creation of the BSNR, one possible explanation for the increased yield from 2000 till 2006 might be the direct effect of protection measures that first contributed to the increase of the common dentex and, second, to maintaining its exploitation. In the BSNR, a restrictive policy has been enforced on fishing activities since the creation of the Marine Protected Area (MPA) in 1999: the number of professional licenses and the minimum mesh size were controlled and various protected perimeters were delimited (Albouy *et al.* 2010). These restrictions tend to decrease fishing pressure on the protected parts and increase catches in terms of CPUE in these areas (Mouillot *et al.* 2008). The increase in the abundance of exploited species can be rapid, but the recovery of age- and size-structures might only occur after a longer period of protection (Seytre *et al.* 2013). A likely hypothesis is that a long term period (several decades) of fishing prohibition is necessary to reach a complete reserve effect that could lead to an increase in catches for fishermen outside the protected zone, as part of a density-dependent process (Seytre & Francour 2008). The stabilization of the yield for artisanal fishing (2007-12), could be explained by the combined impact of recreational fishing and marine tourism. Technological advances for the recreational fishery has led to major advances in the ability to capture fish: (i) with equipment for traveling longer distances, e.g., more powerful motors; (ii) several gear modifications, e.g., using light, prey mimics, additional chemicals, motion and sound to increase bait attractiveness; (iii) the affordability of sophisticated fishing technologies, e.g. electric fishing reels (Cooke & Cowx 2006). Progress has also been made in locating fish more rapidly and effectively: (i) e.g., global positioning systems and sonar and (ii) the improved transfer of knowledge, e.g. internet forums (Cooke & Cowx 2006). Such investments generally result in increased capacity or efficiency (e.g., better access to current fishing grounds) and an extension to existing fishing strategies (e.g., access to new fishing grounds) (Torres-Irineo *et al.* 2014).

In addition, the large numbers of recreational boats that can be found in the MPA of BSNR during summer can have a number of effects on its coastal marine environment. In 2006, 14 003 boats visited the two main tourist ports of the BSNR (Bonifacio, Porto-Vecchio). The rapid growth in the numbers of recreational boats is causing stresses to the marine environment and to many aspects of the biology and ecology of fishes. These stresses include pollution (e.g. heavy metal deposits), habitat alteration (e.g. increased turbidity, physical damage to bottoms by anchoring); behavioral alteration due to pressure wave disturbance and sound disturbance (e.g., avoidance of boating traffic by fish) and invasive species propagation (e.g., direct and indirect introduction of invasive aquatic biota) (Whitfield & Becker 2014). The difficulty in controlling such an influx of tourists is a problem well recognized by the managers of all of those MPAs where marine tourism is practiced (e.g., Port-Cros, Bonifacio, Medes), and does not yet seem to have been resolved (Francour *et al.* 2001). However many other factors, such as biological interactions, variations in recruitment, and environmental variations can also influence ecosystem functioning and have impacts on fish stocks (Pinnegar *et al.* 2000, Brander 2010).

For the first time, our results characterize all fishing boat activities targeting the common dentex within an MPA, with an inventory of the fishing gear used, their selectivity and their rates of exploitation. Our study showed that in the BSNR, common dentex were targeted by both artisanal and recreational fishing using a wide variety of gears. In the BSNR, for common dentex fishing, Longline fishing essentially targets large specimens, whereas the composition by size class for Fish net and Spiny lobster net fishing shows broad variations in terms of catches. The catch by Fish net mainly corresponds to a peak of exploitation, with maximum efficiency in May during the spawning period when individuals aggregate or during seasonal migration. The catch by “Spiny lobster net” is low and mainly corresponds to a bycatch. These results are in agreement with previous studies conducted in the Mediterranean Sea for common dentex (reviewed by Marengo *et al.* 2014).

The gears used most frequently for recreational fisheries in this area are Trolling, followed by Spearfishing and boat Angling. Trolling clearly has the greatest impact in terms of biomass removed, targeting essentially large specimens. Spear fishing might have a relatively minor impact compared to trolling. These results do not agree with the conclusions of Abdul Malak *et al.* (2011), who identified spearfishing as the main threat to the exploitation of the common dentex in the Mediterranean.

The combined impact of artisanal and recreational fishing (e.g Longline, Trolling), targeting large specimens can have serious consequences on the state of stocks of *D. dentex*.

The removal of large individuals can adversely affect the reproductive potential of vulnerable fish populations because larger females are proportionally more fecund, reproduce over an extended period, and spawn better quality eggs and larvae with better survival rates (Birkeland & Dayton 2005). Size selective fishing may not only reduce the biomass but may induce: depensatory mechanisms, truncation of age and size structure, loss of genetic variability, and evolutionary changes (Lewin *et al.* 2006).

CPUE data have been evaluated inside and outside the MPA using the same gear. This allows the use of CPUE as an indicator of population abundance of fish communities according to protection levels (Guidetti *et al.* 2010). This study showed that catches obtained by artisanal and recreational fishermen inside the PPA and outside these areas were consistently different. On average, catches were quantitatively higher in PPA relative to GP and OUT. This effect has been described previously and was consistent with the results of previous studies, which show a higher increase in the biomass and density of common dentex inside the MPAs than outside them (Guidetti *et al.* 2010, Forcada *et al.* 2010). There is a body of evidence suggesting that the differences observed between average CPUEs inside and outside the MPA are likely due to different fishery managements (Guidetti *et al.* 2010). The higher trophic levels tend to show greater responses to protection, likely because higher predators tend to be targeted by fisheries (Lester *et al.* 2009). Other factors can explain a substantial proportion of the variation observed in the abundance of fish species such as habitat structure (Lizaso *et al.* 2000, Miller & Russ 2014, Harasti *et al.* 2014). In this case, two main hypotheses could explain the high catch rates of common dentex in the PPA: (i) the banning of spearfishing in the PPA and (ii) the "refuge effect".

Firstly, Rocklin *et al.* (2011) demonstrated in the BSNR that spearfishing can modify species assemblage structure. The dramatic effects of spearfishing on some of these species have been well established (Coll *et al.* 2004). Secondly, one of the most important benefits to marine coastal species is that MPAs can act as refuges into which fish move to escape fishing (Lester *et al.* 2009). The common dentex is one of those species that benefit from this protection measure, as it is especially targeted by both recreational and artisanal fishing. The trophic balance of an aquatic ecosystem can be disrupted by the direct and indirect effects of commercial and recreational fishing (Cooke & Cowx 2006). Depending on role and dominance within the ecosystem, the removal of a substantial part of a population can significantly affect the trophic process and the community structure (Lewin *et al.* 2006). Cascade processes concern interconnected changes in predation interactions involving keystone species at different trophic levels, which are induced by modifications affecting the identity or the activity rate of top-predators (Francour *et al.* 2001). The abatement of their stocks in overfished areas and, conversely, their replenishment in protected areas may thus trigger cascade processes (Steneck 1998). In Port de la Selva (Spain), the proportion of a top predator such as *Dentex dentex* in total landings increased after the establishment of the MPA to the detriment of *Octopus vulgaris* (Cuvier, 1797), *Diplodus sargus* (Linnaeus, 1758), *Scorpaena sp* (Linnaeus, 1758), and *Palinurus elephas* (Fabricius, 1787) (Gomez *et al.* 2006). For example, in the Bonifacio straits (France) the significant decrease of *Serranus cabrilla* (Linnaeus, 1758) could be explained by the significant increase of *D. dentex* (Rocklin *et al.* 2011). The explanation for this difference was based on increased predation within the reserve due to a number of larger predators such as *Dentex dentex* (Francour *et al.* 2010). Such a trend is generally not expected after the implementation of an MPA, but can be explained by trophic interactions between species through the top-down effect, by which an increase of predators would lead to a decrease of its preys (Pinnegar *et al.* 2000, Seytre & Francour 2008). However, the role of these keystone species is fundamental to ecosystem functioning and their protection is an insurance against the erosion of functional diversity (Sergio *et al.* 2008).

The recreational fishing modalities considered in this study catch around 3.4 tons of common dentex per year, which is equivalent to 58% of the artisanal fishery production in the MPA (artisanal fisheries catch 5.8 tons.year^{-1} of common dentex). The comparison of recreational catch estimates from this study with artisanal catch estimates of common dentex in the MPA suggests that recreational fishing (i) contributes significantly to fishing mortality, (ii) and it can exacerbate the magnitude of the negative effects of artisanal fisheries on the common dentex. However, it is noteworthy that the recreational and artisanal fishing catches reported in this study were probably underestimates. Recreational catches have a degree of imprecision due to the constraints associated with onsite survey methods (Lockwood 2000), and discards and illegal catches were not estimated in this study.

It is becoming increasingly apparent that recreational fishing is contributing significantly to the total fishing mortality of some species in certain regions (Coleman *et al.* 2004).

Other studies have also shown that recreational fishing can represent a significant part of total landings (Cooke & Cowx 2004). Overall, recreational fishing's share of total catches ranges by as much as 10% to 50% of the total commercial fishing catch (European Commission 2004, Morales-Nin *et al.* 2005, Lloret & Font 2013). However, for specific species recreational catches may often be equal to, or exceed, commercial catches (Zischke *et al.* 2012).

This activity may challenge the sustainability of artisanal fisheries sharing the same areas and the same resources (Rocklin *et al.* 2011). Within the BSNR, artisanal and recreational fishing activities generate combined pressure on the ecosystem (Albouy *et al.* 2010). Although rarely considered to be an important factor, the result of recreational fishing has the potential to produce effects that parallel those of commercial fisheries (e.g., reduced stock size, decreasing mean size, genetic changes, ecosystem level changes and habitat degradation) (Cooke & Cowx 2006).

D. dentex is a vulnerable species included on the red list of the IUCN and also a highly important target of artisanal fishing and recreational boat fishing in the BSNR. The data collected and the results presented in this study make a significant contribution to knowledge on several aspects of the artisanal and recreational fishing of common dentex in the Mediterranean, providing an overview of the pressure levels and catches arising from these practices. In this work, we showed that the common dentex was favored by protection measures in Western Mediterranean MPAs. In brief, MPAs are an essential tool for protecting overexploited populations and threatened species (Hackradt *et al.* 2014). Managers of the BNSR predict an increase in recreational fishing activities while the fishing effort from artisanal fisheries may stabilize (Albouy *et al.* 2010). Considering the effect of recreational fishing, it seems important to formulate new regulation policies for recreational activities (Albouy *et al.* 2010). It should be noted that since June 2012, new management tools have been tested by managers within the BSNR to limit the impact of recreational fishing (e.g. daily bag limitations, the restriction of recreational fishing in the PPA).

For the common dentex in the BSNR, managers should consider the implementation of specific measures to safeguard its reproductive potential, such as the establishment of Minimum landing sizes (MLS). It is essential to adjust MLS values so that they are larger than size at maturity, especially for the most vulnerable species (Font & Lloret 2014). Based on the size at first maturity and life history traits of the common dentex (Morales-Nin & Moranta 1997), it would be necessary to establish an MLS of 40 cm.

Common efforts devoted to educating fishers would be also necessary, especially to develop the practice of “catch-and-release”. Unlike in other parts of the world where catch and release is common practice (Cooke & Cowx 2004, Cooke & Cowx 2006), it is not widespread in the Mediterranean.

Fish mortality after catch-and-release is an essential element to evaluate in order to adapt fishing regulations; however, it is highly dependent on variables such as the species considered, the gear used (Bartholomew & Bohnsack 2005) and seawater temperature (Gale *et al.* 2013). Thus, it is recommended that the factors influencing the post-release mortality of released fish be studied to allow accounting for post-release mortalities when estimating fishing mortalities and to assist in the development of best-practice guidelines (Ferter *et al.* 2013).

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Table captions

Table 1. Information on the different recreational and artisanal fishing surveys in which data were collected. The years and months when surveys were conducted, the survey type, and the number of boats sampled are shown.

Table 2. Characterization of fishing gear used by artisanal and recreational fishing (2006-08-11-12) with their catch per unit effort (CPUE).

Table 3. Mean values (±SE) of CPUE by artisanal fishery ($g.50m^{-1}$ of net) and recreational fishery ($g.boat^{-1}h^{-1}$) in the BSNR (2011-12), according to zone (PPA: Partial Protected Area, GP: General Perimeter, OUT: Out of reserve.

Table 1

Survey	Years	Months	Survey type	Number of boats sampled
Artisanal fishing	2000	May-July	Landing	154
	2001	May-July	Landing	152
	2002	May-July	Landing	76
	2003	May-July	Landing	110
	2004	May-July	Onboard fishing vessel	59
	2005	May-July	Onboard fishing vessel	29
	2006	May-July	Onboard fishing vessel	57
	2007	May-July	Landing	125
	2008	May-July	Onboard fishing vessel	56
	2010	May-July	Landing	92
	2011	May-July	Onboard fishing vessel	16
	2012	May-July	Onboard fishing vessel	36
Total				962
Recreational fishing	2006	July-September	Roving-roving	32
	2008	June-October	Roving-roving	82
	2011	May-August	Roving-roving	264
	2012	March-May	Roving-roving	81
Total				459

Table 2

Type of fishing	Fishing gear	Sampling years	Mean CPUE Mass (±SE)	Unit	Depth of operations (Mean)	Mean CPUE Num (±SE)	Unit
Artisanal	Spiny Lobster net	2006; 2008; 2011-12	31.49 (±9.75)	g.50m of net $^{-1}$	64 m	0.011 (±0.003)	Ind.50m of net
Artisanal	Fish net	2006; 2008; 2011-12	69.53 (±11.12)	g.50m of net $^{-1}$	34 m	0.032 (±0.005)	Ind.50m of net
Artisanal	Longline	2004-06; 11-12	3554.28 (±770.52)	g.100 hooks $^{-1}$	48 m	0.779 (±0.175)	Ind. 100 hooks $^{-1}$
Recreational	Trolling fishing	2006; 2008; 2011-12	358.50 (±72.61)	g.boat^{-1} h^{-1}	-	0.077 (±0.015)	Ind.boat^{-1}h^{-1}
Recreational	Spearfishing	2006; 2008; 2011-12	68.02 (±44.74)	g.boat^{-1} h^{-1}	-	0.028 (±0.017)	Ind.boat^{-1}h^{-1}
Recreational	boat Angling	2006; 2008; 2011-12	12.73 (±9.29)	g.boat^{-1} h^{-1}	-	0.007 (±0.005)	Ind.boat^{-1}h^{-1}

Table 3

Zone	CPUE Artisanal Fishery	CPUE Recreational Fishery
OUT	26,2 (±6,6) g.50m of net $^{-1}$	-
GP	17,4 (±4,9) g.50m of net $^{-1}$	55,5 (±26,3) g.boat^{-1} h^{-1}
PPA	98,6 (±17,4) g.50m of net $^{-1}$	355,1 (±87,1) g.boat^{-1} h^{-1}

Figure caption

Fig. 1 Map of the study area showing the boundaries of the Bonifacio Strait Natural Reserve with zoning implemented by the management plan.

Fig. 2 The mean fishing yield (g.day $^{-1}$ boat $^{-1}$) (±SE) and moving average for artisanal fishing in the BSNR during the period 2000-08; 2010-12.

Fig. 3 Catch representativeness in % according to the total number (A) of individuals (n) caught for each fishing type by artisanal fishing and recreational fishing. Catch representativeness in % according to their size class (B) (L: large, M: medium, S: small), for each fishing type caught by artisanal fishing (SL: Spiny Lobster net; FI: Fish net, LL: Longline) and recreational fishing, n= number of *D.dentex* recorded during the surveys (2006-08-11-12).

Fig. 1

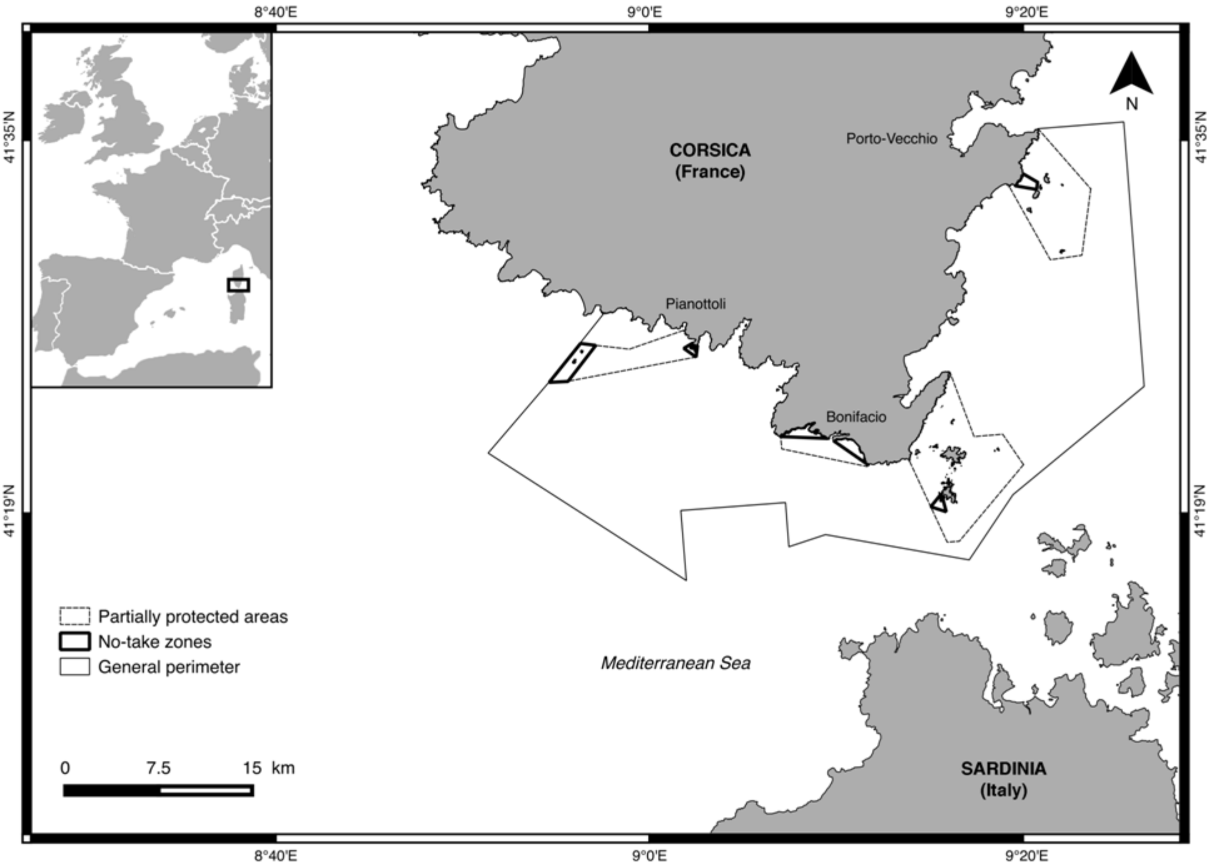
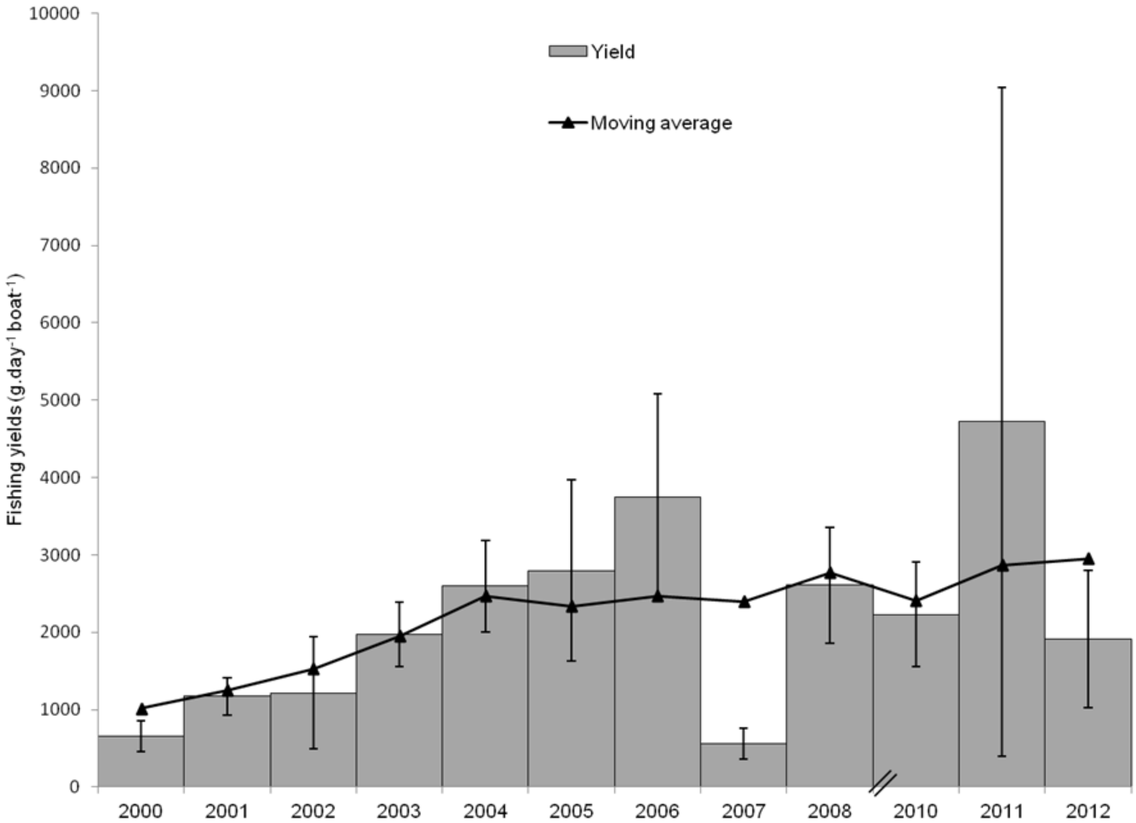
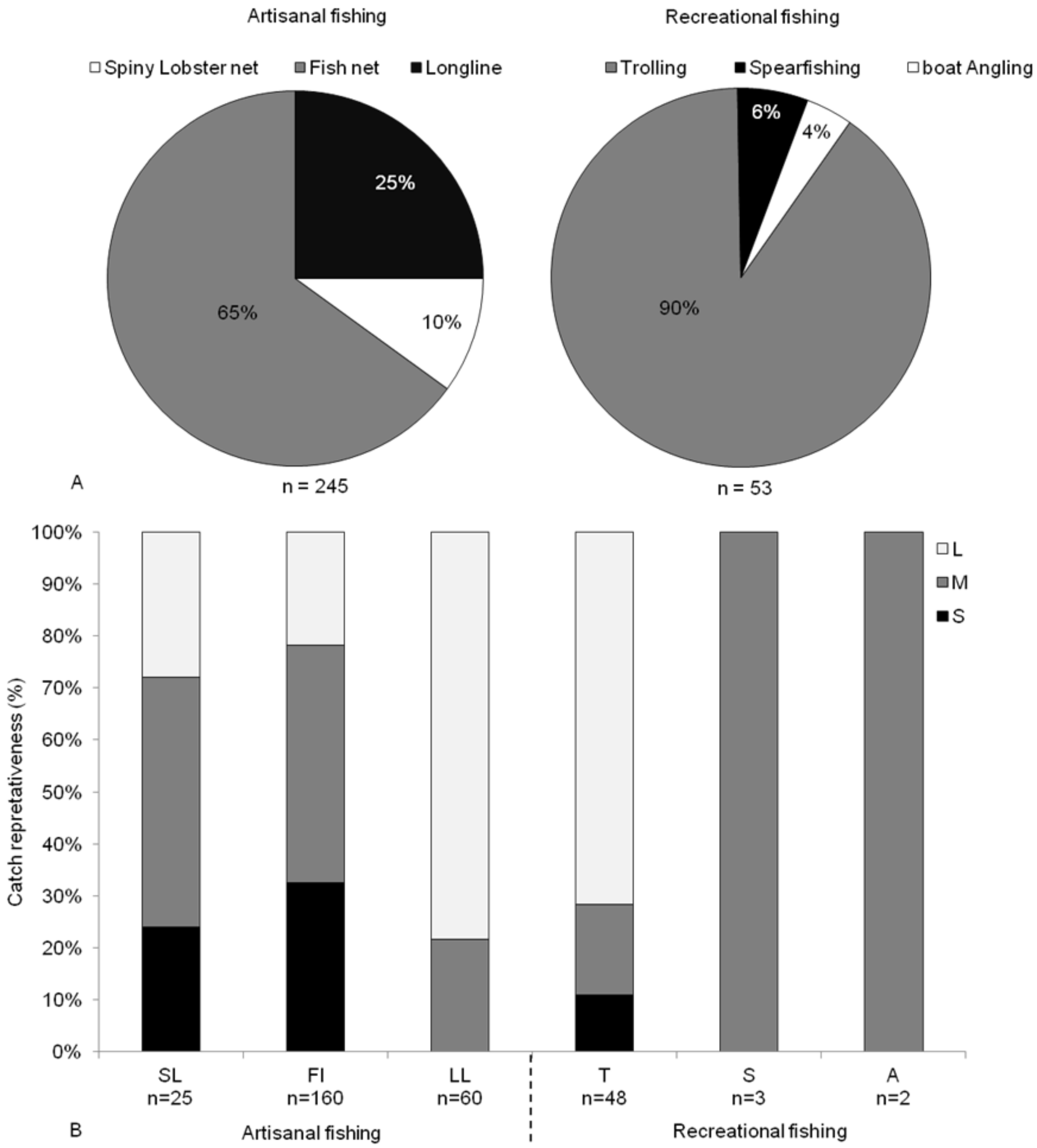

8°40'E
9°0'E
9°20'E
41°35'N
41°19'N
CORSICA
(France)
Porto-Vecchio
Pianottoli
Bonifacio
N
Partially protected areas
No-take zones
General perimeter
Mediterranean Sea
0
7.5
15 km
SARDINIA
(Italy)

Fig. 2



Yield
Moving average
Fishing yields (g.day-1 boat-1)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2010
2011
2012

Fig. 3



Artisanal fishing
Spiny Lobster net
Fish net
Longline
25%
10%
65%
n = 245
Recreational fishing
Trolling
Spearfishing
boat Angling
6%
4%
90%
n = 53
A
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Catch repretativeness (%)
L
M
S
SL
n=25
FI
n=160
LL
n=60
T
n=48
S
n=3
A
n=2
B
Artisanal fishing
Recreational fishing