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The influence of type of natural bait on fish catches and hooking location in a mixed-species marine recreational fishery, with implications for management

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ABSTRACT

Managing bait type might constitute a simple tool to influence the amount and composition of the fish catch in marine recreational fishing. To this end, the relationships between two types of natural bait and catch per unit effort (CPUE), yield per unit effort, species composition of the catch, fish size, and hooking injury were evaluated in a mixed-species recreational boat fishery at the Balearic Islands (Western Mediterranean, Spain). Two hundred and twenty experimental angling sessions were conducted with two of the most common natural baits used by local anglers, pieces of a marine worm (*Perinereis aibuhitensis*) and pieces of shrimp (*Penaeus vannamei*), baited on a standard J-type hook. The average CPUE of hooks baited with worms was significantly larger than the CPUE of shrimp as bait. However, the average yield per unit effort was similar between both bait types because shrimp selected for significantly larger fish. Between-bait differences in species composition were statistically significant. In addition, the use of shrimp caused a significant decrease in the frequency of deep-hooking. As deep-hooking and associated injuries are related to post-release mortality in most fish species, the use of shrimp likely enhances the survival rates of released fish. We recommend the increased use of shrimp as opposed to worms in mixed-species coastal marine recreational fisheries to reduce the catch of undersized fish and the incidences of deep-hooking. Managing bait type might complement standard harvest regulations and facilitate more sustainable exploitation rates.

1. Introduction

Recreational fishing constitutes an important use of coastal fisheries resources in the Balearic Islands (Western Mediterranean, Spain), with nearly 10% of the population actively participating in recreational angling (Morales-Nin et al., 2005). In this mixed-species recreational fishery, boat-angling is the most popular method, representing more than 60% of the total effort. Up to 54 different species are harvested targeted by anglers (Morales-Nin et al., 2005). The fishery is a light-tackle recreational fishery that mainly captures small sized fishes (Morales-Nin et al., 2005; Cardona et al., 2007; Alós et al., 2008b). Daily bag limits, minimum legal landing sizes, maximum number of lines per rod, seasonal closures, marine protected areas and, more recently, minimum hook sizes, are used by the local fisheries administration to manage this recreational fishery.

Some of these regulations result in a high number of undersized fish caught and subsequently released mandatorily. Additionally, voluntary catch-and-release has become popular among anglers, managers and fishing tournament organizers, with the assumption that this practice helps to conserve the fisheries resource. The efficacy of all management tools that result in some form of catch-and-release angling requires scientific evidence that the practices allow sufficiently high survival rates of the fish (Bartholomew and Bohnsack, 2005; Cooke et al., 2006; Arlinghaus et al., 2007a; Coggins et al., 2007).

Recent research in recreational angling has provided information on handling procedures and gear types that minimize injuries and enhance fish survival (reviewed in Cooke and Schramm, 2007; Arlinghaus et al., 2007a,b; Arlinghaus, 2008). One of the most important factors affecting the mortality of released fish is deep-hooking, since fish hooked in critical anatomical locations such as the stomach, the oesophagus or the gills suffer increased mortality after release (Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Arlinghaus et al., 2007a, 2008a,b). The relevance of deep-hooking for post-release survival has been demonstrated in many marine recreational fisheries (Bartholomew and Bohnsack, 2005; St John and Syers, 2005; Broadhurst et al., 2005; Butcher et al., 2006; Alós et al., 2008a; Alós, 2009). Consequently, considerable effort has been devoted to evaluate the capacity of different gears

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for reducing the occurrence of deep-hooking. One outstanding example is circle hooks, which have become popular among management agencies and recreational anglers because these hooks can reduce the probability of deep-hooking (Cooke et al., 2005). Moreover, others gear characteristics such as hook size (Carbines, 1999; Cooke et al., 2005; Grixti et al., 2007; Rapp et al., 2008; Alós et al., 2008b), terminal gear configurations (e.g. short leader length and fixed leads, Beckwith and Rand, 2005; Rapp et al., 2008) as well as bait size (Wilde et al., 2003; Arlinghaus et al., 2008b) are known to affect the probability of deep-hooking, and thus offer targets for fisheries managers interesting in decreasing the probability of lethal injuries in voluntary and/or mandatory catch-and-release recreational fisheries.

In addition to the factors mentioned above, the incidences of deep-hooking increase in some recreational fisheries when natural baits as opposed to artificial baits are used (Pelzman, 1978; Payer et al., 1989; Pauley and Thomas, 1993; Muoneke and Childress, 1994; Arlinghaus et al., 2008b). However, natural bait is common in many marine recreational fisheries for smaller-bodied fish species such that the use of artificial bait is likely not to be accepted by local anglers. In fact many of these small-bodied species cannot be captured effectively by artificial bait (personal observations).

The relationship between different types of natural bait and deep-hooking incidence has received only limited attention in the scientific literature. Butcher et al. (2006) reported that the use of beach worms significantly increased the probability of deep-hooking and mortality on sand whiting, *Sillago ciliata* (C.) compared to the use of live yabbies (*Callianassa* spp.). This indicates that the choice of type of natural bait might affect the probability that fish are hooked in deep-body locations. Thus, regulatory control over the type of bait allowed to be used in marine recreational fisheries might be a simple tool to reduce the incidence of deep-hooking.

The success of promoting a specific bait type as a management tool should not only deliver conservation benefits but should also result in acceptable catch and harvest rates (i.e., catch per unit effort (CPUE) and yield per unit effort produced during an angling day) as anglers satisfaction primarily depends on acceptable fish catches (Arlinghaus and Mehner, 2005; Arlinghaus, 2006; Arlinghaus et al., 2008a). It is very unlike that a particular bait type that offers conservation benefits but produces reduced catch and harvest rates is adopted by recreational anglers (Rapp et al., 2008). Indeed, the influence of bait type on catch per unit effort and species composition of the catch has been reported from hook-and-line commercial fisheries (Løkkeborg and Bjordal, 1992; Woll et al., 2001; Broadhurst and Hazin, 2001). In a recreational fishing context, Lowry et al. (2006) found significant differences in catch rates and species composition related to bait type for the trailer-boat and gamefish-tournament fishery from New South Wales (South-East Australia), and Smith (2002) detected a relationship between the type of natural bait (either maggots or chironomids) and catch rates for a catch-and-release coarse freshwater fishery in the U.K. Interestingly, this last study also reported between-bait differences in the size distribution of the fish captured by similarly sized natural bait. Most available studies only studied the influence of size of bait on size of fish captured typically reporting positive correlations (Orsi, 1987; Payer et al., 1989; Orsi et al., 1993; Wilde et al., 2003; Arlinghaus et al., 2008b). There is thus a need for better information on the impact of similarly sized natural bait types on the characteristics of the catch for fishing environments, where the use of natural bait is, and will continue to be, common. One of such fisheries is the mixed-species marine recreational fisheries from the Western Mediterranean.

The objectives of the present study were to evaluate the effect of type of natural bait on CPUE, yield per unit effort (YPUE, i.e., biomass per effort unit), size of fish captured, species composition of the catch and hooking injury in the recreational boat fishery in the Balearic Islands (Spain). Based on the study by Smith (2002) it was hypothesized that the type of natural bait could significantly affect the species composition and the structure of the catch.

2. Materials and methods

2.1. Study site

Experimental angling sessions were conducted in Palma Bay, south of Majorca Island (Western Mediterranean, N39°33.214, E002°38.384) from August to November 2007. The sampling design comprised 55 randomly selected sites at stratified depths but with the same bottom characteristics (*Posidonia oceanica* beds). Depth ranged between 5.5 and 39.5 m. All sites support a high number of recreational boat anglers and local sport-fishing tournaments. The catch composition of the study site was representative of the most important recreational fishery of the Balearic Islands, principally dominated by *Diplodus annularis* (L.), *Coris julis* (L.) and *Serranus scriba* (L.) (see Morales-Nin et al., 2005 for more details about the fishery).

2.2. Experimental gear

Two natural bait types representing the most common types of bait used in the local recreational fishery were used in our experimental fishing sessions. The first bait was a marine worm (*Perinereis aibuhitensis*). Hooks were baited with one piece of worm that covered the entire hook surface (Fig. 1). The second bait encompassed similar-sized pieces of shrimp (*Penaeus vannamei*). In that case, one piece of shrimp was placed on the hook shank (Fig. 1). These baiting practices are commonly used by local recreational anglers. The same hook model and size was used in all angling sessions. A size 10 large shanks "J" hooks (TUBERTINI® model 1T) was selected because of its common use by local anglers. Front length, gap, outside bend and shaft lengths were measured and the dimensions are shown in Fig. 1. The experimental rig was composed of three hooks mounted on a 4.3 kg main leader with three side leaders (hook line), each 20 cm in length. The experimental rig encompassed a 100 g lead at the end of the main line. Thus, the side leaders with bait were mounted above the lead towards the rod tip. This rig was placed on a 4.5 kg monofilament main line (0.25 mm) on a conventional spinning reel, and 4 m long boat rods (rod action 100–150 g) were used for experimental angling. These gear characteristics are commonly used by local anglers.

2.3. Experimental design

Two anglers were selected for each experimental session, and bait types were assigned by the research team to each angler per site (i.e., angler 1-worm and angler 2-shrimp). One 30-min anchored boat session was completed by each of the anglers at the same time (i.e., two angling sessions per site). When the 30 min angling session was completed, the anglers moved to another site and changed the bait type. The time lost by moving between sites, changing the experimental gear, and anchoring the boat was not included in the angling sessions' time estimate. During one angling day, 4–6 angling sessions were conducted. When angling sessions at the 55 sites were completed, another full cycle at the same 55 sites was completed. In the second cycle, the bait type and angler were reversed in relation to the first cycle. With this design, each angler completed two angling sessions with different bait at each site, and the total number of sessions was $N = 220$. The experimental design was fully balanced for bait type, site and angler.

Hooking locations were evaluated prior to dehooking and categorized as either shallow-hooked (when fish were hooked in the lip or the upper and lower jaws) or deep-hooked (when the fish was

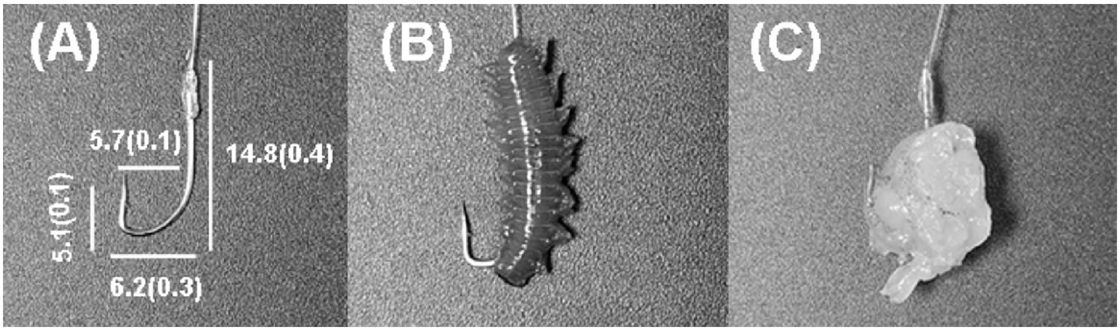

Fig. 1. Hook dimensions (average ± S.E.; $n = 5$ hooks) in mm (panel A). Hook baited with marine worm (*Perinereis aibuhitensis*) (panel B) and hook baited with a piece of shrimp (*Penaeus vannamei*) (panel C).

hooked in the gills, oesophagus or stomach). Fish were also identified to the species level, measured (total length to the nearest mm), and all fish were released into Palma Bay.

2.4. Data analysis

Three different statistical analyses were carried out: (1) univariate analyses to test between-bait differences in CPUE, YPUE and fish size, (2) multivariate analyses to test between-bait differences in species composition, and (3) logistic regression to evaluate the effect of bait type on deep-hooking as an indicator of severe injury. In all analyses the impact of site and angler was controlled.

Mixed-effects linear models were used to test the relationships between bait types (categorical explanatory variable) and the following continuous variables: CPUE (number of fish per 30-min session; all species pooled), yield (biomass per 30-min session, all species pooled) and mean fish size (all species pooled) as described in Heegaard and Nilsen (2007) and Alós et al. (2008b). To estimate yield, the weight of each fish caught was estimated using species-specific length-weight relationships presented in Morey et al. (2003) and Froese and Pauly (2002). In all mixed-effects models, bait type (worm vs. shrimp) was considered a fixed categorical factor, and site, day and angler were considered random factors. The effect of the fixed factor was tested and eventually included in the final model, following a forward step-by-step sequence until maximum explanatory power was reached using the AIC (Akaike Information Criterion). The AIC is the (log) likelihood plus a term that penalizes a model's goodness of fit by the number of model parameters (Burnham and Anderson, 1998). The AIC was used to test for the parsimony of models and the combination of variables with the best fit, but with the minimum number of parameters (Crawley, 2005).

Multivariate analyses focused on testing the relationship between the faunistic composition in terms of relative species

Table 1
Species and total catches by bait type (worm vs. shrimp) during the experimental angling sessions in a mixed-species marine recreational fishery. Total length (TL) and weight are expressed as average ± S.D.

Species and family	Bait type									
	Worm (*Perinereis aibuhitensis*)					Shrimp (*Penaeus vannamei*)				
	Fish	TL (mm)	±S.D.	Weight (g)	±S.D.	Fish	TL (mm)	±S.D.	Weight (g)	±S.D.
Coris julis (Labridae)	794	125.4	17.0	16.4	7.0	436	130.3	18.1	18.5	8.0
Diplodus annularis (Sparidae)	682	112.3	15.2	25.9	11.0	537	117.0	15.4	29.4	12.7
Serranus scriba (Serranidae)	212	126.3	24.0	31.0	18.5	250	136.4	28.3	40.4	27.2
Boops boops (Sparidae)	92	127.5	14.8	17.7	6.4	68	130.9	20.7	19.7	12.8
Diplodus vulgaris (Sparidae)	64	125.7	24.5	33.4	18.5	49	147.7	27.6	53.8	29.4
Pagellus erythrinus (Sparidae)	40	152.8	27.6	47.6	23.9	42	154.6	31.1	50.2	27.4
Serranus cabrilla (Serranidae)	36	128.6	20.0	24.9	11.5	43	133.9	18.0	27.6	10.3
Spondyliosoma cantharus (Sparidae)	35	117.0	28.3	29.6	22.5	33	126.9	27.2	36.2	21.2
Trachurus mediterraneus (Carangidae)	18	152.7	27.4	27.5	15.5	18	147.6	28.0	25.2	13.4
Symphodus tinca (Labridae)	14	125.8	45.0	35.8	39.2	3	111.7	30.6	21.5	15.0
Chromis chromis (Pomacentridae)	11	105.0	8.9	18.8	4.8	8	100.4	12.0	16.7	5.6
Pagrus pagrus (Sparidae)	4	161.3	42.2	76.7	53.3	9	171.6	34.7	88.1	47.4
Serranus hepatus (Labridae)	5	62.8	6.8	3.2	1.1	3	62.0	0.0	3.0	0.0
Oblada melanura (Sparidae)	4	137.5	4.7	30.8	3.2	3	133.3	11.6	29.1	7.1
Pagellus acarne (Sparidae)	4	98.3	5.7	10.2	1.9	2	102.5	14.8	12.0	5.4
Diplodus sargus (Sparidae)	2	140.0	60.8	58.2	62.5	1	193.0	–	121.0	–
Lithognathus mormyrus (Sparidae)	2	126.0	31.1	24.2	16.8	0	–	–	–	–
Mullus surmuletus (Mullidae)	2	173.0	43.8	67.8	49.7	0	–	–	–	–
Thalassoma pavo (Labridae)	2	116.5	0.7	23.5	0.4	0	–	–	–	–
Gobius niger (Gobiidae)	1	112.0	–	15.4	–	0		–	–	–
Sarpa salpa (Sparidae)	1	173.0	–	71.2	–	1	132.0	–	34.3	–
Spicara maena (Cetracanthidae)	1	167.0	–	63.2	–	1	92.0	–	10.2	–
Symphodus ocellatus (Labridae)	1	121.0	–	21.3	–	0	–	–	–	–
Symphodus rostratus (Labridae)	1	96.0	–	10.0	–	0	–	–	–	–
Synodus saurus (Synodontidae)	1	87.0	–	4.8	–	2	114.0	0.0	10.9	0.0
Trachinus draco (Trachynidae)	1	170.0	–	31.1	–	3	243.0	51.7	92.3	49.0
Xyrichthys novacula (Labridae)	1	127.0	–	30.3	–	5	152.8	19.5	46.6	12.9
Labrus merula (Labridae)	0	–	–	–	–	2	220.5	33.2	150.7	69.9
Labrus viridis (Labridae)	0	–	–	–	–	1	122.0	–	18.3	–

–, not caught.

abundance and bait type. For this analysis, a response matrix (species abundance) was built using 220 rows (i.e., 220 angling sessions) and a specific number of columns for species with a frequency of occurrence >5% pooled over all angling sessions. Additionally, an explanatory variables matrix was built with site, day, angler and bait type as dummy variables. In the analysis process, we first described the observed patterns by using Principal Components Analysis (PCA). Then inferential analyses were completed using Redundancy Analyses (RDA) (Legendre and Gallagher, 2001) in order to estimate how much variation in the response matrix (i.e., the relative frequency of species) was attributed to the explanatory variables. The strategy adopted here for model building was model-based for the variables of little direct interest (i.e., day, site and angler were considered co-variables), and their effects were removed before testing for the effect of bait type. Removing partial effects was done in two steps. First, the response variables were regressed on the different explanatory variables that probably affected the response variable. However, we were not specifically interested in some of these variables (i.e., day, site and angler). Thus, after regressing the response variables on these co-variables, the residuals represented the component of the species composition estimate that was not explained by these variables. The residuals thus encompassed the variance in the response variables and we tested how much of this residual variance was explained by our variable of interest (i.e., bait type) plus any unexplained variance. The second step was thus to regress these residuals on bait type. This two-step procedure kept the effects of the co-variables statistically constant while assuming that the interaction between bait type and the co-variables is not significant. This model-based standardization is widely used in multivariate analyses since simultaneous testing of all the effects included in a model is problematic, since the reference distribution can be derived mathematically from the assumptions of the test (Legendre and Gallagher, 2001; ter Braak and Smilauer, 2002). The ratio between the variability (inertia in the multivariate jargon) explained by the model and the residual inertia was used to test the significance of the model using Monte Carlo simulations.

The third group of analyses aimed at detecting the set of variables that affected deep-hooking as a surrogate of hooking mortality (Bartholomew and Bohnsack, 2005). Logistic regression analysis was used to fit the data with a maximum likelihood estimation describing the relationships between the hooking location (categorized as a binary variable; (0) shallow-hooked and (1) deep-hooked), and a number of likely predictor variables. These included fish size, water depth at the fishing site (continuous variables) as well as bait type and angler (categorical variables) (Grixti et al., 2007; Alós et al., 2008b). Site and day of sampling were not considered here to simplify the model since the spatio-temporal patterns of fish catches are likely independent of the probability of deep-hooking. Step-by-step forward selection of the explanatory variables and their interactions using the AIC criterion was used to fit the minimally adequate model. This analysis was performed for all species pooled and for the three most common species caught (i.e., four logistic models in total).

Residual distributions were examined for normality of the continuous data by visually inspecting residual histograms, normal quantile–quantile plots, and the Shapiro–Wilk test was used as a test for normality. Homoscedasticity was examined using box-plots and fitted residuals of the mixed-effects linear models. Normality and homoscedasticity assumptions were violated for the continuous variables CPUE, YPUE and fish size, so adequate transformations as $\log(x+1)$ were applied in all cases. A α-value of 0.05 was chosen as the critical level for rejection of the null hypotheses for all analyses, and we considered $\alpha < 0.05$ significant, $\alpha < 0.01$ highly significant and $\alpha < 0.001$ very highly significant. Model building and ordination analyses were completed using the basic statistical package and the libraries lmer4 (Crawley, 2005) and Vegan (Oksanen, 2005) of the R package. Version 2.6.2 of the R package was used (http://www.r-project.org/). Multivariate analysis was performed using CANOCO 4.5, and the results were visualized with the extension CanoDraw for Windows.

3. Results

3.1. CPUE, YPUE and fish size

We captured 3551 individual fish in 220 angling sessions belonging to 29 species of 10 families (Table 1). Using worm as bait, anglers caught 2031 or 57.2% of the total catch. For shrimp, a total of 1520 fish were caught comprising 42.8% of the total catch. The CPUE (all species pooled) ranged from 0 to 51 fish per angler per 30 min. The mean CPUE ± S.D. was 16.2 ± 10.7 individual fish per angler per 30 min. *C. julis* (L.), *D. annularis* (L.) and *S. scriba* (L.) were the most frequently captured species and average CPUE ranged from 0 to 42, 23 and 20 individual fish per angler per 30 min for these three species, respectively (Table 2). Linear mixed-effects models showed that significantly more fish per unit effort were caught using worm than using shrimp ($\chi^2 = 21.28$; $p < 0.001$). The mean CPUE ± S.D. obtained using worm was 18.5 ± 12.0 fish per angler per 30 min, while for shrimp it was 13.8 ± 8.8 fish per angler per 30 min.

The YPUE ranged from 0 to 1360.9 g per angler per 30 min and was on average ± S.D. 419.11 ± 267.9 g biomass per angler per 30 min (Table 2). The average ± S.D. of the species-specific yield for the three most frequent species (i.e., *C. julis*, *D. annularis* and *S. scriba*) varied from 59.8 ± 89.1 to 160.7 ± 191.66 g biomass per angler per 30 min (Table 2). The average (±S.D.) YPUE when worm was used as bait was only slightly higher (429.0 ± 265.6 g per angler per 30 min) than for shrimp as bait (409.2 ± 271.1 g per angler per 30 min). This difference in yield was not significant ($\chi^2 = 0.506$; $p = 0.477$).

Fish size varied significantly between bait types, and the use of shrimp resulted in the catch of significantly larger fish ($\chi^2 = 59.452$; $p < 0.001$). When anglers used worm, average fish size was 121.8 ± 20.7 mm and for shrimp it was 128.4 ± 24.2 mm, and

Table 2
Summary of average ± S.D. CPUE, yield per unit effort (YPUE) and fish size between bait types observed when all species were pooled, and in the three most frequent species *C. julis*, *D. annularis* and *S. scriba*. Deep-hooking is the percentage of fish hooked in the gills, oesophagus or stomach relative to each bait type.

Bait type		Species pooled	*C. julis*	*D. annularis*	*S. scriba*
Worm	CPUE (fish angler 30-min)	18.5 ± 12.0	7.2 ± 7.9	6.2 ± 7.1	1.9 ± 2.6
	YPUE (g angler 30-min)	429.0 ± 265.6	118.6 ± 127.8	160.7 ± 191.7	59.8 ± 89.2.0
	Fish size (mm)	121.8 ± 20.7	125.4 ± 17.0	112.3 ± 15.2	126.3 ± 24.0
	Deep-hooking (%)	26.4	27.0	26.8	23.0
Shrimp	CPUE (fish angler 30-min)	13.8 ± 8.8	4.0 ± 4.8	4.9 ± 5.8	2.3 ± 3.4
	YPUE (g angler 30-min)	409.2 ± 271.1	73.3 ± 87.2	143.7 ± 181.9	91.7 ± 155.5
	Fish size (mm)	128.4 ± 24.2	130.3 ± 18.1	117.0 ± 15.4	136.4 ± 28.3
	Deep-hooking (%)	14.1	15.4	16.7	10.8

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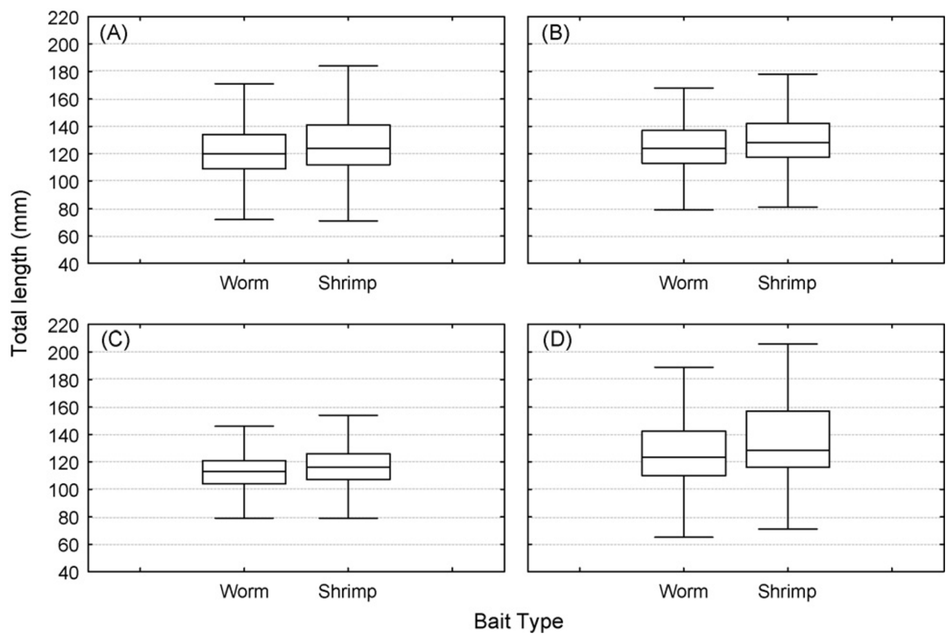

Fig. 2. Box-plots of fish size (in mm) by bait type for all species pooled (plot A) and for the three most frequently caught species (plot B = *Diplodus annularis* (L.), plot C = *Coris julis* (L.) and plot D = *Serranus scriba* (L.)). The median value (horizontal bar) and 25th and 75th percentiles (box) are indicated. Whiskers show the maximum and the minimum observed values of fish size.

these differences were evident for the pooled fish catch as well as for the three most common species caught (Fig. 2).

3.2. Species composition

Variance partitioning of species composition showed that the most important variable affecting species composition was the site (51.8%). The day of sampling accounted for 5.9% of the variability, while only 2.2% and 2.9% of the variability in species composition was explained by the angler and our interest variable bait type. Up to 37.2% of the variability remained unexplained. Patterns of between-sample similarity attributable to bait type were revealed after removing the effects of day, site and angler. These analyses indicated some differences in species composition among bait types (Fig. 3). The bait-type effect was small but highly significant (Fig. 4; after 999 Monte Carlo simulations: pseudo-$F = 11.974$; $p < 0.01$). The species that were caught most frequently using worm were *C. julis*, *D. annularis*, *Symphodus tinca* (L.), *Boops boops* (L.), *Chromis chromis* (L.) and *Diplodus vulgaris* (L.). In contrast, species such as *Pagrus pagrus* (L.), *S. scriba* or *Serranus cabrilla* (L.) were more frequently caught using shrimp (Fig. 4). Other species such as *Trachurus mediterraneus* (L.), *Spondyliosoma cantharus* (L.) and *Pag-*

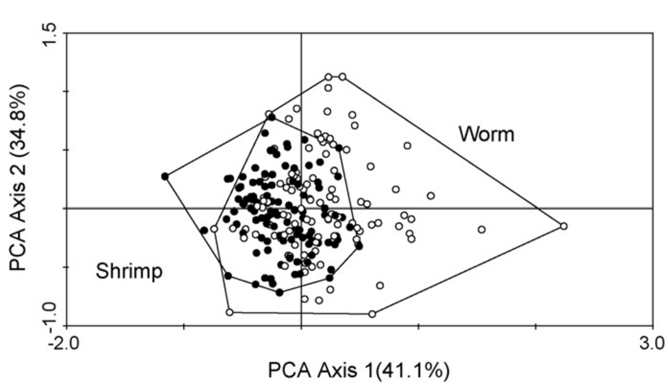

Fig. 3. Scatter plot of the two first axes resulting from a Principal Components Analysis (PCA) of the residuals after removing the effects of day, site and angler on species composition in a mixed-species marine recreational fishery. The scatter plot describes the effects of bait type plus any unexplained variance. The PCA included 12 species and 220 angling sessions. Angling sessions with shrimp as bait (closed points) and worm (open points) are indicated. Differences in the areas surrounding each category are statistically significant.

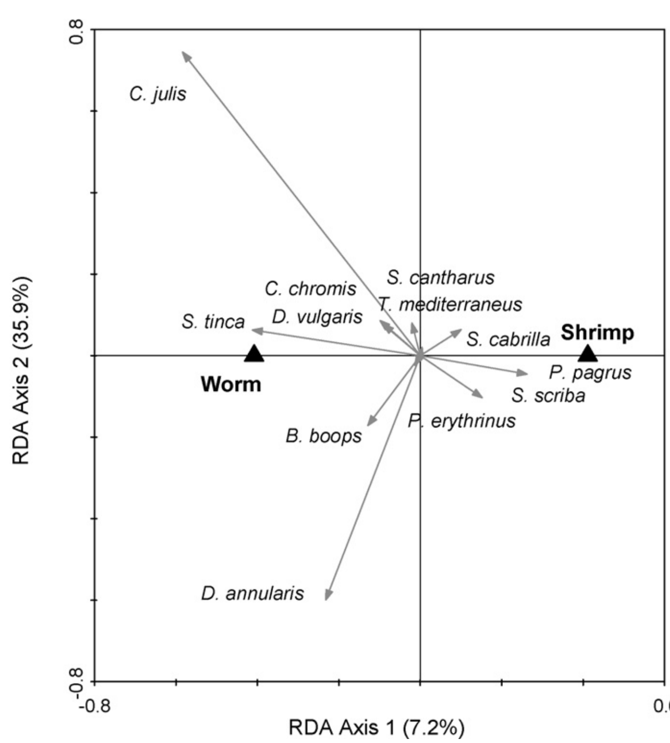

Fig. 4. Bi-plot of the partial Redundancy Analyses results. Species are denoted by arrows and angles are proportional to correlations. The triangles are at the centroid of the sample positions. The first (horizontal) axis is the single canonical axis. A correlation between species vectors and this first axis indicates species-specific patterns in relation to the type of bait (species abundance for each bait type can be approximated by projecting the triangle onto the species vector). Values in brackets show the percentage of variance explained by each axis. For full species names see Table 1.

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Table 3
Logistic regression models to explain the incidence of deep-hooking as a function of bait type, fish size and depth when all species were pooled, and for the three most frequent species in a mixed-species marine recreational fishery.

Minimal adequate model	Factors	Estimate	S.E.	z-value	Pr(>|z|)
Species pooled					
$Y_i = \beta_1 + \beta_2\,(\text{bait}_i) + \beta_3\,(\text{fish size}_i) + \beta_4\,(\text{depth}_i) + \varepsilon_i$	(Intercept)	−2.43	0.24	−10.0	***
	Bait (shrimp = 1)	−0.86	0.09	−9.49	***
	Fish size (mm)	0.01	0.01	5.23	***
	Depth (m)	0.01	0.01	2.57	*
Coris julis					
$Y_i = \beta_1 + \beta_2\,(\text{bait}_i) + \beta_3\,(\text{fish size}_i) + \varepsilon_i$	(Intercept)	−2.91	0.51	−5.71	***
	Bait (shrimp = 1)	−0.79	0.16	−5.02	***
	Fish size (mm)	0.01	0.01	3.83	***
Diplodus annularis					
$Y_i = \beta_1 + \beta_2\,(\text{fish size}_i) + \beta_3\,(\text{bait}_i) + \varepsilon_i$	(Intercept)	−4.63	0.56	−8.29	***
	Fish size (mm)	0.03	0.01	6.66	***
	Bait (shrimp = 1)	−0.77	0.15	−5.16	***
Serranus scriba					
$Y_i = \beta_1 + \beta_2\,(\text{bait}_i) + \beta_3\,(\text{fish size}_i) + \varepsilon_i$	(Intercept)	−2.19	0.64	−3.4	***
	Bait (shrimp = 1)	−1.03	0.27	−3.83	***
	Fish size (mm)	0.01	0.01	1.64	0.101

Minimal adequate model fitted after step-by-step forward selection (AIC) from the full model. The full model included fish size, depth, bait and angler. β_n corresponds to constant parameters and ε_i is the error term. The estimates and their standard errors (S.E.) are in logits.
* Significant: $p < 0.05$.
*** Very highly significant: $p < 0.001$.

ellus erythrinus (L.) did not show any pattern related to bait type (Fig. 4).

3.3. Hooking injury

In total, 537 fish (26.9%) caught using worm as bait were hooked deeply, while with shrimp as bait this value was only 214 fish (14.1%) (Table 2). After step-by-step selection for all species pooled, the minimal adequate model included three explanatory variables: bait type, fish size and water depth (Table 3). The effect of bait type was significant ($p < 0.001$), and the use of shrimp resulted in a reduction in deep-hooking incidence by 12.8% (Tables 2 and 3). Fish size was also significant (Table 3; $p < 0.001$). Increasing fish size increased the probability of deep-hooking. Water depth at the capture site was also included in the minimal adequate model and this effect was significant (Table 3; $p < 0.001$). Increasing capture depth increased the probability of deep-hooking.

With regard to the species-specific patterns of the three most frequently captured species, bait type and fish size were included in all minimally adequate models (Table 3). Bait type was highly significant, and the use of shrimp as bait resulted in a significant reduction of deep-hooking by 11.6%, 10.1% and 12.2% in *C. julis*, *D. annularis* and *S. scriba*, respectively, relative to the use of worm as bait (Table 3). In the case of *C. julis* and *D. annularis*, the effect of fish size was also highly significant: with increasing fish size, the incidence of deep-hooking increased (Table 3). In contrast, for *S. scriba*, the effect of fish size was not significant (Table 3; $p = 0.101$).

4. Discussion

We found that type of natural bait influenced catch rates, size of fish captured, the fish species composition of the catch as well as hooking location in a mixed-species marine recreational fishery. This are noteworthy findings since we used similarly sized natural baits, yet still significant differences in the catch rates and catch composition were detected. Many variables influence the catch rates and species composition of fish caught by hook-and-line fisheries (Løkkeborg and Bjordal, 1992). In our study, between-site differences were the most important factor of variability in species composition in a mixed-species marine recreational fishery. This result is to be expected since it is well known from marine ecosystems that local habitat characteristics and the patchiness of local structures such as macrophyte occurrence generate habitat heterogeneity influencing species occurrence at small spatial scales (Moranta et al., 2006; Alós et al., 2008b). However, we also found that bait type significantly affected the species composition of the catch by recreational anglers. However, the results of the pRDA showed that the effect of bait type explained a low amount of the observed variance in species composition (less than 3%). The magnitude of the effect of bait type on species composition was comparable to those resulting from between-angler differences that are probably related to angling skill and different angling techniques.

The reason for the impact of bait on species composition is probably related to species-specific preferences for food (Stoner, 2004). Moreover, the shrimp bait used in the present study exhibited a more clumped shape compared to the worm. This might have affected catch rates of the smallest fish species targeted by anglers due to gape size limitations (Wilde et al., 2003; Cooke et al., 2005; Arlinghaus et al., 2008b). Indeed, shrimp selected for significantly larger sized fish, and this difference might represent food preferences by larger sized fish or be related to the different shape of the shrimp bait compared to the thinner worm bait, or both. Differences in catch rates and composition of the catch related to bait type have been previously observed both in recreational fisheries (Smith, 2002; Lowry et al., 2006) and hook-and-line commercial fisheries (Løkkeborg and Bjordal, 1992, 1995; Woll et al., 2001), and our results conformed with this earlier research in a mixed-species marine recreational fishery.

Relative to worm, the use of shrimp as bait significantly reduced the CPUE from 18.5 to 13.8 fish per angler per 30 min. The larger CPUE for hooks baited with worm was mainly related to a significant increase in the catch of smaller individuals of *C. julis* and of *S. tinca*. These species have a small gape (Karpouzi and Stergiou, 2003), and their diets are mainly composed of small polychaetes and crustaceans that live within *P. oceanica* meadows (Froese and Pauly, 2002). Other species catalogued as planktophagous such as *B. boops* or *C. chromis* (Froese and Pauly, 2002), were also more frequently captured by worm. *D. vulgaris* was an exception since this is a large species and its diet include some large macroinvertebrates (Froese and Pauly, 2002). However, the average size of *D. vulgaris* caught in the present study on worm was substantially smaller than previously reported from the same recreational fishery (Morales-Nin et al., 2005), and it was also smaller than the minimal legal size stipulated for this species (180 mm). We can thus conclude that the use of worm motivated the increased catch of undersized fish in addition to more frequently capturing microfagous fish. Conversely, species such as *S. scriba*, *P. pagrus* or *S. cabrilla* that are characterized by larger gaps sizes (Karpouzi and Stergiou, 2003) and by diets involving large crustaceans (Froese and Pauly, 2002) were caught more frequently using shrimp. This difference may be very important for promoting the use of shrimp as bait among anglers since the fish species selected by shrimp seem to be more appreciated by local anglers.

In contrast to the catch rates, between-bait differences in yield per unit effort (biomass) were not observed in our study. This contrasted with an earlier report from freshwater fisheries by Smith (2002). Our finding of a divergent impact of bait type on CPUE and YPUE is a relevant result when managers want to promote the use of particular baits from a conservation standpoint. For example, harvest-oriented Spanish anglers will probably not adopt the use of particular bait that offers conservation baits but penalizes yield. In contrast, anglers interested in high catch rates would probably object to any bait regulation that affects catch rates. Here the dilemma of our study becomes obvious. While shrimp harvested the same biomass compared to worms, the catch rates of shrimp baited hooks were significantly smaller than the catch rates of worm baited hooks. Thus, the adoption of a particular bait type will ultimately depend on the preferences and attitudes of local anglers.

From a conservation perspective it is worth realizing that the use of shrimp resulted in a significant reduction of the proportion of undersized fish (<120 mm) in the catch by 28.9%, 14.23% and 24.9% for *C. julis*, *D. annularis* and *S. scriba*, respectively. The size-selectivity of different types of similar-sized natural baits has previously observed in recreational fisheries (Smith, 2002) in agreement with our findings and this constitutes an interesting new phenomenon. Previous research has mainly focused on the size of the bait (Orsi, 1987; Løkkeborg and Bjordal, 1992, 1995; Orsi et al., 1993; Wilde et al., 2003; Arlinghaus et al., 2008b) when looking at size-selectivity patterns in both recreational and commercial angling. Other work in this area has emphasized that the size of the hook can influence the catch of undersized fish in some fisheries, with smaller fish being captured on smaller hooks (Cooke et al., 2005; Grixti et al., 2007; Alós et al., 2008b). Recently, Alós et al. (2008a) used some statistical models commonly used in commercial fisheries to explore the selectivity properties of differently sized hooks in a marine recreational fishery. The results of this study informed the adoption of a minimal legal hook size in most of the marine protected areas managed by the local government from the Balearic Islands to reduce the catch of small fish on small hooks. However, the results of the present study suggest that the size-selectivity resulting from type of bait may affect any form of hook size regulation. This indicates the difficulty associated with any form of gear regulations where both hook size, bait size and bait type influence the size of fish captured (Arlinghaus et al., 2008b). Based on the present study, however, where the impact of hook size was controlled we can suggest that the use of shrimp will probably reduce the catch of undersized fish in a mixed-species marine recreational fishery.

The use of shrimp pieces does not only promote the catch of larger and more valued fish species but also reduces the probability of deep-hooking. Effective mandatory and voluntary catch-and-release practices in recreational fisheries require high post-hooking survival rates but deep-hooking reduce survival rates substantially (Bartholomew and Bohnsack, 2005; Arlinghaus et al., 2007a). Our results showed that bait type is an important predictor of deep-hooking for all species pooled and for the three most frequently captured species (*C. julis*, *D. annularis* and *S. scriba*). For these fish, the effect of the bait type was more important than the impact of fish size. However, Alós et al. (2008b) reported from the same recreational fishery that the effect of fish size to predict deep-hooking was more important than the effect of hook size. Since hook sizes were standardized in the present, our study suggests that deep-hooking is more strongly related to type of natural bait than to hook size. Indeed, the deep-hooking incidence using worm (26.4%) in the present study was similar to the values reported by Alós et al. (2008b) using worm as bait and the same hook size (27.6%). In contrast, in our study the use of shrimp caused a significant reduction in deep-hooking; for example, in the species *S. scriba* this incidence was reduced by half. Therefore, it is reasonable to assume that the use of shrimp as bait will result in better survival rates after catch-and-release due to reduced injuries associated with this fishing practice. However, since shrimp are natural baits, there is still a high probability of deep-hooking compared to artificial baits (Payer et al., 1989; Pauley and Thomas, 1993; Arlinghaus et al., 2008b), and further reducing deep-hooking will probably only be achieved by increasing hook sizes along with using shrimp as bait. Further research is needed to verify this assumption.

In addition to type of natural bait, we also found that depth at the capture site significantly affected the deep-hooking incidence. This is likely caused by the increasingly "passive" fishing style as water depth increases (i.e., at deeper depths fish may swallow the bait before the angler notices the bite and responds by setting the hook). It has previously been reported that passive fishing styles increases deep-hooking compared to more active fishing styles (Grixti et al., 2007; Arlinghaus et al., 2008b; Alós, 2009). This finding is important when designing future fishing tournaments in the Balearic Islands where live release of fish is an explicit target. For example, one might want to limit water depth in fishing tournaments to reduce the incidences of deep-hooking. This might will also indirectly reduce the risk of barotrauma-related post-release mortalities (Bartholomew and Bohnsack, 2005).

In conclusion, our study suggests that the appropriate choice of type of natural bait could constitute a simple management measure completing standard harvest regulations. We suggest an increased use of shrimp in the mixed-species marine recreational fisheries in Spain. It seems that it would be fairly easy to convince more consumptively oriented local anglers that the use of shrimp baits would constitute a superior bait to worm since use of shrimp increases fish yield. Moreover, shrimp bait reduces the frequency of capture of undersized fish and promotes the capture of the more valued species, i.e., *S. scriba*, *S. cabrilla* and *P. pagrus*. Adopting shrimp as bait would also offer conservation benefits because the use of this bait substantially reduces the incidence of deep-hooking (i.e., which can be used as a surrogate of mortality following catch-and-release). Finally, shrimp bait reduces the frequency of capture of very small fish, many of which might be immature. However, one should never forget that any form of bait type regulation might conflict with the desires and fishing styles by some angling groups, e.g. in our case more catch-rate oriented anglers, as shrimp as bait reduces catch rates compared to the use of worm. Irrespective of this dilemma, from a management perspective, the prescription of a particular bait type would be easier to implement and enforce than any form of bait size restrictions and maybe any form of gear restrictions since local angling bait shops might be forced by local regulations to only sell a particular bait type. The popularization of this relatively easy-to-implement measure might contribute to the sustainability of recreational fisheries in the coastal zones of the Mediterranean Sea but clearly cannot substitute more sophisticated measures to curtail excessive fishing mortality.

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