Spearfishing in the Balearic Islands (western Mediterranean): affected species and yield

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In this study, we quantify the pressure of spearfishing on fish communities in rocky coastal habitats of the Balearic islands (western Mediterranean). The study was carried out in four marine protected areas. Spearfishing affected at least 35 species of fishes and cephalopods, among which the most abundant were *Diplodus sargus*, *Octopus vulgaris*, *Mullus* spp. and *Sciaena umbra*, with an intrinsic vulnerability index of 65.43, a value considered to be between high and very high. A decreasing trend over time for the mean of the capture per unit effort (CPUE) (kg/spear fisherman·h) was shown, but an increasing trend over time in the mean size of the more representative species (*D. sargus*, *S. umbra*, *Epinephelus marginatus*, *Scorpaena scrofa* and *Labrus* spp.) was also observed. The results support the assumption that spearfishing may lead to changes in the trophic structure of rocky fish communities in the Mediterranean coasts because it is especially efficient with respect to high trophic level species that have a long life, slow growth and low reproductive potential.
Keywords: *spearfishing, catches, vulnerable species, CPUE, western Mediterranean*.

PESCA SUBMARINA A LES ILLES BALEARS (MEDITERRÀNIA OCCIDENTAL): ESPÈCIES AFECTADES I RENDIMENT. En aquest estudi es quantifica la pressió que la pesca submarina exerceix sobre les comunitats de peixos dels hàbitats rocosos litorals en el Mediterrani i s'ha dut a terme en quatre àrees marines protegides de les illes Balears (Mediterrània occidental). La pesca submarina afecta un mínim de 35 espècies de peixos i cefalòpodes, de les quals les més abundants foren *Diplodus sargus, Octopus vulgaris, Mullus* spp. i *Sciaena umbra*, i l'índex de vulnerabilitat intrínseca de la modalitat és de 65.43, un valor considerat entre alt i molt alt. S'observa una tendència decreixent en el temps de la captura per unitat d'esforç (CPUE) mitjana (kg/pescador·h) però, alhora, coincideix amb una tendència creixent amb el temps de la talla mitjana de la majoria d'espècies més significatives (*D. sargus, S. umbra, Epinephelus marginatus, Scorpaena scrofa* i *Labrus* spp.). Els resultats recolzen l'assumpció de què la pesca submarina pot provocar canvis en l'estructura tròfica de les comunitats de peixos litorals d'hàbitat rocós de la costa Mediterrània atès que és especialment eficient amb les espècies de nivell tròfic alt que tenen una vida llarga, un creixement lent i un potencial reproductiu baix.
Paraules clau: *pesca submarina, captures, espècies vulnerables, CPUE, Mediterrània occidental.*

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Introduction

Recreational fishing is a popular leisure activity that is estimated to account for 10% of the total fishing catches in the Mediterranean Sea (European Commission, 2004). In the Balearic Islands, it is one of the leisure activities with the most participants; in 2021, a total of 47,592 recreational licences were active, out of a total of 1,219,404 inhabitants (unpublished data from GDFMM, 2022).

Due to the intense activity with respect to the number of participants, catches and effort, recreational fishing can cause significant impacts on marine fish populations (Coleman *et al.*, 2004, Radford *et al.*, 2018), and consequently, there is growing concern about its effects on ecosystems (Schroeder and Love, 2002; Cooke and Cowx, 2004; Lewin *et al.*, 2006). Spearfishing may have negative effects on the specific composition, relative abundance and length frequencies, hence affecting coastal ecosystems (Russell, 1977: Harmelin *et al.*, 1995: Coll *et al.*, 2004; Lloret *et al.*, 2008; Frisch *et al.*, 2012). Specifically, spearfishing can modify the abundance and reproductive potential of some coastal fish populations with serious consequences for their viability (Grau, 2008). It can also change the composition and demographic structure of fish communities in rocky habitats, as in certain species, larger mean sizes and higher abundances have been recorded in areas where spearfishing is not allowed (Garcia- Rubies and Zabala, 1990; Francour, 1991; Harmelin *et al.*, 1995; Jouvenel and Pollard, 2001; Coll *et al.*, 2004; Birkeland and Dayton, 2005; Rius, 2007; FAO, 2016).

Some studies have assessed the effect of spearfishing in the western Mediterranean. In the studies from the Balearic Islands, the published data came from spearfishing competitions and were partially biased by the scoring system, which included specific rules such as minimum weights (Coll *et al.*, 2004). In some particular cases, the biomass extracted annually by spear fishermen can reach up to 40% of the biomass extracted by artisanal fishermen (Lloret *et al.*, 2008). Additionally, spearfishing has a direct effect on large sedentary coastal species characterized by slow growth, long life and high commercial value. In the western Mediterranean, these species are groupers, brown meagre, sea bass, red scorpionfish, wrasses of the genus *Labrus* and various breams (common dentex, gilthead seabream, white seabream and black seabream) (Coll *et al.*, 2012). All of these species are highly vulnerable to spearfishing (Coll *et al.*, 2004; Lloret *et al.*, 2008; Rocklin *et al.*, 2011). Furthermore, according to Morales-Nin *et al.* (2005, 2007), in the Balearic Islands, spearfishing is the recreational fishing modality with the highest catches (2.7 kg/bag) and the catches with the greater ecological and commercial value. Therefore, it is important to study spearfishing because despite being the recreational fishing modality with fewer practitioners in the Balearic Islands (between 3.6 and 4% of total), over 1,500 licences are issued each year (unpublished data from GDFMM, 2022).

There are a variety of methods available to obtain information on recreational fishing; all have their own strengths and weaknesses and are more or less appropriate according to the scale and objectives of each study (Pollock *et al.*, 1994; ICES, 2010). In general, a distinction can be made between off-site methods, in which fishermen are surveyed after fishing (for example, by telephone or e-mail), and on-site methods, in which fishermen are surveyed during or immediately after fishing, at locations near the fishing activity (Zarauz *et al.*, 2015). Off-site methods are cheaper and easier to implement and are used to collect information on recreational fishing in many European countries (ICES, 2010), but they have several biases, of which coverage, nonresponse and recall biases are the most important (Tarrant and Manfredo, 1993; Connelly and Brown, 1995; Lyle *et al.*, 2002; Vaske *et al.*, 2003). Therefore, it is advisable to carry out studies with on-site methods, which can be very diverse (collaboration of groups of fishermen who collect information on their outings; surveys or on-site inspections to estimate the catch and effort use of catch forms, fishing logs or mobile applications) and more expensive, but have achieved interesting results (Tracey *et al.*, 2011; Papenfuss *et al.*, 2015; Venturelli *et al.*, 2017; Venturini *et al.*, 2017; Martínez-Escauriaza *et al.*, 2020a).

The objective of this study is to describe spearfishing practised in 4 marine protected areas (MPAs) of the Balearic Islands in terms of fishing effort, yield, abundance and specific diversity and vulnerability of catches. We used and compared two methods of data collection: the reports of the fishermen themselves (off-site method) and inspections by marine reserve rangers (on-site method). The results are compared with those from previous studies on the effects exerted by spearfishing and with the available census data for vulnerable fish species in the study areas. This study also aims to provide essential data needed for coastal zone management, particularly in Mediterranean MPAs. (Lewin *et al.*, 2006; Steffe *et al.*, 2008; Morales-Nin *et al.*, 2010; Kayal *et al.*, 2020).

Material and Methods

Study sites

In the Balearic Islands, there are 11 marine reserves, covering a total area of 61,871 hectares, which are currently managed by the Directorate of Fisheries of the Autonomous Government of the Balearic Islands (GDFMM), and 4 maritime and terrestrial natural parks, with a total maritime area of 19,222 Ha, which are currently managed by the Directorate of Natural Environment of the Autonomous Government of the Balearic Islands. Trawling and purse-seining are prohibited everywhere in the MPAs, while recreational and artisanal fishing are allowed with the exception of spearfishing, which is banned in most of them; in Albufera des Grau Natural Park (AGNP), Palma Bay Marine Reserve (PBMR) and Migjorn de Mallorca Marine Reserve (MMMR), spearfishing is currently allowed, and in Llevant de Mallorca Marine Reserve (LMMR), it was allowed from 2007 to 2016. In the current study, the catches of spear fishermen from these 4 MPAs were analysed (Fig. 1).

AGNP was created in 1995, but in 2003, the boundaries of the park were extended to a total of 5,183 hectares in the northeast of Minorca, of which 1735 ha are marine. Spearfishing is allowed with authorization. PBMR was created in 1982 and is one of the oldest MPAs in the Mediterranean, but enforcement became effective in 2000. This reserve has an area of 2,394 hectares of coastal bottoms, up to 30 metres deep. The MPA is divided into two different zones with different levels of protection (partial reserve and integral re-

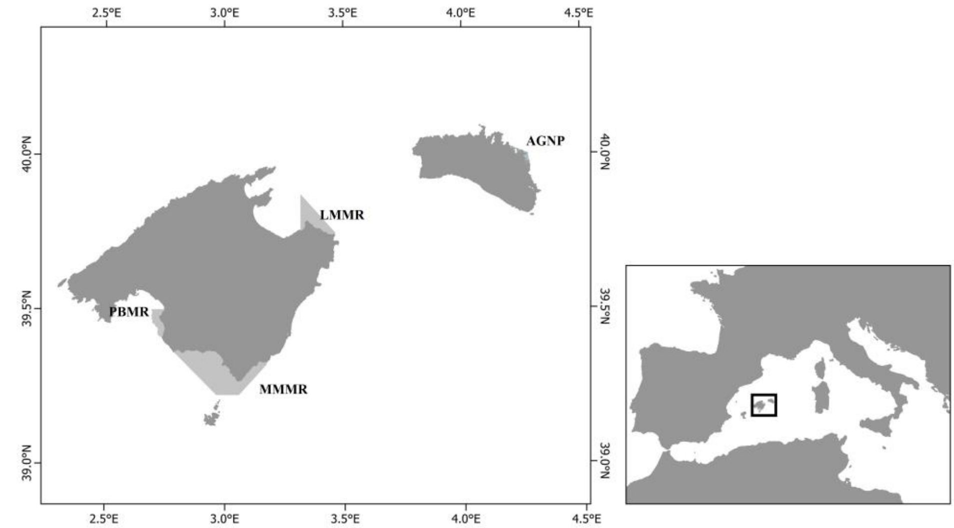

Fig. 1. Location of MPAs where the current study was carried out: Albufera des Grau Natural Park (AGNP), Palma Bay Marine Reserve (PBMR), Migjorn de Mallorca Marine Reserve (MMMR) and Llevant de Mallorca Marine Reserve (LMMR).
Fig. 1. *Localització de les MPAs on s'ha realitzat l'estudi actual: Parc Natural de l'Albufera des Grau (AGNP), Reserva Marina de la Badia de Palma (PBMR), Reserva Marina del Migjorn de Mallorca (MMMR) i Reserva Marina del Llevant de Mallorca (LMMR).*

serve). In the partial reserve, spearfishing is allowed with authorization. The MMMR was created in 2002 and comprises 22,323 hectares on the southeast coast of Mallorca. The MPA is divided into different zones with different levels of protection (partial reserve, park zone, banned recreational fishing reserve and integral reserve). Just in the partial reserve, spearfishing is allowed with authorization. Finally, the LMMR was created in 2007 and covers 14100 hectares located in the northeast of Mallorca. The MPA is divided into two zones with different levels of protection (partial reserve and integral reserve). In the partial reserve, spearfishing was allowed from 2007 to 2016; currently, it is banned.

Data collection

In the Balearic Islands, spear fishermen must have a licence, although they are not required to submit reports of their activity. Only those fishing in MPAs where this modality is allowed are required to file a daily catch statement when they go fishing. In LMMR and AGNP, data came from the spear fishermen's own declarations. However, spear fishermen often do not comply with the obligation to report, which is why reserve rangers, during their ordinary surveys, stop some of the fishermen they see and proceed to sample their catches. Thus, in the case of the PBMR and MMMR, data were obtained from the inspections carried out by the rangers.

A total of 677 records were available between 2003 and 2019: 129 from the LMMR, 250 from the MMMR, 131 from the PBMR and 167 from AGNP (Table 1). Records came from, at least, 75 different spear fishermen, but in fact, it is a minimum because in many cases the spear fisherman could not be identified. In both inspections and statements, the data recorded were date, fishing area, fishing time, number of spear fishermen, number of specimens caught identified to the lowest possible taxa level and total length of each fish. Not all information was available on all records, so some of them were discarded when data were analysed. The weight of the catches was calculated using the length-weight relationship for fish from the Balearic Islands published by Morey *et al.* (2003); for species not listed therein, relationships were obtained from FishBase (Froese and Pauly, 2022, http://www.fishbase.org). Most of the cephalopod catches are from the PBMR and MMMR and thus come from ranger inspections, who calculated the weight with a dynamometer or estimated it based on their experience.

Intrinsic vulnerability and impact on the coastal fish community

To assess the effect of spearfishing on coastal fish communities, the intrinsic vulnerability index (or vulnerability to fishing) of each species was considered (Cheung *et al.*, 2007). This index quantitatively assesses the vulnerability of the species to external factors; it is calculated using fuzzy logic expert systems and is based on the life history and ecological characteristics of marine fish, such as maximum body length, early maturity age, growth rate, natural mortality, longevity, geographic range, fecundity, and behaviour. The index value ranges from 0 to 100, and a higher value represents greater vulnerability. According to Cheung *et al.* (2005), vulnerability is classified into four levels based on its value: low (≤20), moderate (40), high (60), and very high (≥80).

year	LMMR	MMMR	PBMR	AGNP	Total
2003			19		19
2004		21			21
2005		12	20		32
2007		9			9
2008		34	52		86
2009	16	3	24		43
2010	20	3	8		31
2011	18	22			40
2012	16	3			19
2013	15	15			30
2014	22	19			41
2015	9	38			47
2016	13	18	1		32
2017		16		49	65
2018		21		118	139
2019		16	7		23
∑	129	250	131	167	677

Table 1. Summary of the number of records collected by MPA and overall between 2003 and 2019.
Taula 1. *Resum del nombre de registres recopilats per MPA i global entre 2003 i 2019.*

In addition, the mean of the intrinsic vulnerability index of all the species present in the catches, weighted according to their abundance in biomass, makes it possible to determine the degree of vulnerability of spearfishing catches in general (Cheung *et al.*, 2007; Font and Lloret, 2011; Lloret and Font, 2013) and classify the impact of the fishing modality on ecosystems based on its captures.

At the same time, regarding the vulnerability of different species to spearfishing, the criteria of Coll *et al.* (2012) and the Red Book of Fishes of Balearic Islands (Grau *et al.*, 2015) were considered. In the case of the Red Book, those classified in the categories CR (cri-

Year	n	Yield 1 Nº (fish/bag)	n	Yield 2 (kg/bag)	n	CPUE (kg/fisher/h)
2005					4	0,775 ± 0,309
2007					3	2,585 ± 0,791
2008					19	1,110 ± 1,425
2009	16	4,38 ± 1,71	15	5,988 ± 2,288	17	1,755 ± 0,839
2010	20	2,50 ± 1,47	21	2,626 ± 2,587	18	0,705 ± 0,554
2011	17	2,29 ± 1,72	17	1,708 ± 1,459	17	0,533 ± 0,275
2012	16	1,31 ± 0,87	16	0,801 ± 0,597	14	0,370 ± 0,246
2013	15	1,80 ± 1,37	15	1,093 ± 0,882	13	0,417 ± 0,237
2014	20	1,45 ± 1,00	18	0,846 ± 0,792	15	0,336 ± 0,234
2015	9	4,33 ±2,45	8	2,180 ± 1,752	9	0,966 ± 0,623
2016	13	1,23 ± 1,17	12	0,614 ± 0,612	8	0,274 ± 0,096
2017	43	2,40 ± 1,16	47	1,901 ± 1,546	43	0,525 ± 0,433
2018	118	2,34 ± 1,32	113	2,019 ± 1,657	109	0,561 ± 0,424
Overall	**287**	**2,33 ± 1,53**	**282**	**1,99 ± 1,93**	**289**	**0,671 ± 0,676**

Table 2. Yield summary. In the case of the yield 1 (nº fish/bag) and yield 2 (kg/bag), only reports from AGNP and LMMR were considered. In the case of the CPUE, only reports with fishing times equal to or greater than one hour were taken into account.
Taula 2. *Resum de rendiment. En el cas del rendiment 1 (nº peix/pesca) i el rendiment 2 (kg/pesca), només es van considerar els registres d'AGNP i LMMR. En el cas de la CPUE, només es van tenir en compte els registres amb temps de pesca iguals o superiors a una hora.*

tically endangered), EN (endangered), and VU (vulnerable) were considered threatened species.

Data analysis

All data were entered into a database using Excel. The representative parameters of the effort (fishing time) and the yield (kg/bag and number of fish/bag) were calculated exclusively with records from LMMR and AGNP reported between 2009 and 2016 (Table 2) because they correspond to completed fishing journeys. Meanwhile, records from PBMR and MMMR were made when the fishing was not over and they often did not record the total catch.

The mean catch per unit of effort (CPUE), expressed as the weight of catch per spear fisherman and hour of fishing, was computed in general and for each MPA (Table 2). Only records with a fishing time ≥1 hour (289 fishing journeys) were used. Moreover, the mean CPUE obtained from the inspections of the rangers in PBMR and MMMR (N=36) and the mean CPUE calculated from the reports of the spear fishermen of LMMR and AGNP (N=253) were compared to assess the differences between the two methods of data collection (inspections vs. statements).

The normality of the data collected was verified by the Kolmogorov–Smirnov test, and the homogeneity of the variances was verified by the Levene test. In the case of not displaying a normal distribution, data were transformed, and outliers were eliminated to reach a normal distribution. Depending on whether the data finally followed a normal distribution, different tests were applied: ANOVA or Kruskal–Wallis test to verify the existence of significant differences between means, and

Pearson R or Spearman's Rho to verify the existence of significant correlations between variables. When the correlation was significant, a linear regression analysis was applied. All analyses were performed using SPSS Statistics 22.0.

An analysis of clusters was made from the data matrix of the number of individuals per species (N=677) to detect differences in the specific composition of the catches, depending on the area of fishing or the data collection methodology. To reduce chance dissimilarities, only those species that appeared with a frequency equal to or higher than 2% were considered.

With the aim of trying to identify trends that can be related to the state of the populations and their degree of exploitation, the evolution of the mean size of species that exceeded 5% of the total captured biomass were analysed (*D. sargus, S. umbra, S. scrofa, Labrus* spp., *Mullus* spp.). The dusky grouper *(E. marginatus)* was also included, although its abundance was 3.09%, as it is possibly the species most targeted by spear fishermen in the Balearic Islands.

Results

Catch

The catch of 1,581 individuals, corresponding to 2 species of cephalopods, 29 species of fish and 3 major taxa (Mugilidae, Labridae and Mullus spp.) were recorded (Table 3). The use of major taxa is due to the lack of discernment between species of the same genus and even of the same family.

The mean fishing time of spear fishermen was 3.47 h (±1.04 sd) per journey. The ANOVA of fishing time vs. year indicated significant differences between years ($F=7.936$, $p<0.05$), and post hoc analysis showed that 2010 and 2012 were significantly different from the rest of the years, which formed a homogeneous subgroup ($p=0.075$).

In terms of yield, the overall means were 2.33 fish/bag, 1.99 kg/bag and 0.671 kg/spear fisherman·h (Table 2). In general, a wide range of values were reported; as an example, the values reported for CPUE ranged between 0 and 4,182 kg/spear fisherman·h. Consequently, the standard deviations (sd) were very high, reaching values very close to the mean. Furthermore, data about fish/bag, kg/bag and kg/spear fisherman·h did not show a normal distribution, as many records with no catches or with very few catches and, on the contrary, records with great catches were reported.

The temporal evolution of the yield parameters (Table 2) shows a general tendency to decrease (Fig. 2 A, B, C), and specifically in the case of CPUE, the correlation is significant (Rho = -0.015, $p = 0.79>0.05$). Although the study includes catches collected between 2003 and 2019, the years when the lack of data did not allow these parameters to be calculated were excluded (2003, 2004, 2005, 2007, 2008 and 2019).

In addition, the mean CPUEs of the MPAs considered in this study were significantly different ($p=0.0349<0.05$), ranging from 1.561 kg/spear fisherman·h in PBMR to 0.559 kg/spear fisherman·h in AGNP (Table 4). However, when CPUE was compared only between the MPAs with the same methodology of data collection (PBMR and MMMR on the one hand and LMMR and AGNP on the other), the differences between them were considerably reduced (Table 4). The mean CPUE of inspections (PBMR and MMMR) was 1.455 kg/spear fisherman·h (±1.580), while the mean CPUE of the reports (LMMR and AGNP) was much lower at 0.575 kg/spear fisherman·h (± 0.455); thus, they were significantly different ($p=0.0071<0.05$).

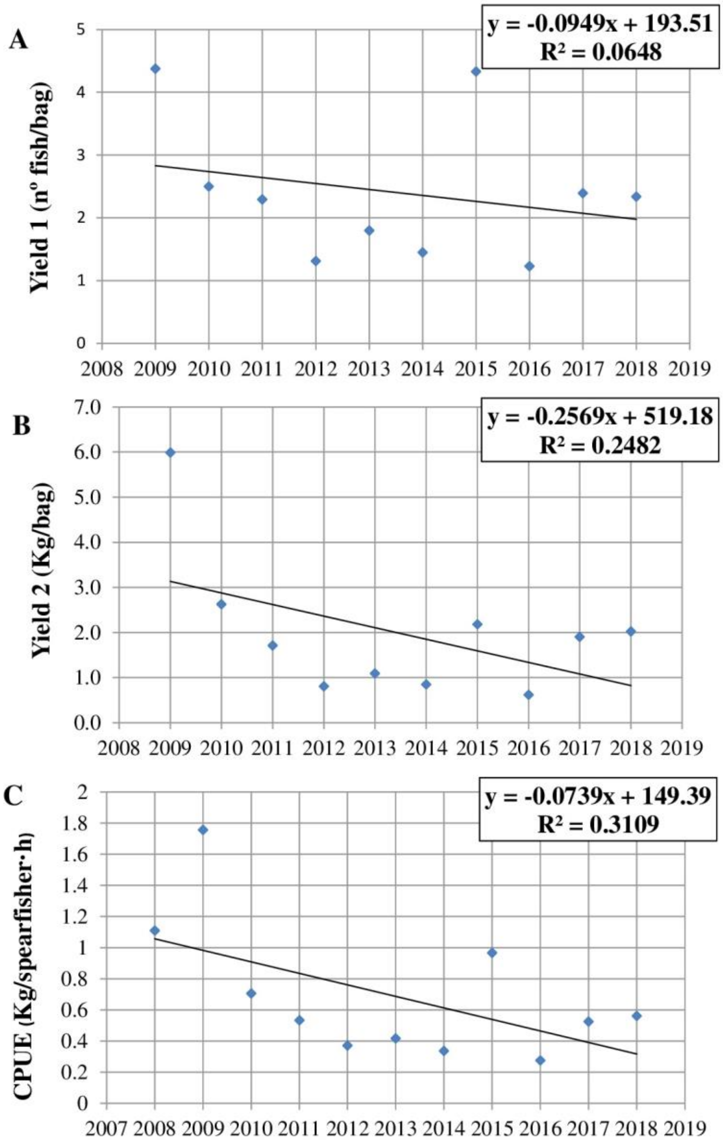

Fig. 2. Temporal evolution of the yield parameters: mean of n° fish/bag vs. year (A), mean of kg/bag vs. year (B) and mean of CPUE (kg/spear fisherman·h) vs. year.
Fig. 2. *Evolució temporal dels paràmetres de rendiment: Mitjana de n° peix/pesca vs. any (A), mitjana de kg/pesca vs. any (B) i mitjana de CPUE (kg/pesca·h) vs. any.*

Catch	nº fish	Size range (cm)	Mean Lt (cm)	LMS(cm)
Diplodus sargus*	449	19-48	29,13	35
Octopus vulgaris	150			
Sciaena umbra	114	23-57	37,54	30
***Mullus* spp.**	111	15-31	23,47	11
***Labrus* spp.**	112	16,5-42	31,13	25-27**
Scorpaena scrofa	96	21,5-35	28,84	25
Seriola dumerili	65	25-60	36,36	
Epinephelus marginatus	49	27-79	50,31	50
Symphodus tinca	44	15-37	22,58	18
Dentex dentex	42	28-70	43,69	35
Sphyraena spp.	41	45-110	71,7	
Dicentrarchus labrax	41	36-68	51,78	43
Spondyliosoma cantharus	36	22-40	31,17	20
Mugilidae	28	18-51	36,82	16
Sparus aurata	27	34-56	43,07	35
Diplodus vulgaris	23	15-34	24,94	18
Balistes capriscus	22	36-50	42,13	
Diplodus puntazzo	21	18-28	24,94	18
Sepia officinalis	20			
Scorpaena porcus	19	23-31	25,31	19
Sarpa salpa	14	15-35	25,5	18
***Phycis* spp.**	13	35	35,00	
Muraena helena*	10	80-99	89,5	95
Serranus scriba	9	14-22	17,43	14
Lichia amia	7	35-98	64,5	
Lithognathus mormyrus	5	24-30	27,00	20
Epinephelus costae*	3	38-55	46,5	53
Diplodus annularis	3	16-35	25,5	12
Umbrina cirrosa*	1	23,2*		35
Scorpaena notata	1			
Pomadasys incisus	1	24		
Oblada melanura	1	31,5		
Coryphaena hippurus	1	61		
Conger conger*	1	86		95
∑=	1581			

Table 3. Specific diversity of catches. Number of specimens, size range in cm, mean of Lt in cm and the minimum legal size (MLS) in cm per species. *(*)* Species with a mean Lt under MLS. (**) The MLS of *L.viridis* is 27 and that of *L.merula* is 25.

***Taula 3.** Diversitat específica de les captures. Nombre d'exemplars, rang de mida en cm, mitjana de Lt en cm i talla mínima legal (MLS) en cm per espècie. (*) Espècies amb una Lt mitjana sota MLS. (**) La MLS de* L.viridis *és de 27 i la de* L.merula *és de 25.*

Affected species

Regarding the capture of species considered vulnerable to spearfishing in the western Mediterranean (Coll *et al.*, 2012), catches of all species were recorded in the four MPAs under study (Table 5), with the exception of *S. cantharus*, of which no catch was reported in the PBMR. Together, they accounted for 61.14% of the biomass. By MPAs, they represented 65.56% in the LMMR, 56.91% in the MMMR, 43.36% in the PBMR and 77.74% in the AGNP. Some of these species (brown meagre, seabass and gilthead seabream) are considered threatened or nearly threatened by Grau *et al.* (2015) (Table 5). Concerning the intrinsic vulnerability index (Cheung *et al.*, 2005), all of them, except *Labrus* spp. and *S. cantharus*, have a value between mode-

CPUE (kg/fisher/h)	n	Mean	sd
Inspections:			
PBMR	23	1,561	1,820
MMMR	13	1,267	1,072
∑ inspections	**36**	**1,455**	**1,580**
Statements:			
LMMR	100	0,599	0,483
AGNP	153	0,559	0,436
∑ declarations	**253**	**0,575**	**0,455**

Table 4. Mean CPUE and standard deviation (sd) by MPAs and reporting methodology.
Taula 4. *CPUE mitjana i desviació estàndard (sd) per MPA i metodologia de recopilació de dades.*

rate (40 out of 100) and very high (90 out of 100) (http://www.fishbase.org). The weighted intrinsic vulnerability index of the spearfishing modality calculated from the catches of the current study was 65.43, which is considered high (between 60 and 80 out of 100).

The frequency of the most abundant species (≥2%) per study area (Fig. 3) showed that although almost all species were present in the 4 MPAs, some differences existed. For instance, there were few catches of *Octopus vulgaris* and Mugilidae in the LMMR, and the catches of *S. scrofa* and *S. dumerili* were practically non-existent in the PBMR, as were those of *S. tinca* in the LMMR and the AGNP. However, the analysis of clusters of the matrix of the number of individuals by species, considering only those that were fished with a frequency ≥2%, showed that there were no differences in the specific composition, thus not allowing us to characterize the catches according to the marine reserve or the method of data collection.

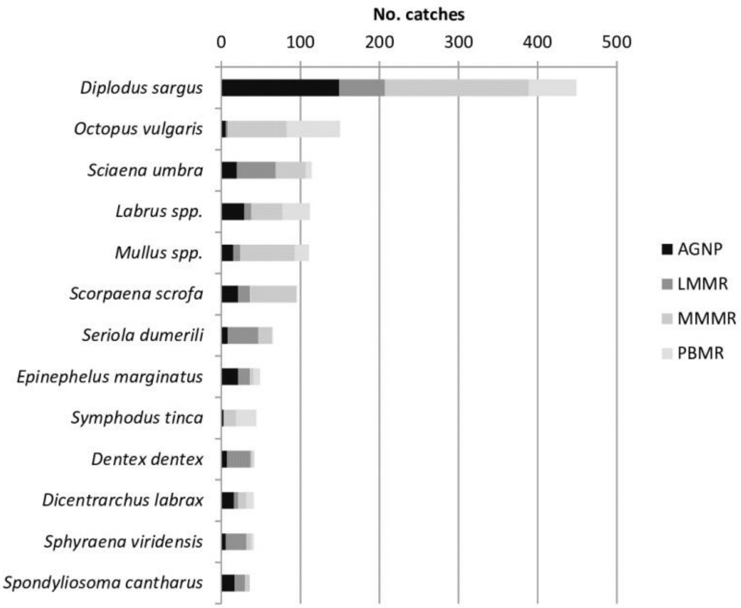

Fig. 3. Number of specimens of the more abundant species (>2%), reported between 2003 and 2019.
Fig. 3. *Nombre d'exemplars de les espècies més abundants (>2%), reportades entre 2003 i 2019.*

Species	Red List of Balearic Islands	Intrinsic vulnerability index	% LMMR	% MMMR	% PBMR	% AGNP	% MPAs
D. sargus	LC	63	19,21	29,59	20,98	39,00	28,33
S. umbra	NT	64	16,23	6,18	2,45	5,23	7,19
***Labrus* spp.**	LC	34-44*	2,98	6,34	12,24	7,59	7,07
S. scrofa	LC	68	4,97	9,59	0,35	5,50	6,06
E.marginatus	LC	72	4,97	0,81	2,80	5,50	3,09
D. dentex	LC	64	9,93	0,49	0,70	1,83	2,65
D. labrax	VU	69	1,66	1,79	3,15	4,19	2,59
S. cantharus	LC	37	4,3	0,98	0	4,45	2,27
S. aurata	NT	40	0,99	0,98	0,35	4,45	1,7
E. costae	LC	66	0,33	0,16	0,35	0,00	0,19
Σ % vulnerable species to spearfishing			65,56	56,91	43,36	77,74	**61,14**

Table 5. Summary of % of vulnerable species per MPA (LMMR, MMMR, PBMR and AGNP) and in general (MPAs) and their category in the Red List of Balearic Islands and the intrinsic vulnerability index (Cheung *et al.*, 2005). (*) The intrinsic vulnerability index of *L.viridis* is 34 and that of *L.merula* is 44.

Taula 5. *Resum del % d'espècies vulnerables per AMP (LMMR, MMMR, PBMR i AGNP) i en general (MPAs) i la seva categoria a la Llista Vermella de les Illes Balears i l'índex de vulnerabilitat intrínseca (Cheung et al., 2005). (*) L'índex de vulnerabilitat intrínseca de* L.viridis *és de 34 i el de* L.merula *és de 44.*

Sizes of the most relevant species

Regarding the distribution of sizes (Fig. 4), in general, the catches respected the minimum legal size (MLS) established in the Balearic Islands at the time of their capture; only in the case of *E. marginatus* and *Labrus* spp. did not so. For E. *marginatus,* considering the MLS established at the time and the area of fishing (Council Regulation (CE) 1626/94; Order of the Councillor of Agriculture and Fisheries, 2006a, 2006b; Decree 21/2007; Decree 41/2015), 22.6% of the individuals were smaller than the regulatory size. With respect to the species of the genus *Labrus* considered in the current study *(L. merula* and *L. viridis)*, many rules had modified the respective MLS (Order of the Councillor of Agriculture and Fisheries, 2006a, 2006b; Decree 21/2007; Decree 41/2015), and the fact that fishermen sometimes did not differ between the two species only allowed us to estimate the % of individuals below the MLS according to the regulations forced at the time and the area of their capture, which was between 17.3 and 25.5% of all pieces collected. Concerning *D. sargus*, 97.3% of the catches exceeded the minimum size at the time of their capture (Council Regulation (EC) 1626/94; Council Regulation (EC)1967/2006; Decree 21/2007; Decree 34/2014), even considering that between 2007 and 2014 in the LMMR, this size was 25 cm.

For *S. umbra*, since 2014 in the Balearic Islands, the species has a minimum size of 30 cm for recreational fishing (Decree 34/2014), and since then, only 2 individuals of all reported (5.1%) did not exceed the MLS, but considering all the catches reported in our study and the specific minimum sizes established in 2006 in the PBMR and the MMMR (Order

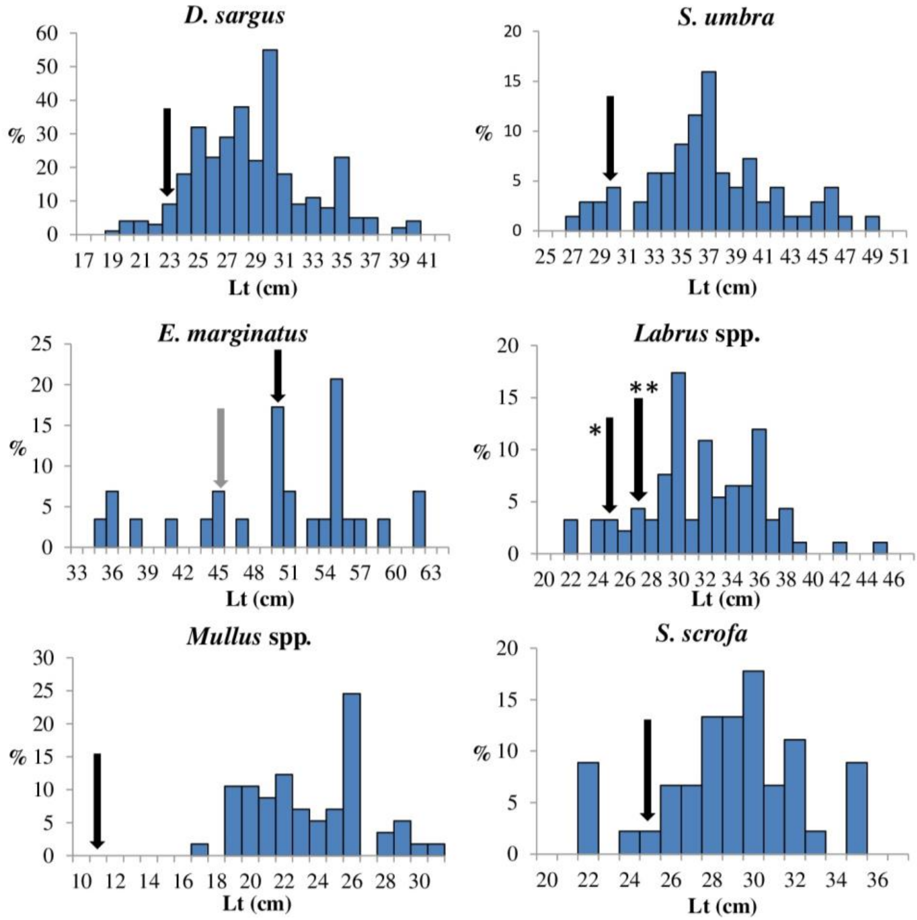

Fig. 4. Size distribution frequency of the most abundant and/or relevant species. The arrows indicate the LMS current status of each of the species within the MPAs of the Balearic Islands. In *E. marginatus*, the gray arrow indicates LMS outside MPAs. In *Labrus* spp. (*) indicates LMS of *L. merula* and (**) indicates LMS of *L. viridis.*

Fig. 4. *Freqüència de distribució de la mida de les espècies més abundants i/o rellevants. Les fletxes indiquen l'estat actual de talla mínima legal (LMS) de cadascuna de les espècies dins les MPAs de les Illes Balears. En* E. marginatus*, la fletxa grisa indica LMS fora de les MPAs. A* Labrus *spp. (*) indica LMS de* L. merula *i (**) indica LMS de* L. viridis.

of the Councillor of Agriculture and Fisheries, 2006a, 2006b) and in 2007 in the LMMR (Decree 21/2007), the percentage of illegal catches reached 11.5%. With regard to *S. scrofa*, a minimum size of 25 cm was also set for recreational fishing in 2014 (Decree 34/2014), and since then, only 3 undersized individuals (6.5%) of all those inspected and reported have been detected. Finally, all catches of *Mullus* spp. exceeded the minimum size (11 cm, Regu-

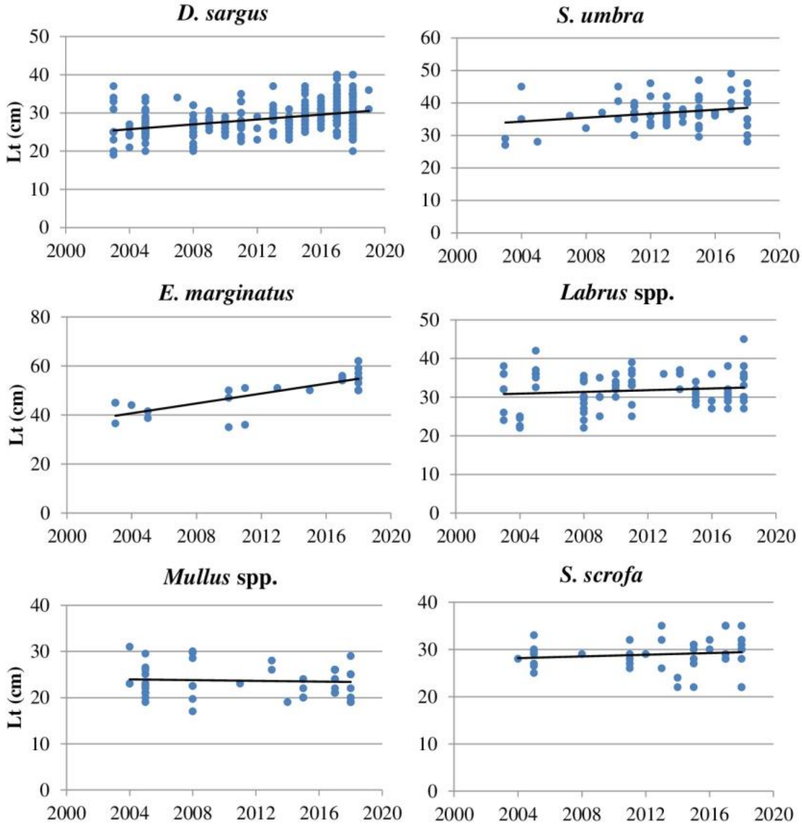

Fig. 5. Representation of the size (cm) of the specimens caught between 2003 and 2019 and linear regression of the most relevant species of the study.

Fig. 5. *Representació de la mida (cm) dels exemplars capturats entre 2003 i 2019 i regressió lineal de les espècies més rellevants de l'estudi.*

Species	n	Lt=a·(year)+ b	r^2	Correlació	p	F	p
D. sargus	323	y = 0,3208x -617,13	0,1456	0,393*(1)*	0,000*	58,740	0,000*
S. umbra	69	y = 0,3042x -575,44	0,059	0,252*(1)*	0,036*	4,559	0,036*
E. marginatus	29	y = 1,01x -1983,4	0,6118	0,782*(1)*	0,000*	45,550	0,000*
S. scrofa	45	y = 0,0898x -151,83	0,0158	0,126*(1)*	0,410	-	-
***Labrus* spp.**	92	y = 0,1113x -192,19	0,0168	0,129*(1)*	0,218	-	-
Mullus spp.	57	y = -0,0405x +105,13	0,0044	-0,085*(2)*	0,530	-	-

Table 6. Results of the correlation test (R de Pearson and Rho de Spearman) and linear regression analysis. *(1)* Pearson R Correlation Test. *(2)* Spearman's Rho correlation test. *(*)* Sig. <0.05; is significant at the 0.05 level.

Taula 6. *Resultats del test de correlació (R de Pearson i Rho de Spearman) i anàlisi de regressió lineal. (1) Test de correlació R de Pearson. (2) Test de correlació Rho de Spearman. (*) Sig. <0,05; és significatiu al nivell 0,05.*

lation (EC) 1967/2006).

The evolution of the mean sizes of the most relevant species (Fig. 5) over the years considered by the study (2003-2019) showed a tendency to increase in *S. scrofa*, *Labrus* spp., *D. sargus, E. marginatus* and *S. umbra*, although only the last three significant correlations and their linear regressions were significant (Table 6). In the case of *Mullus* spp. the mean size showed a tendency to decrease, but it was not significant (Table 6).

Discussion

In the northwestern Mediterranean, spearfishing has documented the capture of at least 47 species of fish, two cephalopods and a decapod crustacean (Chavoin and Boudouresque, 2004; Coll *et al.*, 2004; Lloret *et al.*, 2008; Rocklin *et al.*, 2011; Blanco-Magadán, 2019). This study identified 2 species of cephalopods, 29 fish and 3 major taxa (Mugilidae, *Labrus* spp. and *Mullus* spp.) (Table 3), a specific diversity that fits with that found in other areas of the northwestern Mediterranean and similar to that obtained in other studies of the Balearic Islands. Thus, Coll *et al.* (2004), for a total of 11,272 individuals in spearfishing championships throughout the Balearic Islands, recorded 31 species and 4 major taxa (Serranidae, Mugilidae, Sphyraena spp. and Labridae) and Blanco-Magadán (2019), for a total of 467 individuals, registered 2 species of cephalopods, 27 of fish and 3 major taxa (Mugilidae, *Sphyraena* spp. and *Mullus* spp.) in the Natural Park of s'Albufera des Grau (Menorca).

Spear fishermen in the Balearic Islands showed the same preferences as in other parts of the Mediterranean Sea. Thus, six of the species *(D. sargus, O. vulgaris, S. umbra, S. scrofa, L. merula* and *L. viridis)*, which in our study appeared more frequently (≥5%), coincided with the 7 species considered the main target of spear fishermen (HT) by Rocklin *et al.* (2011) in the Bonifacio Strait Nature Reserve (Corsica). The only species considered HT by Rocklin *et al.* (2011) that did not appear among the most caught in our study was *Sparus aurata*, which is a rare fish in the waters of the Balearic Islands, to the point that Grau *et al.* (2015) considered it a nearly-threatened (NT) species. Otherwise, in our study, *D. sargus* was clearly the most abundant species, reaching almost 25% of the reported specimens.

The main differences between the specific composition of Coll *et al.* (2004), obtained from the results of spearfishing championships, and the present study were due to the bias generated by the scoring system of the competitions, where the gastronomic value of the species is not taken into account and no cephalopods or elasmobranchs can be caught. For this reason, *O. vulgaris* did not appear in the study of Coll *et al.* (2004), while in the current study, it was the second most abundant species (9.5%), being one of the target species of spear fishermen, as already reported in previous studies (Chavoin and Boudouresque, 2004; Rocklin *et al.*, 2011; Martínez-Escauriaza *et al.*, 2020b). On the other hand, in the spearfishing championships large-scale species were caught (between Mugilidae, *Sarpa salpa* and *Dactylopterus volitans*, they add up to 20.07%), which in the Balearic Islands have no gastronomic or commercial interest and represented a low percentage in our study (2.64%). The study of the specific composition based on the statements and the inspections of the MPA rangers allowed us to see the real catches without the bias caused by the regulation of spearfishing championships.

Sedentary species of large, slow-growing, long-lived coastal fish are very vulnerable to spearfishing (Coll *et al.*, 2004; Lloret *et al.*, 2008; Rocklin *et al.*, 2011) and accounted for 61.14% of the total catch in the present study (Table 5). By MPAs, the AGNP had the highest proportion of vulnerable species (77.74%), followed by the LMMR and MMMR, with 65.56% and 56.91%, respectively, and finally, the PBMR, with 43.36%, which, despite being the lowest, is still a considerably high percentage. The fact that species considered vulnerable accounted for such a high fraction of the reported catch, together with the fact that these species do not recover in the same way as those in integral areas or marine reserves where spearfishing is banned, as shown in the monitoring reports of PBMR, MMMR and LMMR (Morey *et al.*, 2018; Grané *et al.*, 2019; Morey *et al.*, 2019, respectively), justify more restrictive regulation for this modality.

Of the 31 species and 3 major taxa identified in our study, 5 were classified as threatened (CR, EN, VU) or near threatened (NT) by Grau *et al.* (2015) -*S. umbra, S. dumerili, D. labrax, S. aurata*, and *U. cirrosa*-, accounting for 15% of the specific composition. This is a higher percentage than the 12% calculated by the IUCN (Malak *et al.*, 2011) for native marine fish species in the Mediterranean Sea (65 species out of a total of 519). Respecting the mean intrinsic vulnerability index of the modality, this was 65.43, a value considered between high and very high. This result is slightly higher than the 64.7 obtained by Lloret *et al.* (2019), calculated from the results of 20 Mediterranean coastal areas (Italy, France and Spain). In addition, the study by Lloret *et al.* (2019) shows that 20% of the species caught by recreational fishermen in coastal waters were vulnerable and warned of the importance of differentiating between modalities and fishing tackles in terms of their impact. In this sense, in the Balearic Islands, the weighted mean intrinsic vulnerability index of recreational fishing from boats, obtained from 341 declarations of fishermen on board marine reserves (with 4,579 pieces of 43 different species), was 38.31 (Riera-Batle, 2019), significantly lower than the index calculated for the spearfishing modality, which supports the concern of Lloret *et al.* (2019) and proves the deleterious effect that the selectivity of spearfishing can have on coastal fish populations.

According to our study and considering only data from the LMRM and AGPN, which were those that reported completed fishing journeys, spearfishing was characterized by a mean effort of 3.47 h/journey (±1.04, sd) and yields of 2.33 fish/bag (± 1.53, sd) and 1.99 kg/bag (± 1.93, sd). It should be noted that the dispersion of the data reported in this regard, as has been commented on in the results, demonstrates the existence in the Balearic Islands of a small number of experienced spear fishermen, much more efficient than the rest. On the other hand, the mean CPUE calculated from the inspections by marine reserve guards (BPRM and MMRM) was 1.455 kg/spear fisherman·h (± 1,580, sd), while the CPUE calculated from the spear fishermen's statements was 0.575 kg/spear fisherman·h (± 0.455, sd). Morales-Nin *et al.* (2005), from 14 spearfishing championships held between 1998 and 2003, reported catches of 2.36 kg/bag (±0.24, sd) and an effort of 4.39 h/journey (±0.32, sd); from these data, we inferred a mean CPUE of 0.574 kg/spear fisherman·h. In addition, Coll *et al.* (2004), based on the catches of the top

10 spear fishermen championships held during the year 2000, reported a mean CPUE of 1.91 kg/spear fisherman·h (±1.09, sd). Therefore, the results of the CPUE of the present study moved within the same range of values that were reported in previous studies carried out in the Balearic Islands.

The negative time trend of all yield indicators (Fig. 2) of the current study is contradictory to the increase in the mean Lt shown by the main target species (Fig. 5). In our opinion, this contradiction could indicate that fishing restrictions within the marine reserves studied are insufficient to avoid a reduction in yield. On the other hand, this downward trend could be related to the limitation within the marine reserves of the Balearic Islands of the number of individuals per fisherman and day that was established in 2015 (Decree 41/2015), which affects the largest part of the target species of spear fishermen.

The high values obtained in terms of catches of vulnerable species (threatened and nearly-threatened species according to IUCN categories) from spearfishing, and the weighted mean intrinsic vulnerability index confirm that its effects on coastal ecosystems are clearly worse than other recreational fishing modalities. This confirmation justifies more restrictive specific regulation for this modality that has even led to banning this activity in 9 of the 11 marine reserves of the Balearic Islands.

Although the evolution of yield over the years did not show improvement, the increase in the mean size of the most captured species (≥5%), in particular *Diplodus sargus*, *Epinephelus marginatus* and *Sciaena umbra*, showed that there is some recovery of the target species presumably as a consequence of the restrictions applied to spearfishing in the MPAs of the Balearic Islands (minimum sizes, limitation of fishing days and number of catches per fisherman per day for some species). In addition, routine scientific monitoring of fish from the three marine reserves (Morey *et al.*, 2018; Grané *et al.*, 2019; Morey *et al.*, 2019) has confirmed the gradual increase in biomass of these three species, along with most commercial species associated with the rocky substrate. White seabream, dusky grouper and brown meagre are very vulnerable species to spearfishing; it is their main threat in the Balearic Islands (Coll *et al.*, 2004; Grau *et al.*, 2015), so it seems reasonable that restrictions on spearfishing are related to their recovery, as our results suggest. MPAs promote abundant populations of coastal fish, including large predatory species that take longer to recover; but over time, they are expected to regulate the abundance of lower trophic species via trophic cascades (Babcock *et al.*, 2010; Mosquera *et al.*, 2000; Rocklin *et al.*, 2011; Schroeder and Love, 2002; Molloy *et al.*, 2009; Curnick *et al.*, 2020; Kayal *et al.*, 2020). Therefore, it is essential that in areas where spearfishing is allowed, their activity has to be monitored to check the impact on the most vulnerable populations and the effectiveness of the applied management plans.

In our opinion, despite the differences between CPUEs obtained from ranger inspections and those obtained from spear fishermen's statements, the two methods have proven their validity as a system for collecting information on spearfishing. Proof of its effectiveness is the absence of differences in the specific composition between the two methods with those described by previous studies (Chavoin and Boudouresque, 2004; Coll *et al.*, 2004; Lloret *et al.*, 2008; Rocklin *et al.*, 2011).

Obtaining accurate data and information is difficult due to the large number of spear fishermen and the poor organization of the sector; although the two methods used in our study avoid the usual biases in the surveys (nonresponse and recall bias), it does not mean that they are free of any other bias. Inspections by marine reserve rangers can lead to a coverage bias because experienced spear fishermen are more likely to be inspected than less skilled fishermen, as they practice spearfishing less often (Martínez-Escuariaza *et al.*, 2020b). This bias would explain, at least in part why in the current study, the mean CPUE obtained from the inspections of the guards was higher than that obtained from the spear fishermen's own statements and closer to that of Coll *et al.* (2004), calculated from the catches of the top 10 in spearfishing competitions. On the other hand, spear fishermen with little or no experience are often less willing to provide information (Zarauz *et al.*, 2015) so that the results are usually skewed towards an overrepresentation of more experienced fishermen with higher catches. In any case, it is important to identify potential biases to better interpret our results.

It seems appropriate to continue combining the two methods evaluated in our study because they have proven to be effective for monitoring the modality and the resource, as well as being complementary. The collection of data reported by the spear fishermen themselves allows a large amount of information to be obtained quickly and involves the sector in the management, while the inspections of the rangers, apart from its deterrent effect on noncompliance, such as the capture of individuals smaller than the legal minimum (especially demonstrated in *E. marginatus* and *Labrus* spp.) serve as a validation method.

In conclusion, the confirmation of the deleterious effects of spearfishing on the coastal fish of the Balearic Islands and the validity of the declarations as a data collection system reinforce the need to maintain the restrictions for this modality and to recommend the involvement of the spear fishermen themselves in management. Effective compliance with the legal obligation to report the activity of spear fishermen within marine reserves is essential for the monitoring of the most vulnerable species and the maintenance of functional coastal natural marine systems.

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