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**Distance to the marine protected area boundary
predicts the naïve behaviour to the recreational
fishing gears in a Mediterranean exploited fish
species**

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S'autoritza la Universitat a incloure el meu treball en el Repositori Institucional per a la seva consulta en accés obert i difusió en línia, amb finalitats exclusivament acadèmiques i d'investigació

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1. Resum

Les Àrees Marines Protegides (MPA) exerceixen un paper fonamental en la millora i manteniment de les poblacions naturals d'espècies exportant biomassa, en forma d'individus adults i fases primerenques del desenvolupament, a àrees subjacents explotades per la pesca. Aquesta biomassa exportada manté estable la biodiversitat de les poblacions exposades a l'impacte de l'home (pesca, contaminació, pèrdua de habitats...). A més provoca directament l'augment de la ràtio de captures per part de la pesca comercial i recreativa; per tant, les MPA's tenen beneficis tant ecològics com econòmics. Un estudi recent, orientat a la pesca submarina, (Januchowski-Hartley *et al.*, 2013) ha observat que la biomassa exportada fora de la reserva, presenta un alt grau d'atreviment i curiositat degut al estricte control de les activitats pesqueres realitzades dins la zona de protecció i una major vulnerabilitat a les arts de pesca. Les poblacions de peixos no estan tant habituades com les de fora a aquestes activitats, de manera que els peixos exportats a l'exterior són els primers en ser capturats. En aquest treball, s'ha realitzat un estudi a la Reserva Marina de la Badia de Palma mitjançant una tècnica de gravació submarina per comprovar si es dona el mateix patró per a la pesca recreativa de volantí per a les espècies *Serranus scriba*, *Diplodus annularis*, *Coris julis* i *Chromis chromis*; utilitzant la distància a la reserva (D) com a variable independent i el Latency Time (LT), temps que tarda un individu des que apareix fins que mossega l'esca, com a variable dependent. Els resultats obtinguts més significatius són els de *Serranus scriba*: els individus localitzats a zones properes de la MPA mostren valors baixos de LT, i a mesura que s'incrementa la D els valors augmenten. D'aquesta manera, la D pot actuar com a indicatiu del comportament d'espècies com *S. scriba* front a la pesca recreativa. Aquests resultats s'oposen, en part, a l'origen conservacionista de les MPA ja que la biomassa exportada fora de la reserva té una probabilitat molt baixa de sobreviure a la pesca.

2. Abstract

Marine Protected Areas (MPA's) play a key role enhancing and maintaining natural wild populations subjected to human disturbances through exporting biomass, in form of adults and early life-stages, to surrounded areas. This exported biomass keeps stable the biodiversity of populations exposed to the impact of human (fishing, pollution, habitat loss ...). Also, it allows the enrichment of surrounded areas to the MPA, directly increasing catch rates by commercial and recreational fisheries; and therefore the MPA's supposes ecological and economic benefits. In a recent study, focused on spear-fishing (Januchowski-Hartley *et al.*, 2013), it has been observed that the biomass exported outside the reserve has a high degree of boldness and curiosity to the fishing gears due the strict control of fishing activities performed inside the protected area, even this fish biomass has become more vulnerable to fishing years. In this study, it has been done an study the Palma Bay Marine reserve where the researchers wanted to check if the same pattern occurs in recreational fishing as hook and line, through an autonomous underwater video recording device, for the species *Serranus scriba*, *Diplodus annularis*, *Coris julis* and *Chromis chromis*; using the distance to the boundary (D) as a independent variable and a parameter named as Latency Time (LT), time taken for an individual since that appears to bite the bait, as a dependent variable. The most significant obtained results are from *Serranus scriba*: individuals located in close areas to the MPA show low values, and as the D increases so does the LT. So, D can act as an indicative of fish behavior as *S. scriba* front recreational fishing. These results contradict, in part, with conservationist origin of MPA as biomass exported to outside the reserve has a lower probability to survive from fishing.

3. Introduction

No-take Marine Protected Areas (MPAs) are considered a key management tool for the conservation of worldwide marine fisheries resources (Russ *et al.*, 2004), even when the species are mainly targeted by the recreational fisheries (Roberts *et al.*, 2001). The ecological basis of success of MPAs relies in the spatial protection of marine fauna through banning harvesting activities allowing, increasing the biomass to reach natural level inside the protected area (Cinner & Aswan, 2007). As many recreational fisheries exploit coastal marine species with high site fidelity and pelagic early life-stages (see. e.g. March *et al.*, 2010; Alós *et al.*, 2011; Koeck *et al.*, 2013), the benefits of the no-take MPAs are extended to the surrounded areas in form of spillover of adult and early life-stages biomass (Gell & Roberts, 2003; Lester *et al.*, 2009). In fact, the exportation of adult biomass through density-density dependent processes and the dispersal of early-life stages generated inside the MPAs have been documented to play a major role avoiding genetic changes induced by fishing (Russ *et al.*, 2004). No-take MPAs and the structure of the meta-population has, therefore, important role maintaining natural populations and ensuring sustainable yields in the worldwide fisheries (Agardy, 2000).

However, the purely conservational issues benefits of exporting biomass from the no-take MPAs to the surrounded exploited areas is under debate as the large vulnerability of the exported biomass to the fishing gears. Januchowski-Hartley *et al.* (2013) has recently pointed out that no-take MPAs export biomass which is highly vulnerable to the fishing. This high vulnerability has benefits enhancing protected areas for stock fisheries purposes, but produce limited benefits when the objective is the biodiversity conservation (i.e. exported biomass will be quickly removed from the population) . There is growing evidence that the D is good predictor of the flight initial distance (FID) which is highly representative of the vulnerability of fish to spear-fishing (i.e. fish located near to the MPAs needs takes more time in make the first flight (Januchowski-Hartley *et al.*, 2013). This is supported by the fact that fish inside no-take MPAs are expected to naïveté behave in the presence of human (Guidetti *et al.*, 2008). Although there still is limited

empirical evidence, all of this new information suggests that fish takes more time to escape (less distance) from the presence of a human or spear-gun (the basis of the FID) in gradient of distance from the boundary of a no-take MPA and therefore an increase of the vulnerability of the fish biomass exported from the MPA to the spear guns. How no-take MPAs export biomass vulnerable to passive recreational fisheries such as hook-and-line is, however, not considered yet.

The behavioral traits play a major role on determining the vulnerability of fish to passive recreational gear with hooks or lures (Alós *et al.*, 2014). There is growing evidence that the individuals more aggressive, bold, more explorative and active fish are more easily captured by anglers are removed from the wild population (Biro and Post 2008; Sutter *et al.*, 2012; but see Wilson *et al.*, 2011), leaving behind individuals that are intrinsically less vulnerable and harder to catch (Philipp *et al.*, 2009; Sutter *et al.*, 2012). Because there is genetic variance associated on behavioral traits and personality-related traits (Conrad *et al.*, 2011), fishing with passive recreational gear has the potential to induce selection on behavioral phenotypes with implications for sustainable yields of wild stocks (Uusi-Heikkilä *et al.*, 2008). The fish behavior plays, therefore, a key role on the fate of wild individuals to the angling gear and provides us a suitable background to test the hypothesis that no-takes MPAs export naïveté adult biomass to the angling gear as in the case of spear fishing (Januchowski-Hartley *et al.*, 2013).

Theoretically, the ban of recreational angling on no-take MPAs should maintain vulnerable and naïve phenotypes/genotypes in their protected waters. Density-dependent processes (Abesamis & Russ, 2005; Gruss *et al.*, 2011) and marine currents (Gaines *et al.*, 2003) should export such as new vulnerable and naïve biomass from the no-take MPA to the surrounded areas through the spillover. This effect should be more enhanced in close areas to the MPA and therefore, as the D has been suggested to be highly correlated with the spillover from MPAs (Harmelin-Vivien *et al.*, 2008). However, testing the idea that the D is a predictor of the naïveté fish behavior to the angling gear (hooks or lure) is not trivial and has to deal with some challenges compared to spear fishing. First, as a direct interaction between human and fish doesn't exist (as is not the case of spear

fishers), the quantification of the behavior is not a easy question. Autonomous underwater video recording devices to record the behavior of the fish when they were exposed to baited hooks can provide a suitable solution for quantify behavior in their wild environment (e.g., Løkkeborg *et al.*, 1989; Mallet and Pelletier, 2014). Second and different to the metric FID, the latency time (LT) to bite a piece of bait or take the lure (as a surrogate of capture) has the challenge that some fish cannot finally ingest it. This is because vulnerability or probability to be captured depends on the final decision of the given fish to bite or take the lure (Uusi-heikkilä *et al.*, 2008). Therefore, the quantification of the naïvete degree of fish to the hooks and lures in marine environments has to consider some complex technological innovations and statistical approaches to solve the problems of fish that don't take the bite before testing any hypothesis related to the spillover of biomass.

In this study we deal with these two challenges to test the hypothesis that, similar to spearfishing, no-take MPAs exports highly vulnerable to the angling gear biomass to the surrounded area. We tested our hypotheses by measuring the LT in fish exposed to the angling gear using an autonomous underwater video recording device in a gradient of D. We expected that species that are known to be more vulnerable to the recreational gears, experience smaller LT in locations close to the boundary indicating an increase in their vulnerability than species that are non-vulnerable to recreational angling. We considered four species (one high vulnerable, two exploited but with no evidence of recreational fishing effect and one fully unexploited) to support our hypothesis. To provide evidence for spillover of naïveté adult biomass we specifically tested the effect of the interaction between $D \times$ species, and we expected an only statistical significant effect in the vulnerable species which should be significant to discard environmental related factors (fish could change their behavior due a hypothetical environmental gradient to the MPAs). We studied the case of a small no-take MPA located in the Mediterranean. The Mediterranean Sea has special interest for the question studied here, as it's a hotspot for marine biodiversity highly vulnerable to fishing (Coll *et al.*, 2012) and the number of no-take MPAs has increased notably in the two last decades to counteract human-related impacts (Francour *et al.*, 2001). Moreover, the role of MPAs in recreational fisheries for the sustainability of the natural resources has

recently emphasized (Font and Lloret, 2014) and the negative impact of angling on life-history of exploited species and their indirect effect on food webs and coastal ecosystems reported (Alós *et al.*, 2014). Therefore, if our hypothesis receive empirical support, we provide for the first time a link between fisheries benefits of MPAs, but that contradict conservational benefits of Mediterranean MPAs for surrounded exploited areas for biodiversity conservational purposes.

4. Materials and Methods

4.1. Species evaluated and study site

We studied the boat recreational angling fishery of the *Posidonia oceanica* seagrass meadows in the Mediterranean Sea (Morales-Nin *et al.*, 2005) and the no-take MPA of Palma Bay. The fishery is characterised by a species-rich fish community that is primarily based on small-bodied coastal fish species that have confined home ranges (Cardona *et al.*, 2007; Alós and Arlinghaus, 2013; March *et al.*, 2014). Three of the most frequent are *Diplodus annularis* (Sparidae), *Coris julis* (Labridae) and *Serranus scriba* (Serranidae) which are the mainly species observed in the fish bags of the anglers (Morales-Nin *et al.*, 2005). Although, they are frequently harvested by the angler, these species have different levels of vulnerability to recreational angling. First, there is growing evidence that the depletion of biomass by recreational angling can alter the wild populations of *S. scriba*. Cardona *et al.* (2007) reported a negative relationship among the relative abundance, biomass and average size of *S. scriba* and the recreational fishing intensity. Alós *et al.* (2013) and Seytre *et al.* (2013) have reported similar result, and exploitation across a gradient from the MPAs to open access areas resulted in lower intensities of *S. scriba* in the exploited areas than in the protected. Alós *et al.* (2014), have recently reported that the exploitation of *S. scriba* by recreational angling may induce strong effect on the life-history of this species with a result of a downsizing of adults with implications for the fisheries sustainability.

The high vulnerability to recreational angling has been attributed to the bold behaviour of this species (Alós *et al.*, 2014), the large mouth area with respect

of the body size (Karpouzi and Stergiou, 2003), his strong site fidelity (March *et al.*, 2010) and because it's a species ecologically less frequent than the other two species. This is not the case of the other two species, and recreationally-induced effects on the wild populations have been never observed in *D. annularis* and *C. julis*. There is no a clear evidence that the depletion of biomass by recreational angling can alter the wild populations of these two species. In all cases, the single effects of the relationship between biomass and density and recreational fishing pressure was not significant (see e.g. Cardona *et al.*, 2007; Alós and Arlinghaus, 2013) or even positive (Seytre and Francour, 2014) for *D. annularis* and *C. julis* which suggests that the biomass extracted by recreational angling for these species could be ecologically not relevant, or at least not as important as in *S. scriba*. Because that reason, we considered *S. scriba* as exploited and vulnerable to angling and in *D. annularis* and *C. julis* as exploited but not vulnerable to angling. To support our working hypothesis we expected a strong change in the behaviour in *S. scriba* across a gradient of D rather than in the other two species. We also considered the case of *Chromis chromis* (Pomacentridae) as a specie very rare in the anglers bags (but very occasionally can appear in the fish bags of the boat anglers, see Morales-Nin *et al.*, 2005), but ecologically highly abundance in the seagrass for control for possible environmental gradients and to separate it from the D-related effects on the fish behaviour.

Fig. 1. Picture of the four species studied here: *Serranus scriba* (Serranidae), *Coris julis* (Labridae), *Chromis chromis* (Pomacentridae) [Author: Guillermo Felix] and *Diplodus annularis* (Sparidae) [Author: Robert A. Patzner, available in: <http://www.fishbase.org/>]

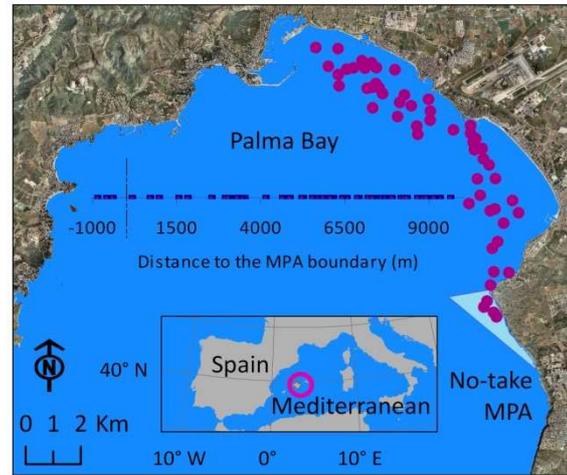




The study was carried out in an MPA located in Palma Bay in the southern part of Mallorca Island (NW Mediterranean; Fig. 2). The Palma Bay MPA extends from the coastline to the 30 m isobaths. Fishing activities have been regulated since 1982, albeit not enforced until the late 1990s (<http://dgpesca.caib.es>). There are two areas with different levels of protection: (1) the sanctuary area (~2 km²), where only no-take activities are allowed, and (2) a buffer area where both artisanal and recreational fishing are regulated (Fig. 1). In the buffer area, temporal closures for some areas, minimum size and numbers of gears, bag and size limits and other management regulations are stipulated. A recent benthic cartography has been developed by the local government (Direcció General de Biodiversitat, Balearic Government) under the Posidonia-LIFE project framework, where 6 different habitat types were identified within the MPA boundaries (<http://lifeposidonia.caib.es>). The different habitat types in the area are: seagrass meadows dominated by the species *Posidonia oceanica* and photophilic algae, sandy and gravel soft bottoms, a mixture of gravel and detritus, and a mixture of algae and seagrasses (AS) (Fig. 2). The area also includes a number of small artificial reefs (~1 m³) that were randomly placed in 1989. We focused our study in the no-take area as all of the extraction activities are not allowed and we used a GIS approach to spatially plot the boundary of the no-take MPA (Fig. 2). Using a GIS-based approach we generated 54 random field sampling sites over the seagrass meadows of *P. oceanica* in the shallow waters to obtain a gradient of distances from the boundary of the no-take MPA (Fig. 2). Field stations were separated from each other by a minimum distance of 250 m. D ranged from -1042 m (located inside the no-take MPA, Fig 2.) to 10649 m (Fig. 2). The whole selected

area is highly frequented by local anglers (Alós and Arlinghaus, 2013), but fishing pressure in the selected sites might differ.

Fig. 2. Map of the study site locations (points, $n = 54$) located in Palma Bay, Mallorca Island, NW Mediterranean where the underwater video cameras ($n = 3$) were deployed to estimate latency times (see M&M) as function of the distance of the boundary of the no-take MPA of Palma Bay (located in the east of Palma bay and marked as a grey polygon). We plotted in the centre of the MAP and one-dimensional distribution of the distances considered in the study. Note that negative distance from the boundary are located inside the no-take MPA, minimum values -1042 m and maximum distance 10649 m from the boundary (approximately x10 the home range size defined for *S. scriba*, (March *et al.*, 2010)).



4.2. Quantification of the naïve behaviour to the recreational fishing gears: the latency time estimated through underwater video recording

The measurement of fish behavior responding to the recreational angling gear in the field is a challenging issue. Different from direct observations made by human estimating the initial flight distance (FID) in spearfishing where a direct contact between fish and fisher exists, the quantification of the latency time (time of fish take the lure and being captured) require of autonomous underwater devices. In this study we used a custom autonomous underwater video recording device to record the behaviors of the fish when they were exposed to baited hooks, which simulated conventional sampling of wild individuals by hook-

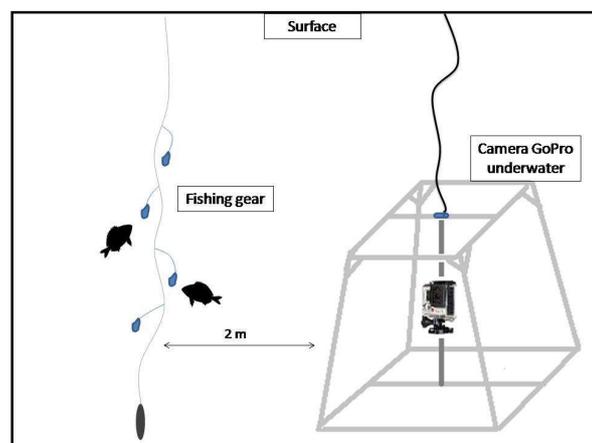


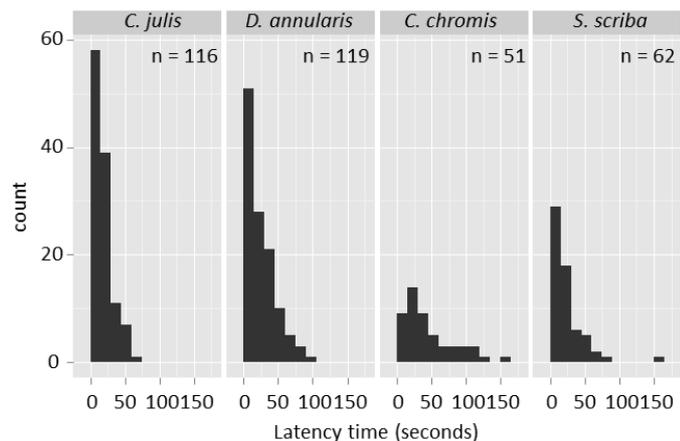
Figure 3. Structure used to carry out the recordings of videos.

and-line recreational gear in the field (Fig. 3), used by Trias (2012) in his Master Thesis. Similar to Carter (2012), in whose study a single observer measured the behavior of lizards (*Agama planiceps*) near a trap, we used the autonomous video recording system to measure the behavior of fish near the capture gear. In our study, we measured behavior using the latency time to attack a bait (as a potential food object) presented above safe refuges above the seagrass habitat. Underwater video has previously been successfully used to record the behavior of wild marine fish around baited hooks (Løkkeborg *et al.*, 1989; Godø *et al.*, 1997). The baited hook that we used was similar to those used by Cerdà *et al.* (2010) in the same fishery and involved a main line of 0.35 mm of nylon, where five hooks (number 4, gape of 7.30 ± 0.03 , $n = 10$) were mounted and baited by similar-sized pieces of frozen shrimp, *Penaeus vannamei* (Fig. 3). The hook shank was cut to prevent hooking the fish. Instead, we assumed a “theoretical capture” event whenever an individual fish ingested the bait, which was visible on the video material.

The experimental protocol was based on simultaneously deploying three different camera devices and baited hooks in each of the 54 sampling stations. The three cameras were identical and were deployed 50 m apart to ensure that there would be no overlap between the cameras. The cameras continuously recorded (in full high definition) over the seagrass for a period of 10 min. Once the three experimental trials in one sampling station were finished, we visited another sampling site until all of the sites were sampled at random. For logistical reasons, it was impossible to sample all 54 sites in one day. Therefore, we structured the sampling into four days (sampling time from 9:00 AM to 1:00 PM). On each sampling day, we visited a number of different sampling stations ($n = 12, 14, 15$ and 13 sampling stations per day), and the sampling day was considered a random factor in subsequent analyses. The order of sampling within days was fully randomized, which meant that we visited sampling stations spaced across the entire field site and covering both harvesting pressure sites on each sampling day. Overall, a total of 162 experimental trials (videos of 10 min duration) were obtained.

The assessment of individual behavior in relation to the hook was similar to the approach that Carter et al. (2012) used to observe lizards approaching a trap. Specifically, we measured the LT to attack the baited hooks for each visible individual of the four species after gear deployment. Visible individuals of *D. annularis*, *C. julis*, *S. scriba* and *C. chromis* were continuously monitored, and we recorded the LT as the duration in seconds from the time at which a focal fish appeared in the video field to the time at which the fish potentially approached and ingested one of the five baited hooks (s). The LT has a second challenging compared to the IFD behavioral data: some individuals behave near the bait, move around but didn't finally bite the bait. We considered the individuals that did not ingest the bait to be right-censored data (see below) and subsequently performed a survival analysis on the latency times of non-captured and hypothetically captured fish. Fig. 4 shows a summary of the sample size per species and the distribution of the LT estimated for each of the study species.

Fig. 4. Histogram of the latency times (i.e. the time that a given individual was monitored since they bite the recreational bait or left the field of the camera, right-censored data) in the four species considered in this study: *C. julis*, *D. annularis*, *C. chromis* and *S. scriba*.



4.3. Data analysis: survival analysis

We used survival analysis methods to investigate the factors that affected the time at which a particular event occurred (Hougaard, 1999). In the present case, the factor of interest was the latency time (in seconds) of an individual fish to ingest the bait after deployment, which is a measure of latency to survive the catch process. However, survival analysis implies an additional and very important challenge: not all fish ingest the bait within the duration of an experimental trial.

Therefore, the exact latency time is unknown for those fish that did not reach the endpoint of the event (i.e. theoretical capture). These partially missing data are called right-censored data (Hougaard, 1999). To account for these aspects, specific likelihood functions have been developed in several survival analysis methods (Crawley, 2007).

Multiple possible confounding variables were assessed and subsequently controlled in the modeling process. Although all of the experimental trials were conducted in seagrass meadows, we also considered the presence of specific microhabitats (e.g., the presence of rocks, sandy or muddy sediment), which generated multiple combinations of habitat types. We reduced the dimensionality of the response matrix by reducing the number of explanatory variables referred to the habitat-type using a principal component analysis (PCA) (Borcard *et al.*, 2011). The first two axes of the PCA explained 82% of the total variability, and one main microhabitat gradient was identified for each of the axes [PC1: gradient from the presence of rocks (negative scores) and sand (positive scores) and PC2: presence of mud (positive scores) in the seagrass]. We used the first two PCA components in all further analyses by adopting the scores of the first and second axes as variables that were representative of the microhabitat characteristics. Using the video footage, we also measured the density of competitors by counting the number of fish of the same and other species located in the sampling area at the moment that a focal individual of either of the two species appeared in the camera field.

We used a Cox regression model (Cox *et al.*, 2003) for describing the probability of non-capture against a set of explanatory variables. The full model included the fixed properties of the treatments (i.e. species, D, habitat type, and abundance of other fishes) and random factors (i.e. day effect). We included the interaction species \times D as it was the main important hypothesis testing (i.e. vulnerable species, *S. scriba* should significantly change its behavior to the angling gear in function of the D, but not vulnerable (*C. julis* and *D. annularis*) or control species (*C. chromis*). The probabilistic nature of the model allowed us to predict both the variation in the timing of the event and the percentage of non-captured

individuals. We used the *coxph* function from the survival library of the R package (developed by T. Therneau and T. Lumley; <http://cran.rproject.org/web/packages/survival/survival>) to estimate the model parameters of the minimally adequate model [Akaike information criterion (AIC)-based stepwise-selection using the function *step*] and the likelihood ratios of the model. The predicted capture rates at different times and for different factors (species and D) were estimated using the function *survfit* from the same library to visualize the results. We categorized of each sampling site as either close or far based on a median split of D to visualize and interpret the results, as survival plot is based in categorical variables.

5. Results

The results of the Cox regression to test the relationship between survivorship (non-biting the recreational fishing gear) and the explanatory variables showed that only the interaction between species and distance to MPA boundary was a significant predictor of the latency time (Tab. 1). Although the final model included the habitat characteristic and the single effect of species and distance they were finally non significant, and only the interaction effect (species x distance) could be interpreted as predictors of latency time (Tab. 1). The coefficients estimated were fully consistent with the hypothesis presented in this study and only the vulnerable species for the recreational fishing *S. scriba* presented a significant change on the latency time (Tab.1). This result suggests that the latency time (as a surrogate to the naïve behavior to the recreational fishing gear) changed across space increasing the latency time and the survivorship with increasing D (Tab. 1). Although the two less-vulnerable species (*C. julis* and *D. annularis*) showed the same pattern, the effect was not significant. Coherent with our expectation, *C. chromis* presented the larger latency time, with a very limited number of fish that bit the recreational bait (5.9%) as this species is non-vulnerable for recreational fishing suggesting that the changes observed of the naïve behavior of *S. scriba* can be attributed to the effect of protection (Tab. 1).

Table 1. Results of Survival analysis to test the relationship between survival probability (being captured) in time (in seconds), and the explanatory variables: species x distance to MPA boundary (m), habitat characteristics (CA1 and CA2), density of other fishes and the random factor day of sampling. The table shows the Cox regression coefficients (coef) and its standard error (se) of the logarithm of the hazard ratio, the z-value and p-value of the minimal adequate survival model after AIC maximization (see M&M). The p-values for overall significance of the model is also presented as the Likelihood ratio test as well as the Concordance of the model and R-square of good fitness. *significant **highly significant ***very high significant

Variable tested	coef	s.e.(coef)	z	Pr(> z)	
<i>D. annularis</i>	-1.07	0.35	-3.07	<0.001	**
<i>C. chromis</i>	-3.21	1.10	-2.93	<0.001	**
<i>S. scriba</i>	0.84	0.34	2.51	<0.05	*
Distance	0.00	0.00	-0.55	0.59	
Habitat (CA1)	-0.16	0.10	-1.57	0.12	
<i>D. annularis</i> x distance	8.55E-05	5.60E-05	1.53E+00	0.13	
<i>C. chromis</i> x distance	-1.03E-04	1.88E-04	-5.46E-01	0.59	
<i>S. scriba</i> x distance	-3.76E-04	6.75E-05	-5.57E+00	<0.001	***

R-square= 0.327 (max possible= 0.991)

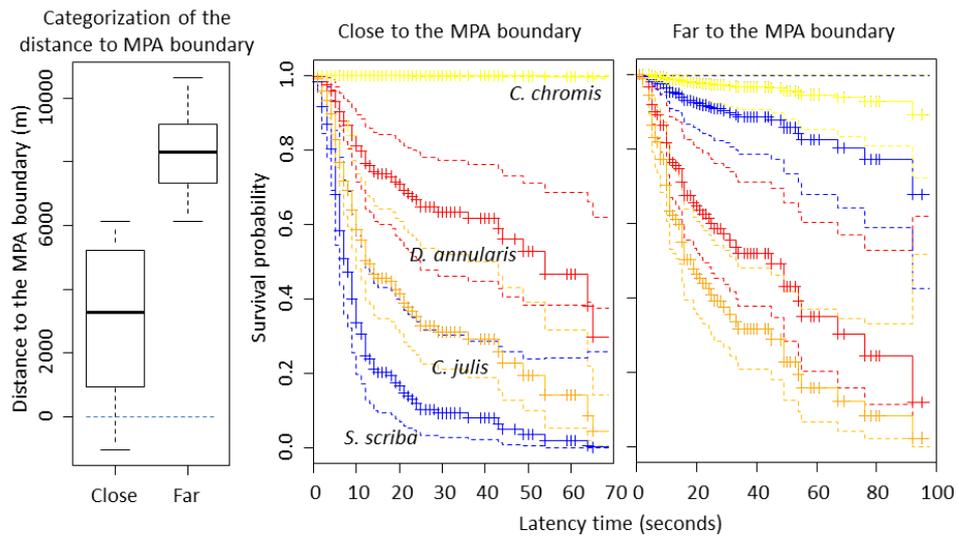
Likelihood ratio test= 138 on 8 df, p<0.001

Concordance= 0.734 s.e. = 0.026)

To visualize the results of the Cox regression, the explanatory variable R was categorized in two categories (close and far to the boundary) and the survivorship probabilities across time were plotted for the four species in the two distance categories (Fig. 5). The survivorship plot fitted for the field station ,categorized as close to the MPA boundary, shows that *S. scriba* was the most naïve species to the recreational fishing gear: most of the individuals showed very small latency times (the 80% will be theoretically captured within the first 10 seconds) in comparisons with the other species (Fig. 5). This suggested a large vulnerability of *S. scriba* compared to the other species. Most of the *C. julis* and *D. annularis* will be also theoretically captured within the first minute of recreational bait exposition; especially for *C. julis* with the 50% of fish will be captured during the first 30 s (Fig. 5). *C. chromis* remained invulnerable to the recreational fishing gear and the probability of survivorship was close to 1 across all the time (Fig. 5).

The survivorship plot fitted for the field station categorized as far to the MPA boundary was similar to those observed in the close locations, with the clear exception of *S. scriba*, as the interaction effect species x distance was significant (Fig. 5). All *C. julis*, *D. annularis* and *C. chromis* behave in the same way than close locations to the MPA, although the first two species increased in a non-significant way their latency times in far locations from the MPA (Fig. 5). In contrast, *S. scriba* changed their behavior and was much less naïve to the recreational fishing gear increasing the distance to the MPA boundary (Fig. 5). In fact, in such as far locations, only the 20% of the fish will be the theoretically captured within the first minute, while in areas close to the MPA almost the 100% of the fish will be captured (Fig. 5). This suggests that the distance to the MPA boundary is a good predictor of the naïve behavior of *S. scriba* in accordance to our work hypothesis, and MPA could be exporting through spillover naïve biomass which is highly vulnerable to recreational fishing gears. The absence of change in the behavior on *C. chromis*, and the limited effect on *C. julis*, *D. annularis* suggest that our prediction is independent of any environmental factor and can be attributed to the effect of the protection.

Fig. 5. Predicted survivorship of the Cox regression fitted to explore changes in the latency time (seconds) to bite recreational bait and the probability to theoretical survival (no-capture) in function to the distance of the MPA boundary (m). The left panel show a box-plot the categorization of the variable distance to the MPA boundary (see M&M) in two categories: close (average \pm standard deviation, 3017.3 ± 2269 m, and far 8254.8 ± 1143.9 m) to improve visualization of the results. The vertical blue dashed line shows the boundary of the MPA. The right panels show the Predicted survivorship across time for the four species studied here: *C. julis* (orange), *D. annularis* (red), *C. chromis* (yellow) and *S. scriba* (blue), in study sites close and far study site locations. The solid lines show the survival distribution and the shaded lines show the confidence intervals (\pm 95%) for each species. Note the change of the survival distribution in close and far locations to the MPA boundary experienced by the vulnerable to the recreational fishing species *S. scriba*, and the absence of change in the other species. Also note the smaller vulnerability (probability of survivorship) of *C. chromis* as non-exploited species.



6. Discussion

We have found empirical evidence that D is a significant predictor of the behaviour to the recreational fishing gear in the vulnerable species *S. scriba*. Individual fishes located in places close to the protected areas where recreational angling is not allowed showed a consistent naïve behavior to the recreational gear as they show very small LT (time to bit the hook). In contrast, *S. scriba* inhabiting places far from the protected area shows large LT to the recreational fishing gear, even some fish never bit the hook. Because the small home range of *S. scriba* (March *et al.*, 2010), we can discard that an individual moves from places located far too close of the protected area and vice versa. Therefore, the findings obtained here supports the recent idea of spillover of naïveté fish form MPAs proposed by Januchowski-Hartley *et al.* (2013), for spear fishing based on the initial-flight distance behavioral metric. Therefore, our study suggest that this exported biomass (through early life stages or adult) is highly vulnerable to recreational fishing gear which as benefits for the fishery (as exported fish enhances catch rates) but conflicts with more biodiversity conservation issues.

Januchowski-Hartley *et al.* (2013) has recently advocated that the spillover from MPAs to the surrounded areas is characterized by fish highly vulnerable which conflict with the conservational objectives of the MPAs. Therefore, similar to

hunting (Ciuti *et al.*, 2012), fishing gears can generate “seascapes of fear” where exploited places generates an increase in the timidity of wild exploited animals. Our results support this hypothesis and fish that inhabit locations far from the MPAs behaves very different from those located near to the MPAs creating safe areas in this so-called seascape of fear (Januchowski-Hartley *et al.*, 2011). In the Mediterranean, as many worldwide coastal areas, the number MPAs has increased notably during the last decade to enhance biodiversity. In fact, the Mediterranean Basin has been considered one of the most important hotspot for the biodiversity worldwide subjected to many different types of human disturbances, including pollution, fishing or habitat fragmentation (Coll *et al.*, 2012). Therefore, understanding the role of MPAs on fish communities is a key aspect ensuring sustainability, and determining the fate of the spillover and the whole biomass exported to the surrounded areas is a fundamental question for the conservation of the marine Mediterranean resources. Our work, therefore, deals with an important aspect for the conservation of resources with implications for the society, as marine resources play a key role in the Mediterranean human populations.

Prior to discuss our results we have to mention that two copied with the two major challenges quantifying behavior in marine fishes. Different to spearfishing (Januchowski-Hartley *et al.*, 2011; Côte *et al.*, 2014; Guidetti *et al.*, 2008), in passive fisheries such as recreational hook-an-line fishing there is no a direct interaction between human and fish. Therefore, the quantification of the naïve behavior to the gear is challenging. We dealt with this issue using a novel approach based in an autonomous underwater video recording device that allowed us to monitor the behavior of fish around the fishing gear. Autonomous underwater has been widely used for the study of the fish behavior (e.g., Løkkeborg *et al.*, 1989; Mallet and Pelletier, 2014) , and here we applied to quantify for the first time to the fishing recreational gear. The second methodological aspect of our behavioral metric is that, different to the FID, our measure of LT involves the fact that some fish cannot finally take the bait. We successfully copied with this issue by adopting a survival analysis of the analysis of the LT. This allowed us to incorporate right -censored data (fish that was

monitored but the event was not observed) in to the modelling process to test how the LT change across distances. This statistical approach allowed to us, not only the proportion of fish vulnerable to be captured, but also how fast they were captured. We hope our methodological contribution stimulate ecologist and fisheries scientist to adopt similar methods and perform in the further a large-scale comparative study incorporating more MPAs to make our conclusions broader.

S. scriba is well known to be highly vulnerable to fishing, compared to the other species (Alós *et al.*, 2014). Our results obtained in our analysis of the LT in sites close to the MPA (as they are more similar to the natural environments) supports this idea. If we consider this site located in areas close to the MPA, individuals of *S. scriba* are much more vulnerable compared to *D. annularis* and *C. julis* because they showed very small LT and most of the fish was captured just few seconds of exposure of the recreational fishing gear. In fact, after just a minute all fish is captured. This fact strongly support the high vulnerability of *S. scriba* to the recreational fishing gear, and is in agree with the literature suggesting that their hunger behavior can increase the vulnerability of this species when compared with other species. There are few studies comparing the vulnerability of different species to fishing, however, they also found that *S. scriba*, an in general fish with larger mouth areas are more vulnerable to fishing with hooks (Karpouzi and Stergiou, 2003). In fact, *S. scriba* has been catalogued as a predatory fish of the seagrass (despite of their small body size) (Pinnegar and Polunin, 2000) and in general, predatory fish are highly vulnerable to the recreational fishing gear (Donaldson *et al.*, 2011). Therefore, our measure of LT can be considered highly representative of the individual vulnerability and we obtained a good measure to quantify naïve behavior and therefore test our hypothesis related to D.

This high vulnerability of *S. scriba* to the recreational fishing gears is not consistent across D, which support the general hypothesis tested in this study: *S. scriba* inhabiting places far from the MPA boundary showed a different behavior in front to the fishing gears. First, most of the theoretical captured fish (fish that bite the bait) spent larger LT compared to those individuals inhabiting areas close to

the MPA. Second, although many fish took many time exploring the recreational fishing gear, they finally didn't take the bait. In fact, the proportion of non-captured fish ranged from almost 0% to 70% in sites close and far from the MPA boundary respectively. This means that most of fish inhabiting areas far from the MPA will never captured. This fact was not so evident in the low vulnerable species *C. julis* and *D. annularis*, and although there was a tendency in the same line of *S. scriba*, the differences were not finally significant. Therefore, we can discard a strong response of the R in the LT in species that are low exploited. The absence of change in the LT of *C. chromis* (our control species for environmental changes), suggests that the change in the behavior observed in *S. scriba* can be attributed to the D rather than a potential gradient of any environmental variable that covariates with D. Therefore, the general hypothesis tested of this study has received substantial support.

The change of the behavior observed in *S. scriba* in function of R have different implications, both ecological but also social related. First, as it was mentioned early in this discussion, MPAs can notably contribute to the generation of "seascapes of fear" in exploited fish, or areas where fish is especially timid. This has notable implications for deeply understanding the ecosystems functioning (Wolf and Weissing, 2012). For example, more "timid" fish are expected to forage in a limited area reducing the number of prey consumed and therefore altering food web and social structure (Mittelbach *et al.*, in press). In fact, there is growing evidence documenting the existence of personality/temperament in fish, defined as a suite of behaviors that are correlated with each other and are consistent over time and contexts within individuals (Sih *et al.*, 2004; Sih *et al.*, 2012). Our measure of latency time is probably one of the many aspects of boldness personality (Toms *et al.*, 2010). But as we did not measure repeatability and/or individual consistency, this prevents us from interpreting our single measure as a personality trait. However, others have reported that recreational fisheries select for boldness and aggression (Cooke *et al.*, 2007; Philipp *et al.*, 2009; Sutter *et al.*, 2012; Klefoth *et al.*, 2013) which suggests that the naïvete behavior measured here could be a boldness-related traits. This suggest that MPAs induces a decrease in the average degree of avoidance behavior becoming shy in *S. scriba*, at least in front to the

human predator. This finding is consistent with the recent literature evidence for harvesting-induced adaptive changes in behavioral traits (e.g., Biro and Post, 2008; Wilson *et al.*, 2011; Alós *et al.*, 2012; Carter *et al.*, 2012; Ciuti *et al.*, 2012; Klefoth *et al.*, 2012; Olsen *et al.*, 2012; Sutter *et al.*, 2012; Januchowski-Hartley *et al.*, 2013). Therefore our results suggests that spillover form MPAs is characterized by bold fish and that's the cause of the increased vulnerability.

The second consequence of our results considers the good relationship between animal productivity and boldness. There is many evidence across taxa (see the review by (Biro and Stamps, 2008) and in fish (Conrad *et al.*, 2011) that bold individual have a larger growth capacity and are more productive in terms of biomass. This link could contribute to the large biomass observed in most of the of MPAs worldwide compared to exploited areas (Edgar *et al.*, 2014) because bold individuals have a larger ability to reach larger sizes and weight (biomass) independently of protection. In fact, there is evidence for more bold fish inside MPA (Guidetti *et al.*, 2008). Our work supports this idea, but further work is needed involving more MPAs and considering aspects of life-history (growth or reproduction) to validate this hypothesis. The link between boldness and individual productivity has, however, their counterpoint considering fish living in places far to the protected areas (timid fish or fish invulnerable to the fishing gears). Becoming more timid is the right strategy to stay alive in highly exploited fished areas as our results show. However, those surviving fish should be less productive (growth and biomass) and therefore the quality of the fisheries become poor as fisher and angler derive satisfaction from high catch rates and yields (Arlinghaus, 2006). Therefore, our work suggests that MPAs has an indirect benefit to the fisheries providing vulnerable fish that can maintain satisfaction of the anglers and fishers in acceptable levels.

In direct relationship with the catch rates is the third and final implication of our work. We found that increasing D decreased to the vulnerability (or probability of being captured) to the recreational fishing gear. This has direct implications to the catch rates as well and an increase on D should also induce decrease in the catch rate. Hilborn and Walters (1992) defined the concept

hyperdepletion as a mechanism that would explain why catch rates decline more drastically than fish abundance. Although hyperdepletion and its complement (i.e., the hyperstability of catch rates (Hilborn and Walters, 1992)) should be common in exploited systems, few mechanistic studies have studied the behavioral processes that lead to hyperdepletion. Our work provides a mechanism of hyperdepletion and suggests that the interpretation of the decrease of the catch rate in function of R based on fishery-dependent data (from the catch rates) can be highly biased because a mismatch between catch rates and true abundance. In fact, the decrease in the abundance from MPAs to exploited areas based in catch rates might look much worse than it actually is, which feeds the current debate about whether catch rates are representative of true abundance (Branch *et al.*, 2011; Agnew *et al.*, 2013; Pauly *et al.*, 2013). More studies such as the present one are needed to fully understand the magnitude of sampling bias and its implications for stock assessments and the recommendation derived from them. Before such research becomes available, one should be careful when inferring spillover trends from passive sampling methods such as recreational angling, or long-lining because change towards more timid behavior increasing D.

Finally one should consider the question of: What's the mechanistic process that generates this relationship between R and boldness (if we consider LT as one aspects of boldness)? Recently, Côté *et al.* (2014) suggested two potential mechanism that can induce the same pattern: the selective exploitation of bold fish or the forgetting of the information acquired through learning. As presented in the introduction, there's growing evidence that more bold, explorative and active fish are prone to be captured by fishers ((Biro and Post, 2008; Philipp *et al.*, 2009; Sutter *et al.*, 2012), but see (Wilson *et al.*, 2011)) leaving behind individuals that are intrinsically less vulnerable and harder to catch (Philipp *et al.*, 2009; Sutter *et al.*, 2012). This selective process, however, should enhance bold phenotypes inside protected areas where all fishing activities are not allowed. Because there is genetic variance associated to the boldness degree, spillover from MPAs through early life stages should be characterized by bold phenotype/genotypes (Conrad *et al.*, 2011; Mittelbach *et al.*, in press). Moreover, due the growing evidence that adult fish, like many other vertebrates, show consistent individual differences in

their behavioral patterns including boldness (Conrad *et al.*, 2011), adult fish that move from MPAs to exploited areas due to the density-dependent processes should be more bold individuals. As there is substantial evidence that both types of spillover (adult and early life-stages) are more pronounced in places close to the MPAs, this could explain the relationship between D and boldness in *S. scriba*.

The second mechanism focuses on the ability of fish to alter their behavior after learning from previous encounters with predators, which includes fishing gear (Warburton, 2003; Brown *et al.*, 2013). Such deviations from normal behavior have been well documented in catch-and-release (non-lethal) recreational fisheries (Beukema, 1968; Anderson and LeRoy Heman, 1969; Beukema, 1970; Raat, 1985; Young and Hayes, 2004; van Poorten and Post, 2005; Askey *et al.*, 2006; Klefoth *et al.*, 2013). Fisheries where the primary goal is consumption have received less attention, but there's also documented examples for seined fisheries (Handegard *et al.*, 2003; Özbilgin and Glass, 2004; Ryer, 2008) and spear fishing (Guidetti *et al.*, 2008; Januchowski-Hartley *et al.*, 2013). However, with the absence of fishing predation risk (as in the case of MPAs) this information previously acquired is expected to rapidly disappear (Brown *et al.*, 2013). Therefore, fish located in protected areas where fishing is banned should eventually increase the naïve behavior to the fishing gear inside the protected areas, also explaining the relationship between boldness and D. In that case the response should be related of plastic responses through fish learning rather than a genetic explanation. In all case, and with our experimental design, we can fully disentangle the mechanistic that causes the relationship between naïve behavior and D. In fact, any similar work can provide an answer of the exact mechanism that produces this pattern worldwide. To answer this question one should adopt more complex approach including genetics and multidisciplinary research involving oceanography to understanding the final fate of early life-stages in the Mediterranean. Our work, has therefore opened a new line of research for the conservation of the exploited marine resources.

Finally, fish behavior plays a key role in determining and moderating the impact of fishing on wild populations because it affects the vulnerability of

individual fish to fishing gear (Uusi-Heikkilä *et al.*, 2008). Despite its importance technological limitations in tracking fish at fine scales in the wild has prevented the behavioral dimension of fisheries to be largely unexplored (Conrad *et al.*, 2011) and more studies are needed to understand how the behavior of fish interacts with exploitation and fisheries management (Arlinghaus *et al.*, 2013). We hope our contribution contribute to enhance the link between conservationists, fisheries scientists and behavioral ecologists with the aim of protecting marine resources.

7. Conclusions

It's not the first nor will be the last study that shows an empirical evidence for behavioral changes on fish species caused by fishing activities. More specifically, spillover of no-take MPA's to close areas may increase the ratio's catches of recreational and artisanal fishing. In addition, these fishes present a naïve behavior (more curiosity and boldness) caused by the almost lack of fishing gears in the reserve, remember that there's many fish regulations in the MPA's, and when they move to the not protected area are more likely to be captured by fishers. In this study it has been observed this behavior change in *Serranus scriba*, the results observed for other species as *Diplodus annularis* and *Coris julis* haven't been significant. These changes in behavior of vulnerable species, as *Serranus scriba*, can be very negative for the productivity and survival of the species, with clear implications for the ecosystem and fisheries.

Thus, behavioral changes related with fisheries impacts to MPA's must be studied because it interfere negatively with population dynamics. MPA's and surrounding areas must be managed correctly, with a strict regulations for recreational and commercial fisheries; and above all it should be understood that fish spillover are essential to maintain and preserve our marine resources and also sustainably manage recreational fishing that is a widespread activity in the Balearic Islands.

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