Discards regulation vs Mediterranean fisheries sustainability
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Reducing discards in trammel net fisheries with simple modifications based on a guarding net and artificial light: contributing to marine biodiversity conservation

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Summary: Experimental fishing trials with standard (control) and modified trammel nets were conducted to assess the possible reduction of discards. The standard trammel net was the commercial net used in the area (80 mm stretched mesh inner panel) targeting *Sepia officinalis*. This configuration produced 19% discards in weight. The modifications researched were of two kinds: a "guarding net" consisting of a 2.5-mesh-high (200 mm stretched mesh) net between the footrope and the trammel net and artificial lights of two colours (white or green) mounted on the floating ropes. Catches were identified, measured and categorized (commercial, discards and reason for discarding), and the different configurations were tested for statistical differences. Our results show that trammel net deployments with guarding net produce 32% higher catches of commercial species and as much as 95% higher catches of the target cuttlefish. Artificial lights produced a low but significant increase in total catches of commercial species of 13%, with no differences due to light colour. The amount of discards in deployments with guarding net was 6%, i.e. *ca.* 1/4 of the amount produced by the standard configuration. The effect of lights on discard reduction was not significant.

Keywords: experimental fishing; discard reduction; trammel net fisheries; Mediterranean Sea; cuttlefish.

Reducción de descartes en pesca de trasmallo mediante modificaciones simples basadas en el ajuste de un faldón y luz artificial: una contribución al mantenimiento de la biodiversidad marina

Resumen: Se llevaron a cabo pescas experimentales con trasmallos estándar (control) y modificados para evaluar la posible reducción de descartes. El trasmallo estándar empleado fue el trasmallo comercial que se usa habitualmente en la zona (paño interior de 80 mm de malla estirada) que tiene por objetivo la sepia *Sepia officinalis*. Esta configuración produjo 19% de descartes en peso. Las modificaciones investigadas fueron de dos tipos: el ajuste de un faldón en la parte inferior del trasmallo de 2.5 mallas de alto (200 mm malla estirada) y luz artificial de dos colores (blanca o verde) colocadas en la relinga de flotadores. Se identificaron, midieron y categorizaron (comercial, descartes y razones del descarte) las capturas y se evaluaron estadísticamente las diferencias debidas a las distintas configuraciones. Los resultados indican que el trasmallo con faldón produjo un incremento del 32% en las capturas comerciales, y en el caso de la sepia un 95% más elevadas. La luz artificial produjo un aumento débil, pero significativo, en el volumen de capturas totales de 13%, sin diferencias debidas al color empleado. Los descartes en trasmallos con faldón fueron del 6% (es decir, cerca de una cuarta parte de la cantidad producida en la configuración estándar). El efecto de las luces sobre la reducción de los descartes no fue significativa.

Palabras clave: pesca experimental; reducción descartes; pesca con trasmallo; mar Mediterráneo; sepia.

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INTRODUCTION

The coastal small-scale fisheries practised in southern European waters employ mainly set nets as fishing gear (trammel nets and, to a lesser extent, gillnets and longlines) (Stergiou et al. 2006). Given the low economic performance of small-scale fisheries in Europe and their importance as a producer of high-quality fresh seafood of local origin (Griffiths et al. 2007, Guyader 2007), technical measures promoting their viability without increasing their impact on fisheries resources or habitats need to be introduced (Gonçalves et al. 2007, Maynou et al. 2011). Among these, the reduction of unwanted catches in small-scale fisheries can reduce maintenance and operational costs for fishermen as well as the impact on benthic communities.

Unwanted by-catch is relatively low in Mediterranean fisheries using set nets compared with that of fisheries using towed gears. In set nets, the mesh sizes employed are usually large enough to guarantee compliance with minimum landing sizes for most species (Erzini et al. 2006), while in longlines the selectivity can be reasonably controlled by the choice of hook size. However, discarding of unwanted by-catch or damaged commercial specimens is frequent and represents a cost for fishers (Gonçalves et al. 2008). Additionally, damaged commercial catches cannot be commercialized and represent a loss of income (Rossetti et al. 2006).

South European small-scale fisheries using set nets can have discards of 15-25% of the total catch (EC 2002). However, Gonçalves et al. (2008) report discards of 50% and estimate that the trammel net may be the main fishing gear in terms of ecological impact on benthic communities in the coastal zone, due to its widespread use and relatively high proportion of discards compared with other small-scale fishing gear. On the other hand, Rossetti et al. (2006) showed that large amounts of unwanted catches (non-commercial crabs or gastropods) reduced the economic profitability of the caramote prawn (*Penaeus kerathurus*) fishery in the Ligurian and Tyrrhenian sea due to the extended sorting times and shortened duration of the fishing gear.

The EU discards ban, or Landing Obligation, published in Art. 15 of EC Regulation 1380/2013 (EC 2013), was aimed at reducing discards in EU fisheries and working towards more selective fishing by incentivizing the adoption of technical solutions and other changes in fishing practices. The discards ban aims at rationalizing the fishing process by means of more selective gears and sustainable practices, which would ultimately result in more productive fisheries (Gullestad et al. 2015).

Improving size or species selectivity of trammel nets is difficult because of the different modes of capture currently encountered in trammel nets (entangling, gilling, wedging and pocketing), which depend on the species caught (Erzini et al. 2006). Among the possible solutions that can be applied to reduce unwanted catches in static nets are modifications to the inner mesh size or the hanging ratio, fitting an extra panel of non-fishing net to minimize the impact of scavenging organisms, using visual or acoustic cues to repel unwanted by-catch, and avoiding fishing grounds with potentially high unwanted catches. Testing modifications to the standard designs based on changes to mesh sizes and hanging ratios is a favoured solution to enhance trammel net selectivity, but will be beneficial for a limited number of species only. Modifications to the existing fishing gear that preclude the access of scavenging organisms to the fishing gear can be a solution to mitigate the problem of excessive unwanted catches damaged by scavengers. For instance, the guarding net has been successfully trialled in different areas of the Mediterranean (Sartor et al. 2007, Metin et al. 2009), and it has been shown to be an effective by-catch reduction device with low impact on sea bottoms. A guarding net is a piece of single net from 10 to 30 cm high positioned on the lower part of the trammel net panels to produce a physical barrier to climbing scavengers that might damage the capture (Metin et al. 2009, Rossetti et al. 2006).

The objectives of this study were to evaluate the effect of two modifications made to a professional trammel net, a) a guarding net fitted to the footrope and b) artificial lights fitted to the head rope, in terms of reduction of unwanted by-catch, catch of commercial species and undersize specimens.

MATERIALS AND METHODS

Investigated fisheries

Small-scale fisheries in the Murcia Region (SE Spain) are carried out by a large number of vessels (129 licensed units in 2016 or 72% of the local fleet: General Directorate of Agriculture and Fisheries, Region of Murcia) with length overall (LOA) between 6 and 13 m (engine power 50-100 hp) operated by a crew of two or three persons. The main fishing gears deployed during the year are trammel nets, gillnets and boat seines used to catch a variety of demersal resources. The fleet rotates the métiers practised during the year, depending on the availability of the main target species. In the case of trammel nets, the métiers are defined by the target species: for instance, in winter and spring the target species is the cuttlefish (*Sepia officinalis*), but it changes to finfish in summer and to striped red mullet (*Mullus surmuletus*) in late autumn and early winter. The fishing activity with trammel nets is carried out close to home ports, with daily fishing trips of less than 12 h. The trammel nets employed by this fishery are made of 50-m sheets for a total length of 1500 to 2000 m, and they are 1.5 to 2.5 m high.

Experimental setup

Two local fishing boats practising the cuttlefish métier were used to carry out the experiments with the modified trammel nets. In the first boat (coded "SP") two trammel nets of 1500 m length and 1.6 m high with the same technical characteristics were employed (inner panel 80 mm nylon (polyethylene) mesh, 40 meshes high; outer panel 200 mm nylon mesh, 8

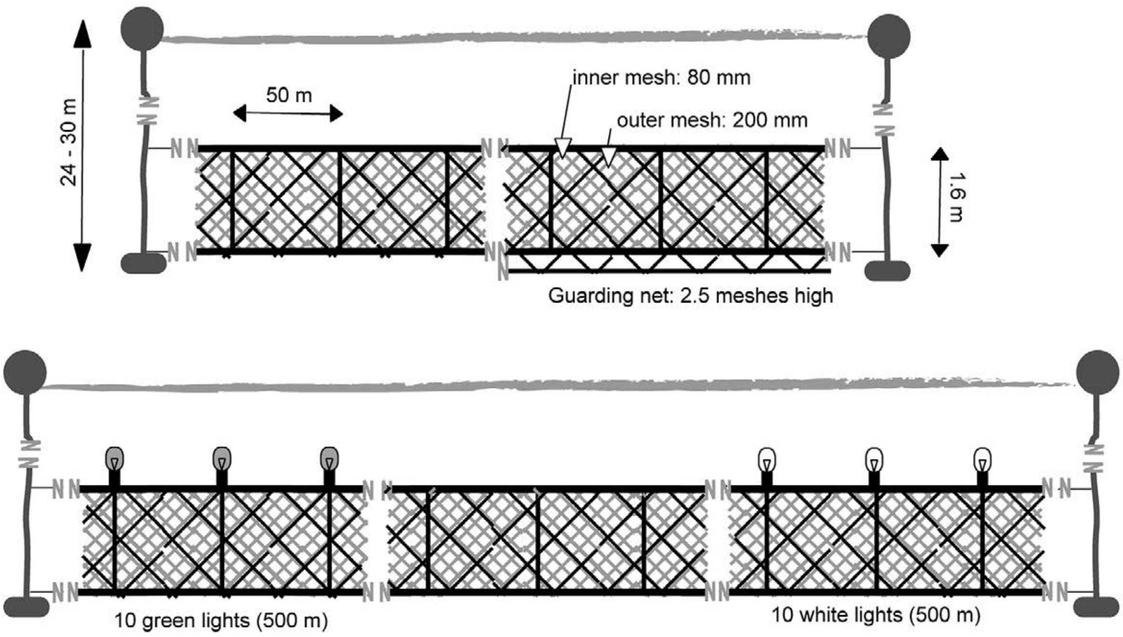

Fig. 1. – Schematic design of the trammel nets used in the experiments. Each trammel net was built of 30×50-m panels (total length 1500 m) with a vertical span of approximately 1.6 m, using 80-mm inner meshes and 200-mm outer meshes. The control trammel net is shown in the top left figure. The modified trammel net with a guarding net was created by adding 2.5 meshes (of the external type, i.e. 200 mm) between the footrope and the panel (top right). In the second experimental trammel net, the net was divided into 3×500-m sections (10 panels each). Two of the sections were fitted with green or white lights every 50 m and one section was left unmodified. The position of the three sections along the net was randomized from one day to another during the experiment.

meshes high; hanging ratio 0.82) following the usual professional configuration. One trammel net (the experimental one) was fitted with a guarding net made of 2.5-mesh-high polyethylene mesh (200 mm, twine thickness 4.2 mm) and positioned between the trammel net and the footrope (weighed rope 10 mm diameter). The other trammel net was employed without modification and served as a control (Fig. 1). From 2 to 23 March 2017, the two fishing gears were set on sandy bottoms between 24 and 30 m depth at approximately 7 p.m. and were recovered the following day at around 9 a.m. The second experiment was carried out concurrently with the first: a standard trammel net was divided into three sections of 500 m each. Two sections were provided with artificial lights fixed on the floatline (12 mm float nylon rope): one section was provided with white lights, the other with green lights (Fig. 1). The artificial lights were units employed in tuna longlining fisheries, commercialized as "LED fishing light, deep sea drop light" manufactured by Ningbo Solars Lighting Electrics (Zhejiang, China). Each unit used two AA batteries whose duration in the laboratory was in excess of one week (nominal manufacturer's specification 300 h), but the batteries were replaced every two days in each unit to avoid decreasing light intensity. The position of the three sections along the trammel net was changed randomly in each fishing operation to randomize the effect of light position. The second fishing vessel (coded "AG") only carried out the part of the experiment testing artificial lights from 10 April to 16 May 2017.

Each experimental setup was fished on ten consecutive days, on the basis of operational constraints due to weather conditions and permitted working days. For each fishing operation, the entire catch was analysed for species composition (number and weight). Non-commercial organisms were classified in three categories, D, K1 and K2, where "D" are undersize specimens of commercial species (e.g. belonging to species included in Annex III of EU Reg. 1967/2006 and therefore included in the Landing Obligation provisions), "K1" are damaged specimens of legal size that cannot be commercialized, and "K2" are marine organisms without commercial interest (usually epifaunal invertebrates).The most abundant commercial species were also measured [mantle length (ML) in cm for cuttlefish; total length (TL) in cm for fishes].

Catch data were standardized in number or weight per 100 m h (soaking time). The commercial species were analysed on the basis of standardized weight data because the possible benefits of using the experimental fishing gear will be assessed by fishers as increases in catch in weight (or in economic value). Conversely, the metric used for discards was standardized number of individuals because trammel net fishers sort the catch specimen by specimen and any reduction of unwanted catches should appear as a reduction in the number of unwanted specimens to be sorted. The immediate expected benefit of the modifications should be reduced sorting time.

Statistical analyses

The standardized catch rates in weight of commercial species (kg/100 m h) were compared by means of linear mixed models using the treatment as a fixed factor (green light, white light, no light) and the boat as a random factor. The assessment of the effect of

Table 1. – Standardized catch (kg/100 m h) and frequency of occurrence of commercial species caught by each net configuration adopted in this study. The 20 most important species in weight are highlighted in bold face.

Species	kg/100 m h	frequency of occurrence (%)	control	guarding net	green lights	white lights
Sepia officinalis	1.43	100	0.73	2.33	1.71	1.40
Dardanus arrosor	0.17	53	0.12	0.02	0.17	0.30
Bolinus brandaris	0.10	49	0.05	0.01	0.08	0.23
Uranoscopus scaber	0.26	47	0.21	0.53	0.20	0.24
Pagellus erythrinus	0.33	46	0.17	0.70	0.36	0.27
Sparus aurata	0.29	46	0.16	0.24	0.21	0.58
Hexaplex trunculus	0.04	44	0.03	0.02	0.04	0.06
Pagellus acarne	0.08	44	0.03	0.07	0.13	0.12
Dentex dentex	0.44	36	0.10	0.87	0.25	0.83
Scorpaena porcus	0.62	36	0.42		1.10	0.39
Diplodus vulgaris	0.13	33	0.03	0.13	0.15	0.25
Symphodus tinca	0.71	33	0.79		0.67	0.65
Octopus vulgaris	0.52	31	0.40	0.93	0.51	0.64
Pagrus pagrus	0.07	30	0.04	0.10	0.11	0.09
Sciaena umbra	0.28	30	0.10	0.86	0.25	0.33
Chelidonichthys lastoviza	0.14	30	0.03	0.42	0.18	0.18
Dicentrarchus labrax	0.69	27	0.35	1.01	0.79	0.88
Zeus faber	0.10	24	0.02	0.17	0.07	0.18
Mullus surmuletus	0.10	20	0.03	0.49	0.06	0.10
Spondyliosoma cantharus	0.06	20	0.03	0.09	0.06	0.09
Diplodus sargus	0.08	19	0.10		0.08	0.06
Scorpaena scrofa	0.21	19	0.06	0.93	0.09	0.11
Serranus cabrilla	0.03	16	0.01	0.11	0.01	0.04
Raja asterias	0.45	14	0.23		0.34	0.83
Solea senegalensis	0.12	14	0.06		0.16	0.20
Diplodus puntazzo	0.06	13	0.01	0.17	0.03	0.12
Lithognathus mormyrus	0.13	11	0.25		0.08	0.10
Palinurus elephas	0.16	11	0.04	0.25	0.13	0.19
Phycis phycis	0.05	10	0.02			0.08
Merluccius merluccius	0.03	9	0.02		0.06	0.05
Mullus barbatus	0.03	9	0.01		0.03	0.04
Solea solea	0.05	7	0.05		0.06	0.07
Conger conger	0.60	6	0.24	0.92	0.20	1.03
Lophius piscatorius	0.51	6	0.15		0.40	1.32
Sarpa salpa	0.24	6	0.33			0.14
Torpedo marmorata	1.47	6	1.20		2.30	0.07
Trachinus draco	0.07	6	0.01		0.03	0.12
Dactylopterus volitans	0.20	4	0.18			0.21
Diplodus annularis	0.07	4	0.07			
Lepidorhombus boscii	0.02	4	0.01			0.03
Serranus scriba	0.05	4			0.05	
Sphyraena sphyraena	0.42	4			0.40	0.48
Balistes capriscus	0.48	3				0.48
Bothus podas podas	0.01	3	0.00		0.02	
Lepidotrigla cavillone	0.01	3	0.01		0.01	
Mugil cephalus	0.34	3			0.28	0.40
Muraena helena	0.28	3			0.23	0.32
Pagellus bellottii	0.15	3	0.13			0.17
Scophthalmus maximus	0.34	3		0.54	0.13	
Squilla mantis	0.00	3	0.00			
Trachinus araneus	0.26	3	0.06	0.46		
Argyrosomus regius	0.08	1	0.08			
Euthynnus alletteratus	0.19	1				0.19
Homarus gammarus	0.32	1			0.32	
Labrus merula	0.14	1			0.14	
Loligo vulgaris	0.14	1			0.14	
Microchirus ocellatus	0.02	1			0.02	
Mustelus mustelus	0.06	1	0.06			
Oblada melanura	0.21	1				0.21
Pagrus auriga	0.09	1	0.09			
Trachurus trachurus	0.01	1	0.01			

the guarding net was carried out similarly, but without the random factor, as only one vessel was used; in this case, the linear mixed model reduces to classical ANOVA. The models were fitted with function lme of the R library nlme using the restricted maximum likelihood algorithm. The posterior difference in means for factors with more than two levels was tested by post-hoc analysis using library lsmeans. The effect of the modification was assessed by calculating its magnitude (1 = no effect) and its confidence interval (significant effect when the CI does not cross 0). The standardized number of discarded weight (ind./100 m h) was subject to a similar statistical analysis, adding the factor type of discard (D, K1 and K2).

The species composition of catches (commercial and discards fraction) was also assessed by means of descriptive multivariate analysis, comparing the species composition in the different treatments (control; lights; guarding net). PRIMER® (Clarke and Gorley 2006) routines were used to examine the ordination in

Table 2. – Standardized catch in numbers (ind./100 m h) and frequency of occurrence of unwanted catches (non-commercial species or undersize/damaged specimens of commercial species).

species	Frequency of occurrence (%)	ind./100 m h	control	guarding net	green lights	white lights
Holothuria sp.	27	54.59	10.46	4.37	19.23	20.53
Pagellus acarne	19	14.95	3.97	0.45	6.36	4.17
Raja asterias	17	10.58	2.26	0.67	5.23	2.42
Sepia officinalis	13	9.00	1.06	1.99	2.89	3.06
Torpedo marmorata	13	5.91	1.38	0.32	1.86	2.35
Astropecten sp.	12	8.67	0.95	0.67	3.47	4.24
Echinaster sepositus	11	7.30	0.98	0.40	3.40	2.51
Dactylopterus volitans	9	4.55	0.97	1.00	0.96	1.61
Dicentrarchus labrax	7	9.30	0.84	0.40	5.61	2.45
Pagrus pagrus	7	1.63	0.34	0.17	0.70	0.42
Pagellus erythrinus	7	5.85	0.89	0.40	2.91	1.65
Chelidonichthys lastoviza	7	2.46	0.24	1.40		0.82
Mullus surmuletus	6	3.19	0.36		2.00	0.83
Aporrhais pespelecani	6	5.93	0.71		4.09	1.12
Paracentrotus lividus	6	1.63	0.40		0.95	0.29
Symphodus tinca	5	3.58	0.48		2.20	0.91
Diplodus vulgaris	4	1.12	0.21	0.54	0.38	
Scorpaena porcus	4	2.64			1.77	0.87
Sparus aurata	4	1.50	0.23		0.69	0.59
Spondyliosoma cantharus	4	1.19	0.50	0.50		0.50
Diplodus annularis	3	3.04	2.04		1.00	
Myliobatis aquila	3	0.69	0.16		0.20	0.33
Sarpa salpa	3	4.33	3.32		0.71	0.31
Bolinus brandaris	2	3.90				3.90
Dardanus arrosor	2	1.93	0.88		1.05	
Loligo vulgaris	2	0.52	0.13		0.20	0.19
Scorpaena notata	2	4.28	1.89		0.67	1.72
Dentex dentex	2	0.58	0.05		0.54	
Diplodus puntazzo	2	0.56	0.06		0.50	
Hexaplex trunculus	2	6.23	2.57		1.33	2.32
Lissa chiragra	2	0.67	0.04		0.50	0.14
Merluccius merluccius	2	0.73	0.16	0.29	0.29	
Mustelus mustelus	2	0.40	0.11			0.29
Octopus vulgaris	2	1.26			0.67	0.60
Phycis phycis	2	1.04			0.90	0.14
Sciaena umbra	2	1.04				1.04
Serranus cabrilla	2	0.64	0.36			0.27
Zeus faber	2	1.20		0.40		0.80
Apogon imberbis	1	0.10	0.10			
Pagellus bellottii	1	1.24			0.67	0.57
Scyliorhinus canicula	1	0.15	0.15			
Torpedo torpedo	1	0.40		0.20		0.20
Arbacia lixula	1	0.19		0.19		
Bothus podas podas	1	0.40			0.40	
Conger conger	1	0.48	0.48			
Leucoraja naevus	1	0.40			0.40	
Mullus barbatus	1	0.04	0.04			
Oblada melanura	1	0.52	0.52			
Solea senegalensis	1	0.04	0.04			
Solea vulgaris	1	0.05	0.05			
Synodus saurus	1	0.29			0.29	
Uranoscopus scaber	1	0.68				0.68

multivariate space using non-metric multidimensional scaling (nMDS). The significance of factors (treatment guarding net or lights against control) was tested by means of analysis of similarities (ANOSIM).

RESULTS

Commercial species

During the experiments, 61 species of commercial interest were caught (Table 1). The target species, cuttlefish, was present in all nets sampled, with a yield of 1.43 kg/100 m h on average. Other important commercial species in the catch were different species of sparids (e.g. the pandora *Pagellus erythrinus*, the gilthead seabream *Sparus aurata*, the dentex *Dentex dentex*, the seabass *Dicentrarchus labrax*, the scorpion fish *Scorpaena scrofa*, the octopus *Octopus vulgaris* and, due to their individual weight though they were not frequent, the rays *Torpedo marmorata* and *Raja asterias*) (Table 1). The hermit crab *Dardanus arrosor* was very frequently caught; this species is locally commercialized as bait for hook and line fisheries, not for human consumption.

The number of taxa discarded was 53, including damaged or undersize specimens of commercial species that could not be commercialized because they were undersized or damaged (Tables 2 and 3). The unwanted catches of non-commercial species (mainly epifaunal in vertebrates) were dominated by sea cucumbers (*Holothuria* sp.) and seastars (*Astropecten* sp. and *Echinaster sepositus*). Within commercialized species, the main reason for discarding was damage (type “K1”), which was particularly important for five spe-

Table 3. – Number of fishing operations in which the commercial species indicated would have been discarded and reason: D, undersize individuals; K1, damaged individuals that cannot be commercialized.

Species	D	K1
Bolinus brandaris		2
Dentex dentex		3
Dicentrarchus labrax		12
Diplodus annularis	1	4
Diplodus puntazzo		3
Diplodus vulgaris		7
Loligo vulgaris		4
Merluccius merluccius		3
Mullus barbatus		1
Mullus surmuletus		10
Mustelus mustelus		3
Octopus vulgaris	1	2
Pagellus acarne	17	14
Pagellus bellottii	2	
Pagellus erythrinus	1	10
Phycis phycis		3
Sciaena umbra		3
Scorpaena notata		4
Scorpaena porcus		5
Sepia officinalis		21
Sparus aurata		6
Spondyliosoma cantharus		7

cies: *D. labrax*, *M. surmuletus*, *P. acarne*, *P. erythrinus* and *S. officinalis* (Table 3). Only specimens of *Pagellus acarne* and *P. bellottii* were discarded because of small size (Table 3).

The standardized yield of commercial catch species was lowest in both weight and number in the control trammel net, whereas that of unwanted catches was lowest in trammel nets fitted with the guarding net and highest in the trammel nets with lights on the head rope (Table 4). By typology of unwanted catches, the control trammel net had the highest amount of undersize fish and green lights the lowest. In terms of unwanted catches of categories K1 and K2, the trammel nets with the guarding net always had the lowest amount of unwanted catches and green lights the highest.

As regards the commercial species with frequency of occurrence higher than 30%, the yields due to the different net configurations were compared. The total commercial catch was 32% higher in the trammel nets with the guarding net than in the standard configuration (Fig. 2). This was due mainly to the increased catches of the target species *Sepia officinalis* (increase of 95%), *Octopus vulgaris* and some sparids (*Diplodus vulgaris*, *Dentex dentex* and *Pagellus erythrinus*) (Fig. 2). Notably, the catch of the gastropods *Bolinus brandaris* and *Hexaplex trunculus* showed no difference, while the catches of *Dardanus arrosor* were significantly lower with the guarding net (Fig. 2, see also Supplementary Material, Fig. S1).

The yields of the most frequently caught commercial species were tested also for the effect of artificial lights (Fig. 3). Overall, the commercial catch was significantly higher (around 13%) in the trammel nets with head rope lights, but no statistical differences were observed between green or white lights. This re-

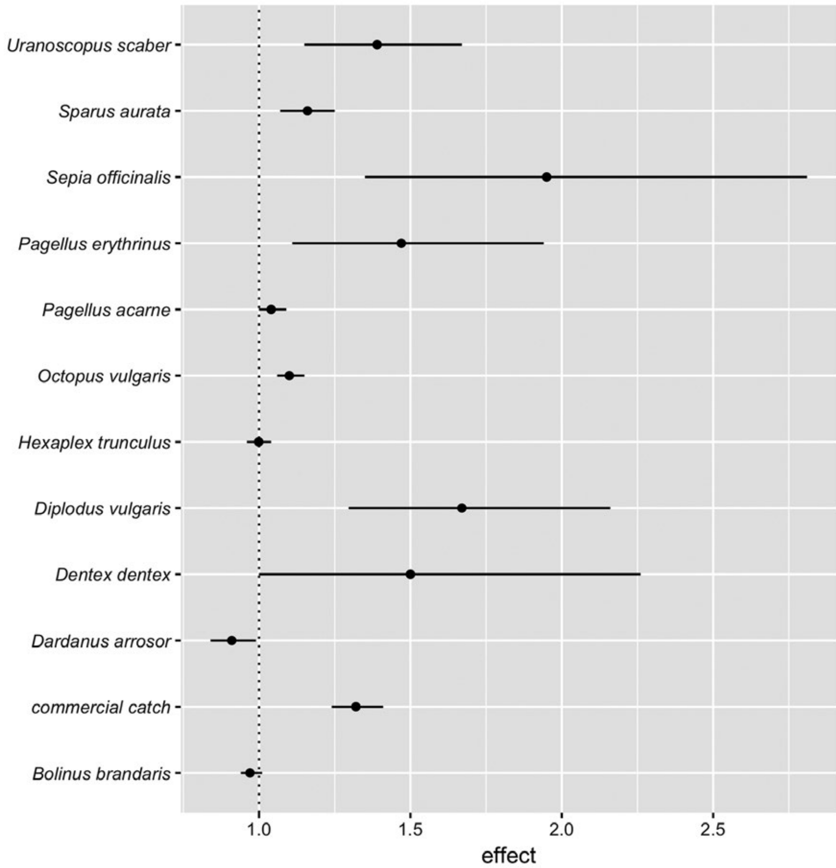

Fig. 2. – Relative measure of effect of the guarding net on the catches of the main commercial species in cuttlefish trammel nets (average and 95% confidence interval). A value of 1 corresponds to no effect (i.e. catches in kg/100 m h of the modified net were not different from those of the standard net).

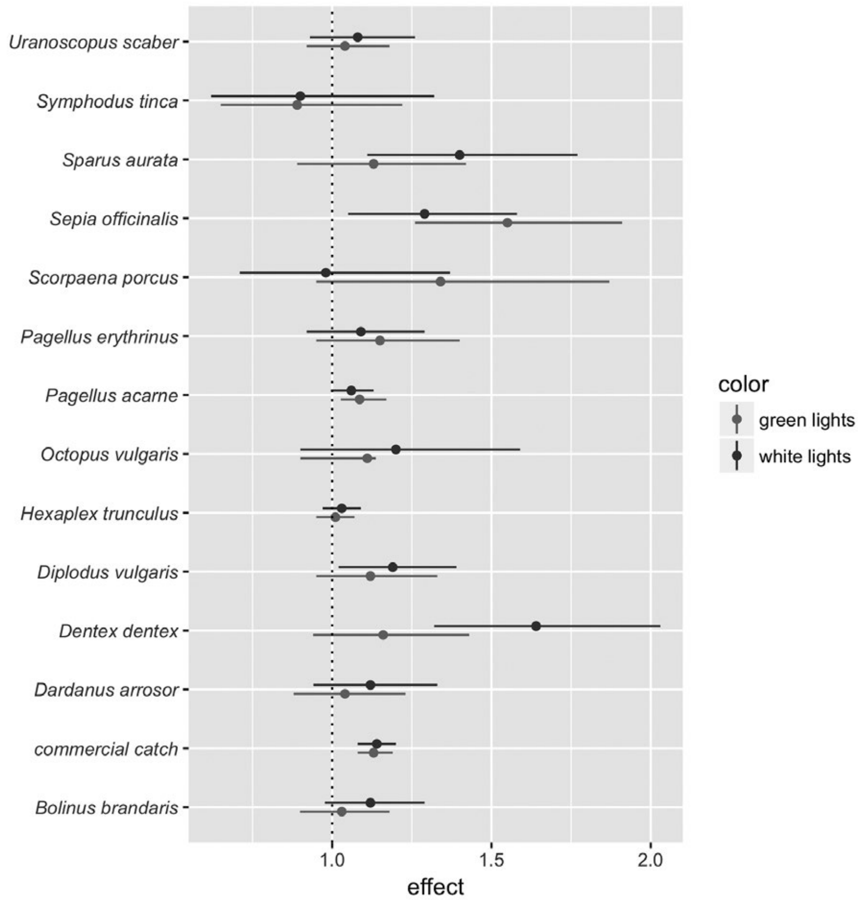

Fig. 3. – Relative measure of the effect of colour of lights mounted on the head rope on the catches of the main commercial species in cuttlefish trammel nets (average and 95% confidence interval). A value of 1 corresponds to no effect (i.e. catches in kg/100 m h of the modified net were not different from those of the standard net).

sult was primarily due to the increased catches of the target species *Sepia officinalis* (37% higher combining both lights; no statistical difference between the two colours). As regards fishes, only the sparids *Dentex dentex* and *Spaurus aurata* showed a positive effect of lights, but in these two species the effect was significant for white light, not for green light. In other species, the effect of light was usually positive (except for *Symphodus tinca*), although not statistically significant (Fig. 3, see also Supplementary Material, Fig. S2).

Unwanted catches

The catch rates of unwanted catches were always significantly higher in the control nets (mean of 2.74 ind./100 m h compared with 1.37 ind./100 m h; Figs 4 and 5, Table 4). The differences in unwanted catches between standard nets and nets with a guarding net varied depending on the reason of discarding, showing no interaction with the experimental treatment. A post-hoc analysis showed that undersize unwanted catches (category "D") were not different between the control and modified configuration, while damaged individuals (K1) and non-commercial organisms (K2) were significantly lower in the modified configuration.

The amount of unwanted catches (ind./100 m h) was not significantly different in the nets modified with

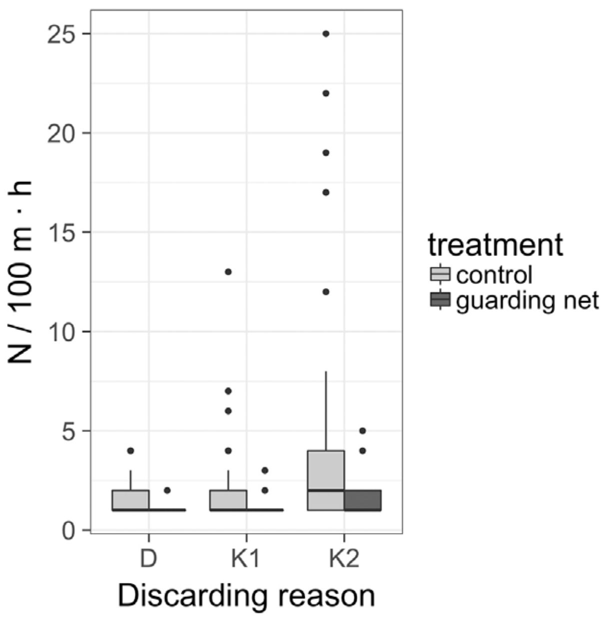

Fig. 4. – Abundance of unwanted catches in the guarding net configuration. (N/100 m h per species) compared with the control net. Discarding reasons: (D) undersize individuals falling under the Landings Obligation (Art. 15 of EU Reg. 1380/2013); (K1) damaged individuals of otherwise commercial species; (K2) non-commercial benthic invertebrates.

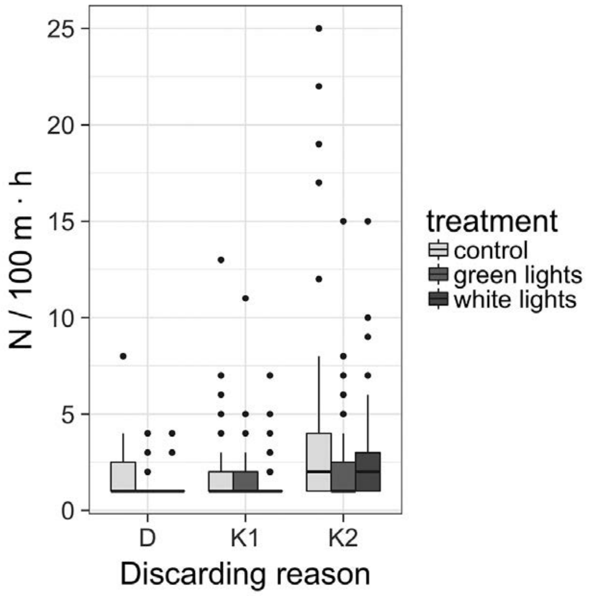

Fig. 5. – Abundance of unwanted catches in the configurations with artificial lights (each observation is a species). Discarding reasons: (D) undersize individuals falling under the Landings Obligation (Art. 15 of EU Reg. 1380/2013); (K1) damaged individuals of otherwise commercial species; (K2) non-commercial benthic invertebrates.

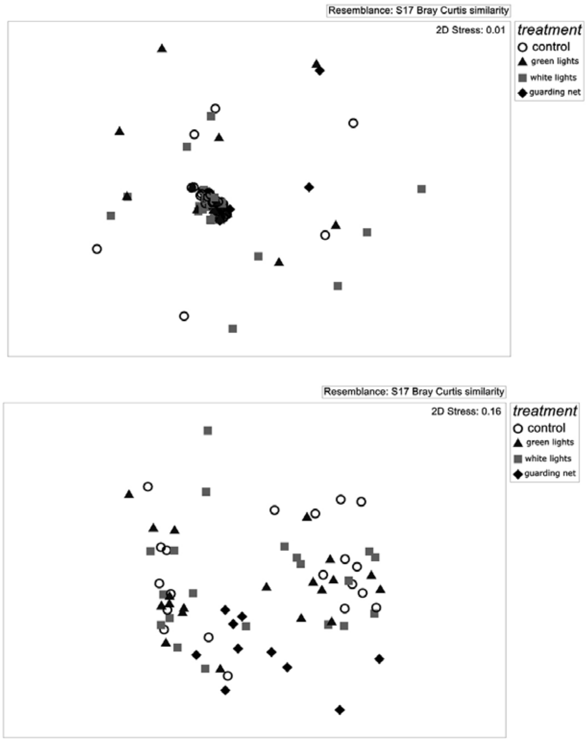

Fig. 6. – Non-metric multidimensional scaling (nMDS) of catch composition. TOP, species composition of unwanted catches; BOTTOM, species composition of the commercial fraction.

lights on the head rope compared with the control nets (Fig. 5). However, there were significant differences in the type of unwanted catches captured in the modified net ($p=2.3\ 10^{-6}$), with a significantly higher amount of category "K2" non-commercial invertebrates.

Multivariate analysis

The species composition of unwanted catches did not vary significantly according to treatment, either in the modified nets with a guarding net or in the nets fitted with lights (Fig. 6). The ANOSIM yielded a global correlation r=0.062 for the comparison of faunal assemblages in the control against guarding net experiments (p=0.016). The ANOSIM results for the comparison of lights yielded a correlation r=–0.004 (p=0.68), with partial correlations lower than 0.01 in all cases and p-levels higher than 0.1. In the commercial fraction, although the difference between the configuration with guarding net and the other nets was not significant, examining the species lists showed that the importance of fishes (especially sparids and seabass) was higher in the trammel nets with a guarding net than in the other configurations, where commercial invertebrates such as purple dye murex or commercial hermit crabs came second to the target species (cuttlefish) in abundance.

DISCUSSION

In our experimental trammel net deployment, unwanted catches of commercial species were mainly bitten or otherwise damaged individuals that could not be commercialized, frequently the target species *Sepia officinalis* and the fishes *Pagellus acarne*, *Pagellus erythrinus*, *Dicentrarchus labrax* and *Mullus surmuletus*. Few specimens were considered unwanted catches because of their size (covered by Art. 15 of

Table 4. – Summary results of the trammel net experiments. UWC, unwanted catches that would normally be discarded. Discarding reasons: (D) Undersize individuals falling under the Landings Obligation (Art. 15 of EU Reg. 1380/2013); (K1) damaged individuals of otherwise commercial species; (K2) non-commercial benthic invertebrates. Asterisks represent the significance level of the comparison (larger or smaller catches) between the modified net and the control net (NS, not significant, * p=0.05, ** p=0.01, *** p=0.001).

	control trammel net	guarding net	green lights	white lights
Commercial catch (ind./100 m h)	208.81	272.28***	229.29**	243.62**
Commercial catch (kg/100 m h)	49.11	64.04***	53.93*	57.30**
Total UWC (ind./100 m h)	40.39	19.81**	69.52 NS	64.83 NS
Undersize UWC (D, ind./100 m h)	8.44	7.77 NS	2.31 NS	7.15 NS
Damaged UWC (K1, ind./100 m h)	11.24	5.69*	26.03 NS	20.39 NS
non-commercial UWC (K2, ind./100 m h)	20.71	6.35**	41.18**	37.29**
Percentage of UWC, in weight	45%	24%	56%	53%
Percentage of D UWC, in weight	9%	9%	2%	6%
Percentage of K1 UWC, in weight	13%	7%	21%	17%
Percentage of K2 UWC, in weight	23%	8%	33%	31%

EU Reg. 1380/2013), both because the list of species caught by trammel net with minimum conservation reference size is limited and because the selectivity of the trammel nets used in south European fisheries is usually sufficient to guarantee a low percentage of undersize catches (Erzini et al. 2006). Only *Pagellus acarne* and *P. bellottii* were categorized as unwanted catches in more than half of the instances. Unwanted catches of non-commercial invertebrates were dominated by echinoderms (*Holothuria* sp., *Astropecten* sp. and *Echinaster sepositus*), as seen in other trammel net fisheries elsewhere (Gonçalves et al. 2008)

Our results show that discards can be significantly reduced in trammel net fisheries targeting cuttlefish through the simple adoption of a guarding net attached to the footrope of the trammel net. This modification has been tested successfully in other Mediterranean fisheries (Sartor et al. 2007, 2018, Metin et al. 2009). For instance, Sartor et al. (2007) showed that the unwanted by-catch in trammel nets targeting the caramote prawn (*Penaeus kerathurus*) was significantly reduced. However, in trammel nets targeting flatfish (different species of soles) the guarding net may unduly reduce the catches of the bottom-dwelling target species and may prove unacceptable to fishers (Szynaka et al. 2018). In our experiments with the guarding net on a trammel net used in the cuttlefish métier (spring), the commercial catches were significantly increased compared with the control net. Hence, although the reduction of unwanted by-catch is generally observed (Sartor et al. 2007, 2018, Metin et al. 2009, Szynaka et al. 2018), the effects of the guarding net on the catches of the target species must be considered on a métier by métier basis.

The types of unwanted by-catch that decreased significantly in the trammel nets with a guarding net were damaged individuals of commercial species and non-commercial organisms. This finding suggests that the main benefit of the guarding net is the reduction of predatory epifaunal invertebrates, which may damage the catches and also become entangled themselves. In addition to contributing to the conservation of epifaunal organisms (subject to a large amount of discarding: Gonçalves et al. 2008), the reduced catchability of these organisms helps reduce the sorting costs of trammel netters. The trammel nets with the guarding net modification did not affect the catch rates of commercial species by size (no difference in abundance of undersize commercial species). In addition to reducing unwanted by-catch, the catches of commercial species, particularly the target cuttlefish and some fishes, increased by 30%. The combination of increased catches and reduced sorting costs suggests that the adoption of the guarding net can be easily accepted by industry if it is well demonstrated and disseminated.

In the experiments with commercially available lights, there was also a moderate (13%) increase in commercial catches, mainly due to the increase in the catches of the cuttlefish. It is known that artificial light is attractive to cephalopods (Ben-Yami 1988), with well-documented examples in pelagic cephalopods (Inada and Arimoto 2007). In addition to cuttlefish, two sparids (dentex and gilthead seabream) showed attraction to white light (but not green), although the physiological basis for these results would require specific study (Arimoto et al. 2010). However, the deployments with artificial light also had a higher amount of unwanted catches than the control or guarding net configurations, perhaps because lights are more attractive to epifaunal invertebrates, as well as to cuttlefish. An effect of green light on the reduction of catches of undersize fish was appreciated (Table 4) but was not statistically significant.

In summary, though small-scale fisheries have relatively low amounts of unwanted catches, there is still room for improvement thanks to the adoption of relatively simple technological measures such as the guarding net tested here. The use of artificial lights to enhance selectivity in these fisheries operating by night in relatively shallow waters should be investigated further (Ben-Yami 1988), both in the laboratory and in the field, to understand the cues that can be manipulated to improve selectivity of trammel net fisheries, although this is probably a complex issue due to the different capture methods operating simultaneously in a trammel net (Erzini et al. 2006).

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SUPPLEMENTARY MATERIAL

The following supplementary material is available through the on-line version of this article and at the following link:
http://scimar.icm.csic.es/scimar/supplm/sm04710esm.pdf

Fig. S1. – Effect of trammel net modification on main commercial species. Contrasts between standard trammel net and trammel net with a guarding net.

Fig. S2. – Effect of trammel net modification on the main commercial species. Contrast between standard trammel net and trammel et modified with head rope lights.

Discards regulation vs Mediterranean fisheries sustainability
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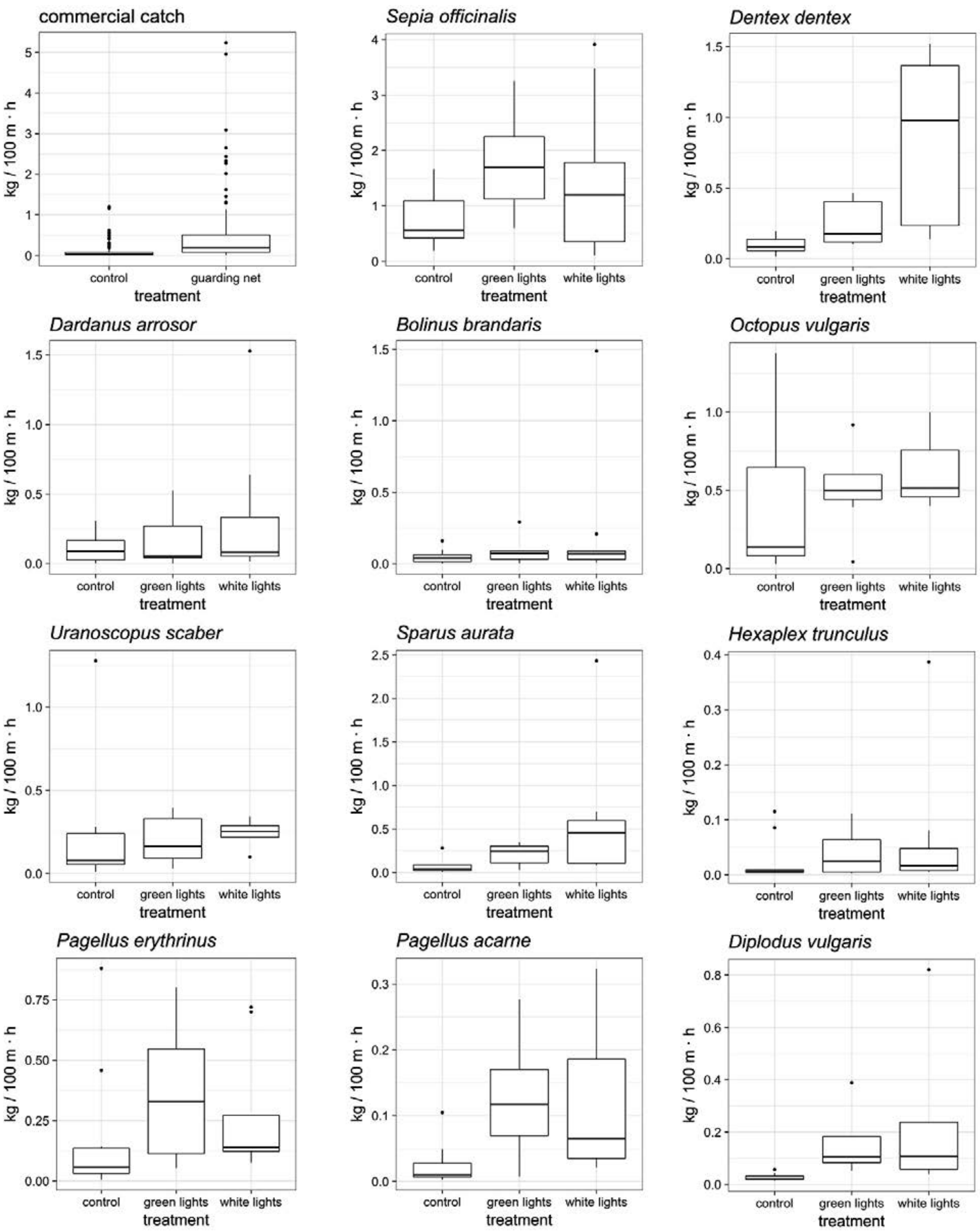
Reducing discards in trammel net fisheries with simple modifications based on a guarding net and artificial light: contributing to marine biodiversity conservation

Pedro Martínez-Baños, Francesc Maynou

Supplementary material



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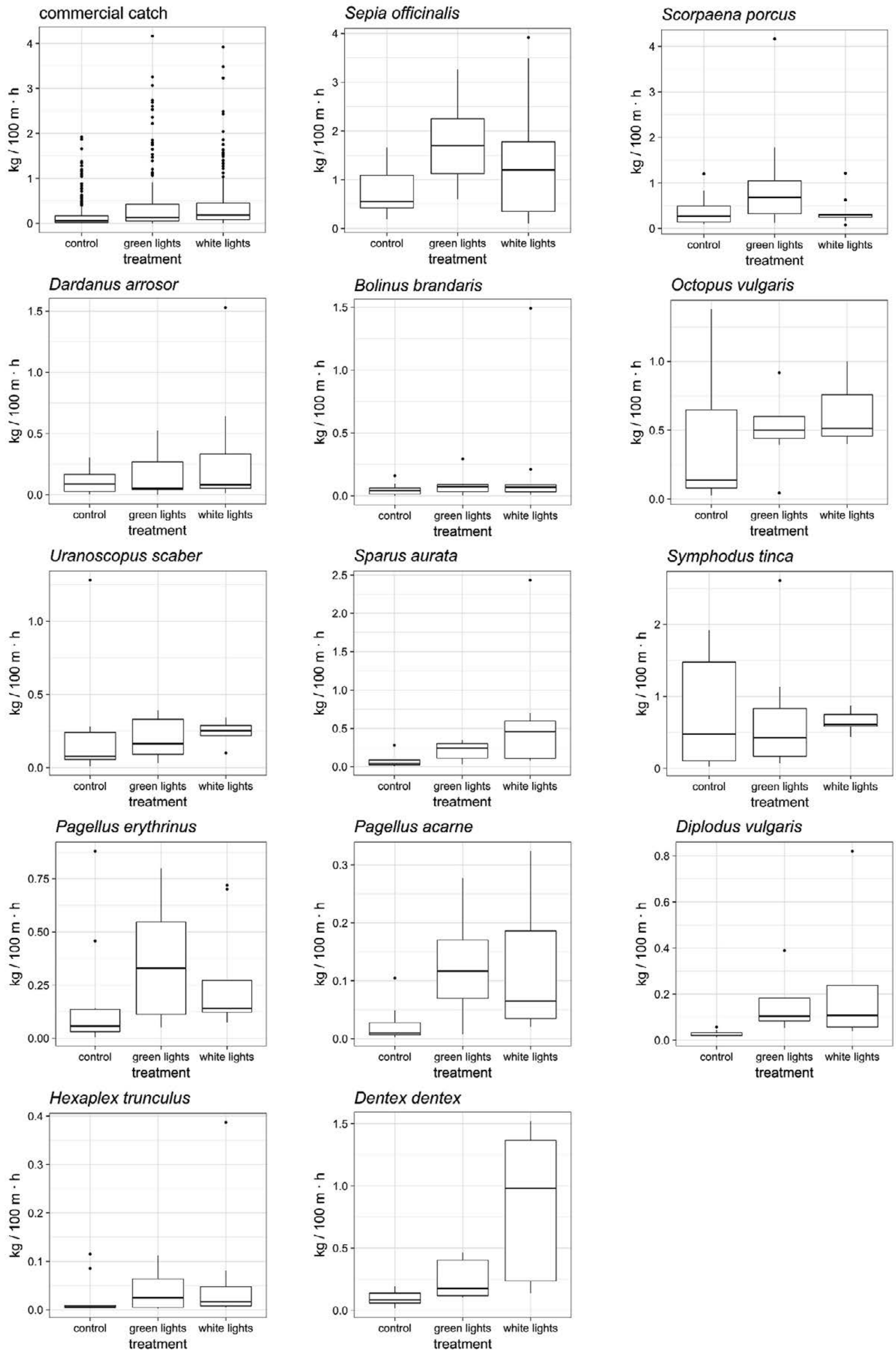

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