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ARTICLE

Effect of Bait Type and Bait Size on Catch Efficiency in the European Hake *Merluccius merluccius* Longline Fishery

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Abstract
We investigated the effect of bait type and bait size on the catch efficiency of a demersal longline fishery targeting European Hake *Merluccius merluccius* in the North Sea. Automation of the labor-intensive processes onboard fishing vessels requires finding alternatives to the traditional bait used in the fishery (i.e., whole European Pilchard *Sardina pilchardus*). Of the six alternative baits investigated, four resulted in significant reductions in catch efficiency ranging from 32% to 90%. Only chopped Atlantic Herring *Clupea harengus* was a reasonable alternative bait, with an estimated non-significant loss of only 2.12% in European Hake catch efficiency. Our results demonstrated that choice of bait type and size can affect the catch efficiency of different sizes of European Hake. Thus, the choice of bait may also affect the size distribution of the catch. The latter highlights the importance of considering fish size when inferring the effect of bait choice on the catch efficiency of longline fisheries.

Longlining is a widely used passive fishing method that is efficient and selective and can catch top-quality fish (Løkkeborg et al. 2010). In contrast to other popular fishing gears, such as trawls and seines, the effectiveness of a longline depends on both the construction of the gear (Herrmann et al. 2017) and the attractiveness of the bait

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used for the target species (Coelho et al. 2012; Løkkeborg et al. 2014). Several studies have shown the importance of the different components of a longline. The size and shape of the hooks, as well as the length, thickness, and material used for the leaders, are important parameters to consider when constructing an efficient longline (Alós et al. 2008; Herrmann et al. 2017). However, many consider bait to be the most crucial element in a longline, as it often determines the species composition and size composition of the catch (Sutterlin et al. 1982; Løkkeborg and Bjordal 1992). For a longline to be effective, the fish in the area first must be attracted to the bait by its odor, and once they are near the bait, they need to be lured to bite it (Løkkeborg et al. 2010). Thus, a fish needs to be attracted not only to the smell of the bait but also to the size and shape of the bait used (Johannessen et al. 1993). These factors become relevant to determining a fish's final response to the bait once the fish approaches the bait: to attack or not attack.

In Spain and other European Union (EU) waters, longlines are widely used to target various demersal fish species, especially gadoids such as the European Hake *Merluccius merluccius*, Atlantic Cod *Gadus morhua*, and Haddock *Melanogrammus aeglefinus*. For Spanish vessels fishing in the North Sea and along the north coast of Spain, the European Hake is the main target species. However, the onboard operation is manpower demanding, and fishermen and vessel owners have expressed interest in automating the operations onboard.

Automation of an artisanal longline requires adaptation of the gear so that it can be handled automatically. Herrmann et al. (2017) recently described these changes and their consequences (e.g., increased leader thickness can reduce the catch efficiency of a longline). In addition, an automated longline system requires the use of bait that can be handled automatically. The Spanish artisanal longline fishery as well as many other fisheries along the EU coast have traditionally used whole European Pilchard *Sardina pilchardus* (hereafter, sardine) as bait (Figure 1). This bait has been used effectively for generations to catch European Hake; thus, fishermen are skeptical about using alternative baits. However, automation does not allow the use of whole sardine because the machines available today are not able to hook small sardine precisely enough. Therefore, the fishing efficiency of alternative baits that allow automation must be tested to determine whether gear automation is possible for this fishery with the machines available today.

Sardine, Atlantic Mackerel *Scomber scombrus* (hereafter, mackerel), and squid *Loligo* spp. are the most commonly used baits in the North Atlantic longline fisheries (Foster et al. 2012; Santos et al. 2012). Because these baits can all be used in automatic baiting machines, they are potential alternatives to whole sardine in the Spanish longline fishery. However, demand and price—especially for sardine and mackerel—can be high at times, leading to low availability and high cost. Thus, there is a need for alternative bait species with properties such as good hook holding, odor, and firmness that would make them attractive for use in longline fisheries (Løkkeborg et al. 2014). Efforts to produce artificial baits based on surplus products have not yet been able to provide the necessary effectiveness in the fisheries where they have been tested (Løkkeborg 1990, 1991; Januma et al. 2003).

In this study, we used sardine, mackerel, Atlantic Herring *Clupea harengus* (hereafter, herring), and squid as well as the Pacific Saury *Cololabis saira* for bait, which has been introduced in other fisheries (e.g., the Barents Sea Atlantic Cod and Haddock fishery) as an alternative to more traditional baits due to price and availability. Our goal was to test the effectiveness of different bait types that would enable use of an automated longline system in the labor-intensive longline fishery targeting European Hake. In many studies, the efficiency of different types of bait has been measured based on the CPUE associated with the different alternatives (e.g., Broadhurst and Hazin 2001). However, the analysis method used in the present study considers the size of the target species when inferring the effect of bait choice on the catch efficiency of longline fisheries.

The current study addresses the following questions: (1) "Would the catch efficiency of the Spanish longline fishery change if the bait was changed to comply with automation?"; (2) "If the catch efficiency is different, which of the different bait types would perform best compared to the currently used bait in the fishery (whole sardine)?"; and (3) "If the catch efficiency differs among the baits, is this difference dependent on the size of European Hake?"

METHODS

Experimental fishing.— The survey was conducted onboard the Spanish longline vessel *Anxuela* (overall length = 30 m; 500 hp) from May 11 to May 16, 2012. The experiments were carried out on the banks of Gran Sole around 180 km south of the coast of southern Ireland. We fished a total of 120 longline units that were rigged using the traditional Spanish longline design employed to fish European Hake in the North Sea. In this design, the mainline that contains the leaders is attached to a security line that minimizes gear loss. The security line is made of polyethylene and therefore floats, which avoids entanglement problems with the main line. The main line is kept at the seabed by 4-kg weights that are attached to the gear, as illustrated in Figure 2. Each of the 120 longline units used was 250 m long and contained 85 leaders (Figure 2). The length of the leaders was 1.8 m, and the thickness was 0.7 mm. The hooks used during the trials were Mustad size 3/0 533D. The Mustad 3/0 533D is a J-shaped hook that is flattened and has an offset of 20°

FIGURE 1. Pictures showing whole sardine hooked to the longline and ready to be deployed.

(Figure 2). The bait was kept the same within each unit. However, the bait used in contiguous units was different, alternating whole sardine (baseline) with alternative baits.

The 120 experimental units included in this study were fished over a period of 2 d: 20 units during day 1, and 100 units during day 2. The vessel deployed the gear between 0400 and 0600 hours and retrieved it between 1700 and 2300 hours. The gear was retrieved from the end that was first deployed, meaning that the soaking time between the units could vary between 13 and 17 h. However, given that the tests carried out in this study were pairwise comparisons of alternated gear (alternative bait versus baseline), the potential difference in soaking time created by the fishing operation would not have introduced any bias in the results. Practically all fishing was carried out during daylight, and the fishing area used on day 1 and day 2 was the same.

Fifty-five units baited with whole sardine were used as baseline to examine the potential effect of bait type on catch efficiency. The sardine were all hooked through the

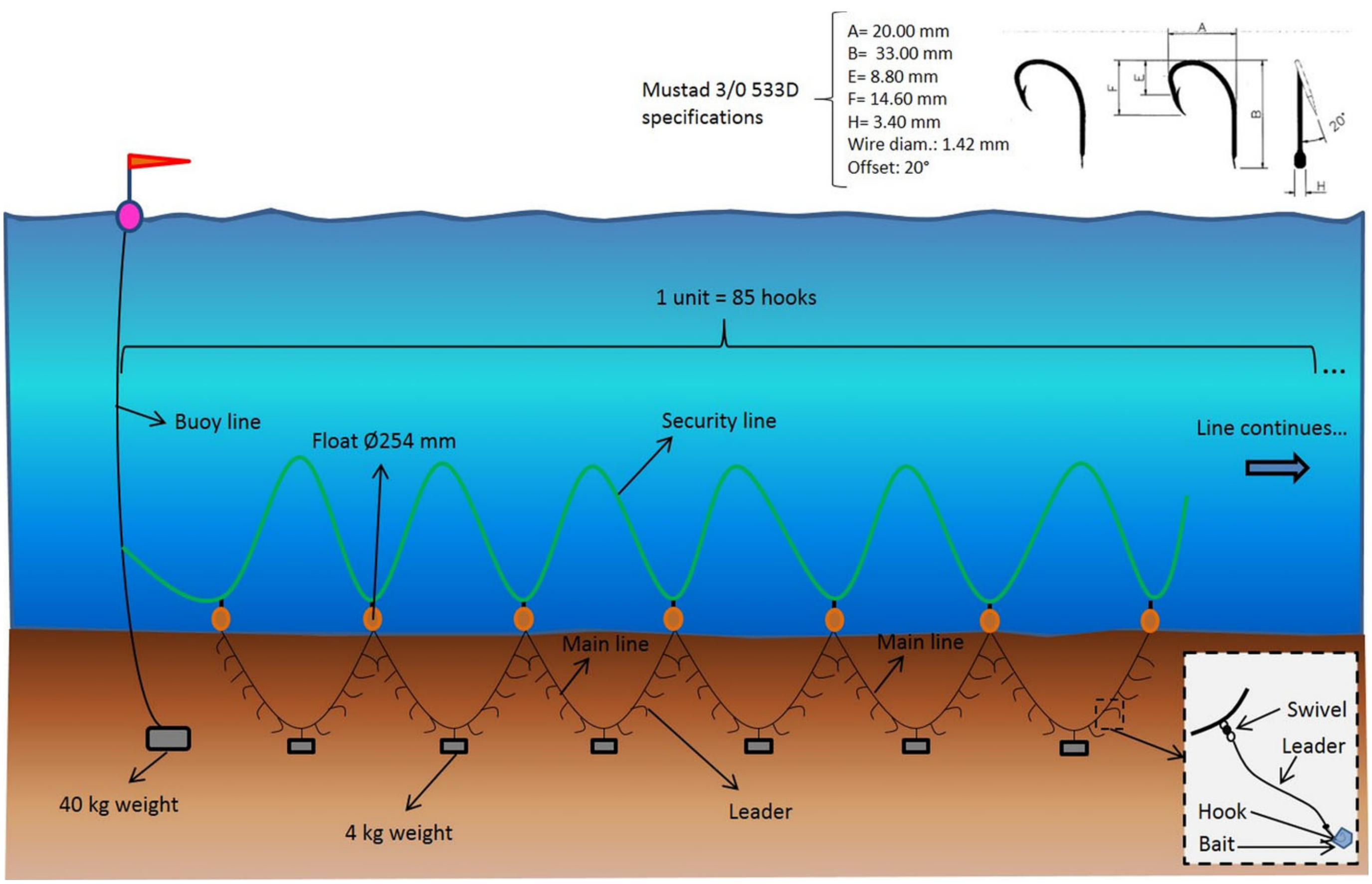

FIGURE 2. Illustration of the longline design and hook (Mustad 3/0 533D) used during the trials, showing the main elements of the gear (diam = diameter).

eyes or upper part of the opercula, as is usually done in this fishery (Figure 1). The remaining 65 units for the bait type investigations were baited with whole herring (20 units), chopped Pacific Saury (15 units), chopped squid (10 units), chopped mackerel (10 units), chopped sardine (5 units), and chopped herring (5 units). The reason for the imbalance between the baseline and each of the alternative baits used was that we wanted to establish a firm baseline and therefore the baseline unit was often alternated between the units with alternative baits. On the other hand, results from previous undocumented trials have led fishermen to believe that some of the baits tested would be better potential substitutes for whole sardine than others, which resulted in these baits being tested in more units. The order in which the alternative baits were tested was randomly selected.

For this experiment, all baits were chopped by hand. Pacific Saury and mackerel were chopped into 30-mm pieces, whereas squid, herring, and sardine were chopped into 60-mm pieces (Figure 3) because the difference in weight/volume among the baits would have been large if all bait types had been cut into 30-mm pieces. Whole herring were hooked the same way as whole sardine, whereas the chopped pieces of bait were hooked through the skin on both sides (Figure 3).

For each unit (each with 85 hooks), the TL of each European Hake caught was measured to the nearest centimeter. Hence, for each unit i deployed during the experimental fishing period, we counted the number of European Hake n_{il} caught that belonged to each length-class l. In the following section, we describe how these data were used to obtain an estimate of the relative catch efficiency of the different baits tested.

Estimation of the relative catch efficiency of different bait types.— To address the three research questions posed in the Introduction, we used a general analysis method that compared the relative catch efficiency of different designs or configurations of a fishing gear carrying multiple pairwise comparisons.

Based on the catch information (numbers and sizes of European Hake for each of the units), we wanted to (1) determine whether there was a significant difference in the catch efficiency among the different bait types tested and (2) investigate whether bait type had any influence on the size of European Hake caught. Specifically, to assess the effect of changing from bait type a to bait type b on the relative length-dependent catch efficiency, we used the method described by Herrmann et al. (2017). In the multiple pairwise comparisons tested, bait type a was always whole sardine (baseline), whereas bait type b differed (six

FIGURE 3. Photographs illustrating **(A)** the size of chopped herring (60 mm) used as bait on longlines during the trials; **(B)** the size of chopped Pacific Saury (30 mm) used as bait; **(C)** how the pieces of bait were hooked during the trials; and **(D)** hooked pieces of Pacific Saury that were ready to be deployed on the longline.

alternative baits) among the pairwise comparisons. This method modeled the length-dependent catch comparison rate (cc_l) summed over deployments,

$$cc_l = \frac{\sum_{j=1}^{bq} nb_{lj}}{\sum_{i=1}^{aq} na_{li} + \sum_{j=1}^{bq} nb_{lj}}, \quad (1)$$

where na_{li} and nb_{lj} are the numbers of European Hake measured in each length-class l for units deployed with bait types a and b, respectively. In equation (1), aq and bq represent the number of deployments carried out with units having bait types a and b, and the summations in the equation represent the summation of the data from the deployments. The functional form of the catch comparison rate $cc(l,\mathbf{v})$ (the experimental catch comparison rate is expressed by equation 1) between longline units with the two bait types a and b was obtained using maximum likelihood estimation by minimizing the following equation:

$$-\sum_l \left\{ \sum_{i=1}^{aq} na_{li} \times \log_e[1.0 - cc(l,\mathbf{v})] + \sum_{j=1}^{bq} nb_{lj} \times \log_e[cc(l,\mathbf{v})] \right\}, \quad (2)$$

where $\mathbf{v}$ represents the parameters describing the catch comparison curve defined by $cc(l,\mathbf{v})$. The outer summation in the equation is the summation over the length-classes l. When both the catch efficiency of bait types a and b and the number of deployments are equal ($aq = bq$), the expected value for the summed catch comparison rate is 0.5. In the case of unequal numbers of deployments, $bq/(aq + bq)$ would be the baseline to judge whether there is a difference in catch efficiency between bait types a and b. The experimental cc_l was modeled by the function $cc(l,\mathbf{v})$ of the following form:

$$cc(l,\mathbf{v}) = \frac{\exp[f(l, v_0, \ldots, v_k)]}{1 + \exp[f(l, v_0, \ldots, v_k)]}, \quad (3)$$

where f is a polynomial of order k with coefficients v_0 to v_k. The values of the parameters $\mathbf{v}$ describing $cc(l,\mathbf{v})$ are estimated by minimizing equation (2), which is equivalent to maximizing the likelihood of the observed data. We considered f up to an order of 4 with parameters v_0, v_1, v_2, v_3, and v_4. Leaving out one or more of these parameters led to 31 additional models that were also considered as potential models for the catch comparison $cc(l,\mathbf{v})$ between a and b. Among these models, estimations of the catch comparison rate were made

TABLE 1. Main catch data for the summed deployments of the different bait types tested in the longline fishery for European Hake.

Variable	Whole sardine	Whole herring	Chopped squid	Chopped mackerel	Chopped Pacific Saury	Chopped sardine	Chopped herring
Number of units fished	55	20	10	10	15	5	5
Total number of European Hake caught	1,090	267	20	54	127	75	97
Mean number of European Hake caught	19.82	13.35	2.00	5.40	8.47	15.00	19.40
SD of number caught	6.81	5.84	2.87	3.13	2.87	9.08	3.97
Minimum number of European Hake caught	7	2	0	2	4	7	16
Maximum number of European Hake caught	40	25	9	11	13	28	26
Mean TL (±95% CI) of European Hake caught (cm)	65.18 ± 0.41	65.55 ± 0.75	68.80 ± 2.98	67.81 ± 1.81	65.22 ± 1.35	62.2 ± 1.83	63.94 ± 1.51
SD of TL (cm)	6.98	6.28	6.79	6.77	7.77	8.08	7.61
Minimum TL of European Hake caught (cm)	37	41	60	52	39	39	42
Maximum TL of European Hake caught (cm)	95	89	83	81	92	78	84

using multimodel inference to obtain a combined model (Burnham and Anderson 2002; Herrmann et al. 2017).

The ability of the combined model to describe the experimental data was evaluated based on the *P*-value, which quantifies the probability of obtaining by coincidence at least as large a discrepancy between the experimental data and the model as was observed, assuming that the model is correct. Therefore, this *P*-value, which was calculated based on the model deviance and the df, should not be less than 0.05 for the combined model to describe the experimental data sufficiently well (Wileman et al. 1996; Herrmann et al. 2017). Based on the estimated catch comparison function $cc(l,\boldsymbol{v})$, we obtained the relative catch efficiency (also termed the catch ratio), $cr(l,\boldsymbol{v})$, between fishing with the two bait types *a* and *b* by using the general relationship

$$cr(l,\boldsymbol{v}) = \frac{aq \times [cc(l,\boldsymbol{v})]}{bq \times [1 - cc(l,\boldsymbol{v})]}, \quad (4)$$

The catch ratio provides a direct comparison of the catch efficiencies of bait types *a* and *b*, and it provides a value independent of the number of deployments carried out with units *a* and *b*. Thus, if the catch efficiency of both bait types is equal, $cr(l,\boldsymbol{v})$ should always be 1.0. It follows that a $cr(l,\boldsymbol{v})$ equal to 1.25 would mean that bait type *b* catches, on average, 25% more fish with length *l* than does bait type *a*. In contrast, a $cr(l,\boldsymbol{v})$ equal to 0.75 would mean that bait type *b* is only catching 75% of the fish with length *l* that bait type *a* is catching.

The confidence limits for the catch comparison curve and catch ratio curve were estimated using a double-bootstrapping method (Herrmann et al. 2017). This technique accounts for the uncertainty in the estimation resulting from between-deployment variation in catch efficiency and availability of fish as well as uncertainty about the size structure of the catch for the individual deployments. We performed 1,000 bootstrap repetitions and calculated the Efron 95% confidence limits (Efron 1982). To identify sizes of European Hake with significant differences in catch efficiency, we checked for length-classes in which the confidence limits for the catch ratio curve did not contain 1.0 (i.e., at 1.0, the catch efficiency is equal between bait types).

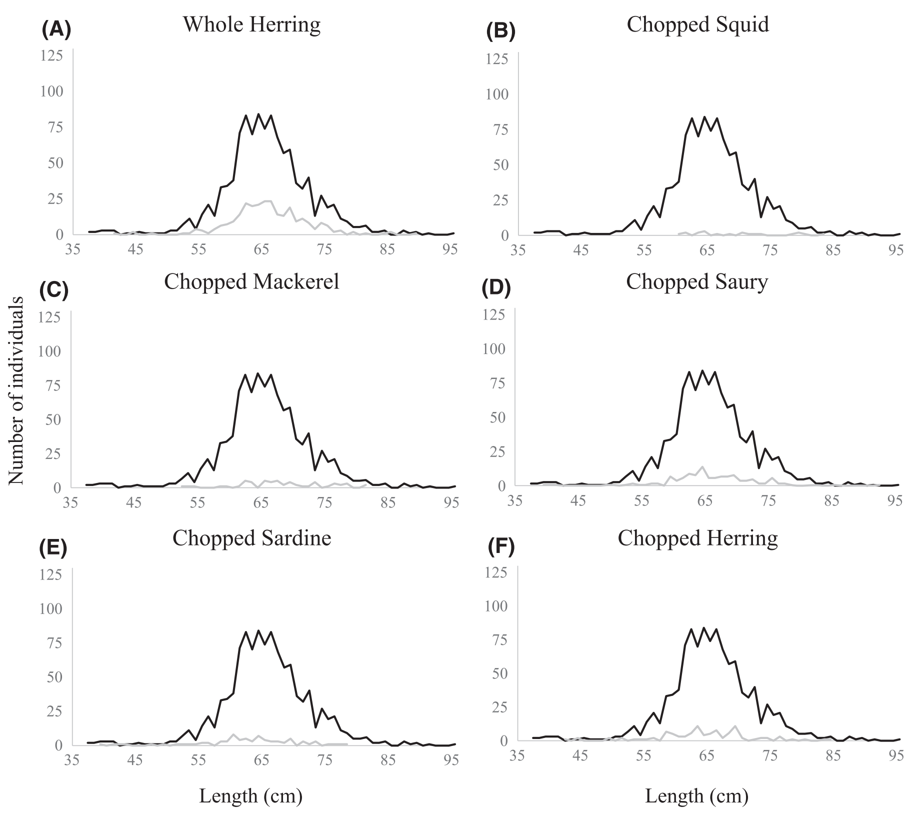

FIGURE 4. Comparison of the length distribution of European Hake captured on longlines using whole sardine as bait (solid black line in each panel) and the length distribution of European Hake captured with alternative baits (solid gray line): **(A)** whole herring, **(B)** chopped squid, **(C)** chopped mackerel, **(D)** chopped Pacific Saury, **(E)** chopped sardine, and **(F)** chopped herring.

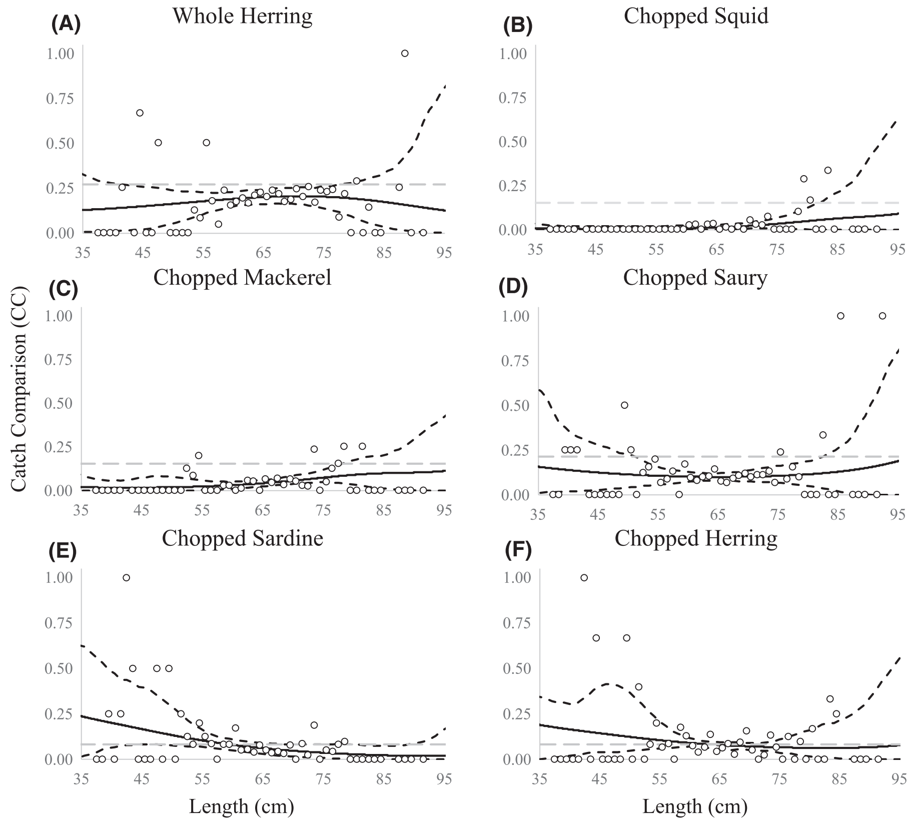

FIGURE 5. Catch comparison (CC) rate and curve with 95% confidence intervals (black dashed lines) for European Hake caught on longlines with alternative baits: **(A)** whole herring, **(B)** chopped squid, **(C)** chopped mackerel, **(D)** chopped Pacific Saury, **(E)** chopped sardine, and **(F)** chopped herring. The gray dashed line in each plot shows the level at which the tested bait would fish as effectively as whole sardine (baseline).

A length-integrated average value for the catch ratio was also estimated directly from the experimental data by

$$cr_{average} = \frac{\frac{1}{bq}\sum_l \sum_{j=1}^{bq} nb_{lj}}{\frac{1}{aq}\sum_l \sum_{i=1}^{aq} na_{li}}, \quad (5)$$

where the outer summation covers the length-classes in the catch during the experimental fishing period.

By incorporating $cr_{average}$ into each of the bootstrap iterations described above, we were able to assess the 95% confidence limits for $cr_{average}$. We used $cr_{average}$ to provide a length-averaged value for the effect of changing bait type a to bait type b on the catch efficiency. In contrast to the length-dependent evaluation of the catch ratio, $cr_{average}$ is specific for the population structure encountered during the experimental sea trials. Therefore, its value is specific for the size structure in the fishery at the time the trials were carried out, and it cannot be extrapolated to other scenarios in which the size structure of the fish population may be different.

The analyses described above were performed using SELNET software (Herrmann et al. 2012) and were applied separately for each set of bait comparisons.

RESULTS

Catch Data

The 120 longline units fished captured a total of 1,730 European Hake with a length range that varied between 37 and 95 cm TL. The mean size of the European Hake caught also varied between 62.20 cm for the longlines baited with chopped sardine and 68.80 cm for the longlines baited with squid (Table 1). The confidence intervals (CIs) for the mean size of the European Hake caught indicated that chopped squid or chopped mackerel caught significantly larger European Hake than did whole sardine, chopped sardine, or chopped herring. Similarly, the average size of the European Hake caught when using whole sardine or herring as bait was higher than the average size of European Hake caught by using chopped sardine (Table 1).

Catch Efficiency of Alternative Bait Types

To evaluate the potential differences in catch efficiency between whole sardine and the six alternative baits tested (whole herring, chopped Pacific Saury, chopped squid, chopped mackerel, chopped sardine, and

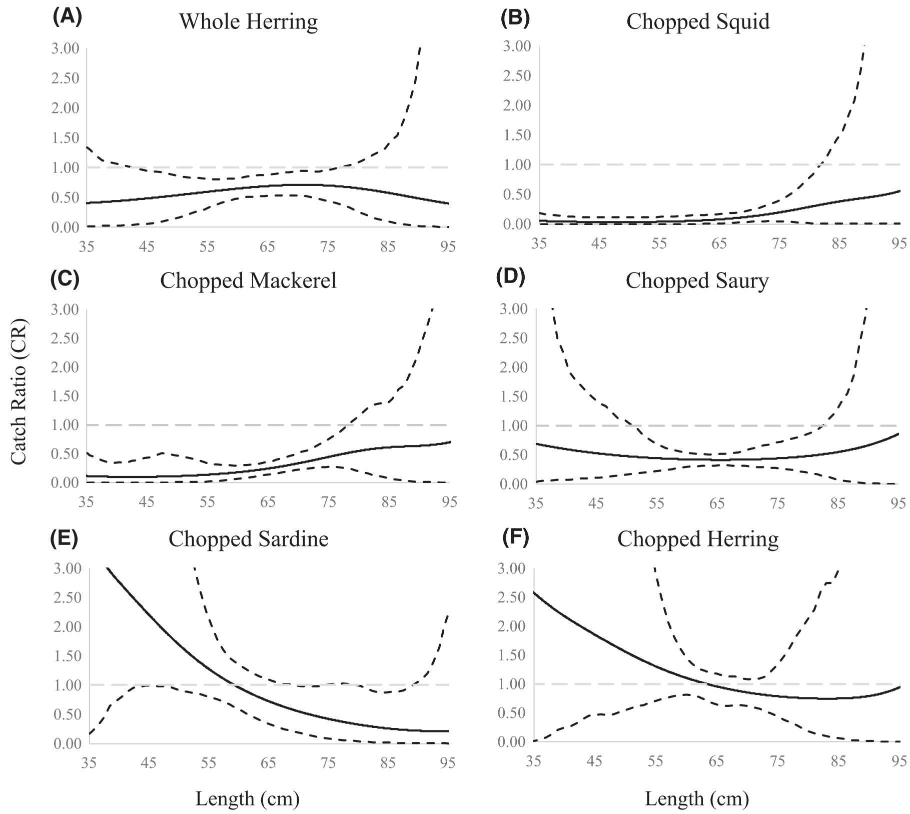

FIGURE 6. Catch ratio (CR) curve with 95% confidence intervals (black dashed lines) for European Hake caught on longlines with alternative baits: **(A)** whole herring, **(B)** chopped squid, **(C)** chopped mackerel, **(D)** chopped Pacific Saury, **(E)** chopped sardine, and **(F)** chopped herring. The gray dashed line in each plot shows the level at which the tested bait would fish as effectively as whole sardine (baseline).

chopped herring), a comparison of the captured size distributions of European Hake, the length-dependent catch comparison, and catch ratio rates were estimated and plotted for each of the six cases (Figures 4–6). The catch comparison results plotted in Figure 5 show that the model used represents the trend in the data well but that the binominal noise in the data and the CIs increase outside the areas with the most data (see fish distributions in Figure 4).

The catch comparison and catch ratio curves showed that four of the six alternative baits tested significantly reduced catch efficiency for the longline. For whole herring, the results showed a significant reduction for European Hake between 42 and 78 cm TL (Figure 6A). For chopped squid, the reduction was significant for European Hake between 35 and 82 cm TL (Figure 6B). Although squid caught significantly larger fish on average than whole sardine (Table 1), the results in Table 2 indicate that for the largest European Hake (70–90 cm TL), the catch efficiency of squid was inconclusive due to wide CIs. For chopped mackerel, the reduction in catch efficiency compared to whole sardine was significant for European Hake between 35 and 78 cm TL (Figure 6C). As was observed for squid, mackerel caught significantly larger European Hake on average than did whole sardine (Table 1), but the results for the catch efficiency of the largest European Hake were inconclusive due to wide CIs (Table 2). For chopped Pacific Saury, the reduction in catch efficiency was significant for European Hake between 51 and 82 cm TL (Figure 6D).

The results indicated also that chopped sardine were more efficient than whole sardine at capturing smaller European Hake, whereas whole sardine were significantly more efficient than chopped sardine at capturing large European Hake (Figure 6E). These results demonstrate that the effect of sardine bait size is size dependent. Comparison of catch efficiency between chopped herring and whole herring showed a similar tendency, as chopped herring was significantly more efficient than whole herring at capturing small European Hake up to 63 cm TL. For European Hake exceeding 70 cm TL, the results were inconclusive due to the wide CIs, which most likely were a consequence of the low number of deployments available.

Table 2 shows that chopped sardine were between 64.77% and 24.14% more effective at capturing 50–55-cm

TABLE 2. Catch ratio (*cr*, %; defined in Methods) results and fit statistics for the six alternative baits tested in the longline fishery for European Hake. In all cases, whole-sardine bait was used as the baseline. Values in parentheses represent 95% confidence limits.

Statistic	Whole herring	Chopped squid	Chopped mackerel	Chopped Pacific Saury	Chopped sardine	Chopped herring
$cr(50,\nu)$	54.24 (17.26–84.59)	3.31 (0.01–11.01)	11.25 (0.55–46.17)	47.21 (16.26–103.81)	164.77 (89.58–412.71)	155.81 (54.70–638.72)
$cr(55,\nu)$	59.96 (34.70–80.51)	3.93 (0.03–12.25)	13.89 (1.98–32.00)	43.91 (22.95–66.14)	124.14 (78.90–201.16)	130.33 (70.74–291.16)
$cr(60,\nu)$	65.29 (49.01–83.23)	5.39 (0.12–14.47)	18.29 (6.75–29.63)	41.97 (29.50–53.11)	93.37 (55.72–131.86)	110.39 (81.85–144.52)
$cr(65,\nu)$	69.32 (53.09–88.91)	8.20 (1.25–17.17)	25.02 (14.50–36.77)	41.32 (31.84–51.08)	70.48 (31.99–107.79)	95.66 (64.80–117.25)
$cr(70,\nu)$	71.05 (52.70–94.81)	13.04 (4.12–24.47)	34.39 (22.83–52.72)	41.99 (29.69–59.72)	53.58 (17.30–97.70)	85.26 (61.79–107.82)
$cr(75,\nu)$	69.62 (42.56–97.10)	20.46 (4.02–42.54)	45.54 (27.21–78.54)	44.20 (26.20–72.34)	41.10 (8.07–101.33)	78.57 (43.33–133.37)
$cr(80,\nu)$	64.69 (23.48–110.91)	29.87 (1.19–83.44)	55.63 (18.26–120.3)	48.42 (18.38–87.57)	31.75 (3.53–98.47)	75.17 (18.33–212.99)
$cr(85,\nu)$	56.82 (8.26–146.18)	38.85 (0.58–155.59)	61.37 (6.11–144.85)	55.65 (5.94–139.41)	25.24 (1.51–88.22)	74.81 (6.31–299.27)
$cr(90,\nu)$	47.55 (1.90–314.59)	45.99 (0.44–402.02)	63.90 (1.04–247.25)	67.80 (0.74–377.05)	21.75 (0.45–109.19)	79.10 (1.12–556.07)
$cr(95,\nu)$	38.97 (0.32–1,361.10)	56.87 (0.40–1,059.80)	70.99 (0.10–425.90)	88.39 (0.23–1,766.6)	21.32 (0.12–235.49)	94.33 (0.03–1,398.74)
$cr_{average}$	67.36 (54.50–82.33)	10.09 (2.63–19.09)	27.25 (18.30–37.37)	42.72 (34.09–51.47)	75.69 (43.16–114.69)	97.88 (83.09–119.93)
P-value	0.4912	0.899	0.5754	0.72	0.7404	0.035
Deviance	47.55	35.13	44.53	42.84	41.34	67.22
df	48	47	47	49	48	48

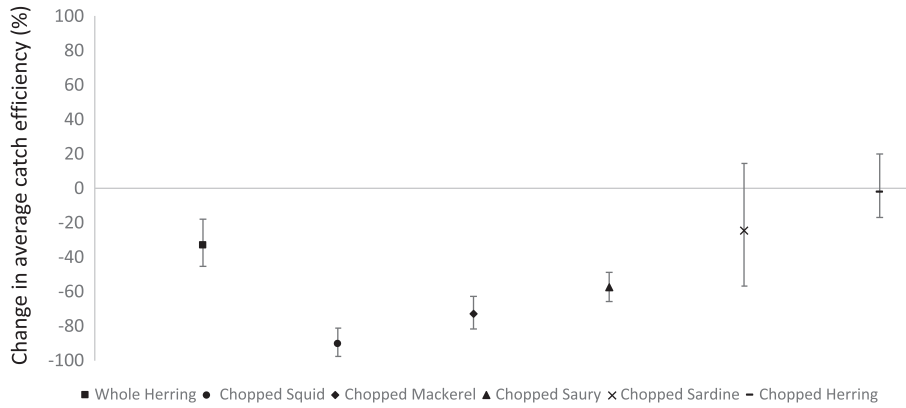

FIGURE 7. Whisker plot showing average changes in European Hake catch ratio for the six different longline baits tested, using whole-sardine bait as the baseline. The vertical bars represent 95% confidence limits.

European Hake than whole sardine, whereas they only captured between 21% and 22% of the largest European Hake. On average, whole sardine were 24.31% more efficient than chopped sardine at capturing European Hake (Table 2; Figure 7). When chopped herring and whole sardine were compared, whole sardine were on average only 2.12% more efficient than chopped herring at capturing European Hake. Chopped herring was the most efficient alternative bait and the one with least difference in average catch efficiency compared to whole sardine (Table 2). The difference between these two baits (chopped sardine and chopped herring) and whole sardine was not significant in any case. In contrast, the difference in average catch efficiency between whole herring and whole sardine was statistically significant, as was also true for chopped mackerel, chopped squid, and chopped Pacific Saury. In all four cases, whole sardine captured significantly more European Hake on average. The difference in average catch efficiency between whole herring and whole sardine was 67.36% (Table 2; Figure 7), whereas average catch efficiency produced by Pacific Saury bait was 42.72% that of whole sardine. Mackerel and squid were the baits with the highest difference in average catch efficiency compared to whole sardine: their average efficiencies were 27.25% and 10.09%, respectively, that of whole sardine (Table 2; Figure 7).

The catch comparison curves of the six different baits tested showed that the model described the experimental data well; this was also demonstrated by the fit statistics listed in Table 2. The *P*-values were greater than 0.05 for all baits except chopped herring, which means that the deviation between the experimental data points and the fitted curves could well be a coincidence. For chopped herring, the catch comparison curve seemed to follow the main trend in the experimental data (Figure 5F); thus, we assume that the low *P*-value in this case is simply due to overdispersion in the experimental data. In addition, the deviance and df were of the same magnitude in all six cases, further indicating a good fit of the model to the experimental data.

DISCUSSION

Use of an alternative to whole sardine, which traditionally are used as bait, is one of the main adaptations that would have to be applied to automate the Spanish longline fishery and other EU longline fisheries operating in the North Sea. The gear design changes needed for automation were summarized by Herrmann et al. (2017). The aim of the present study was to evaluate the importance of bait type on the catch efficiency of the European Hake fishery. Thus, comparisons of efficiency between the traditional, whole-sardine bait and alternative baits that are compatible with automation were conducted. The six alternative baits tested were chopped mackerel, chopped Pacific Saury, whole herring, chopped squid, chopped sardine, and chopped herring. All of these different baits have different properties in terms of odor, shape, and consistency. Løkkeborg et al. (2014) previously noted that bait odor is the most important parameter in attracting fish to the gear. Once the fish is close to the bait, other factors, such as size and shape, increase in importance for attracting the fish to attack the bait. Additional factors, such as the firmness of the bait and how well it holds to the hook, are important characteristics influencing the final effectiveness of each type of bait, as they determine how long the bait stays on the hook (Kumar et al. 2016).

In this study, four of the six alternative baits tested were significantly less efficient than whole sardine at capturing European Hake. Squid performed the worst in terms of efficiency at catching European Hake; this bait type captured significantly less European Hake than did sardine, Pacific Saury, and herring. However, squid is in some cases used in longline fisheries because it holds the hook much better than fish (He 1996; Ward and Myers 2007), which in some fisheries results in better hooking rates of the target species (Amorim et al. 2015). On the other hand, squid is believed to produce less odor than other types of fish bait, such as mackerel, which is why these two bait types sometimes are used together on longlines (Bjordal 1983). Mackerel is one of the main baits used in longline fisheries worldwide (Løkkeborg et al. 2014) and in demersal fisheries; however, in the present study, mackerel caught significantly less European Hake than did both sardine and herring. Like mackerel, the Pacific Saury, which has been tried as an alternative bait in several demersal longline fisheries in the North Sea and Barents Sea, was significantly less efficient at catching European Hake than herring or whole sardine. Whole herring had a higher catch efficiency than mackerel, Pacific Saury, and squid, but the catch efficiency of whole herring was still significantly lower than that of whole sardine (Table 2; Figure 7).

Johannessen et al. (1993) reported that bait size and/or shape are important factors in determining the catch efficiency of longlines. Often, these are confounding parameters, as differences in bait size imply differences in bait shape. To investigate the effect of bait size in the present study, we compared catch efficiency between chopped sardine and whole sardine. Chopped sardine were on average 24.31% less efficient at capturing European Hake than were whole sardine, but the differences were not statistically significant, most likely due to low sample size. In comparison with whole sardine, the average catch efficiency of chopped herring was only slightly lower.

These results clearly show that the catch efficiency of this longline fishery will change if the type of bait used is changed. Moreover, of the alternatives tested that could comply with automation, only chopped herring provided acceptable catch efficiency rates. However, considering the limited number of deployments available for chopped sardine and herring, further tests with these baits are recommended to reach a conclusion about their effectiveness.

Bait size has been shown to affect not only the catch efficiency of a longline but also its size-selective properties (Løkkeborg and Bjordal 1992; Løkkeborg 1994). The results obtained here also indicate an effect of bait size on the size of captured European Hake. For sardine, chopped bait rather than whole fish was more efficient at capturing small European Hake; this difference was marginally significant (Figure 6E). In contrast, whole sardine were significantly more efficient than chopped sardine at capturing large European Hake. These results clearly demonstrate that in this type of study, it is important to use a method that considers fish size so as to avoid obtaining results that can be misinterpreted. As our results illustrate, different baits can have different effects on large and small fish, which is crucial information for both fishermen and fisheries managers.

Overall, the present results demonstrate that both bait type and bait size are important parameters for the overall catch efficiency of European Hake. Of the different baits tested, only chopped herring would be a realistic alternative to whole sardine for automation of the gear. Furthermore, the results confirm that bait size can influence the size selectivity of longlines, as was reported previously (Løkkeborg and Bjordal 1992; Løkkeborg 1994). Finally, this study demonstrates the importance of using data collection and analysis methods that explicitly consider target fish size in addition to catch rates.

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