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ARTICLE

Effect of Hook and Bait Size on Catch Efficiency in the Persian Gulf Recreational Fisheries

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Abstract

The effect of hook and bait sizes on the catch efficiency and size composition of Spangled Emperor *Lethrinus nebulosus*, Orange-spotted Grouper *Epinephelus coioides*, and Narrowbarred Mackerel *Scomberomorus commerson* was investigated in the recreational and semi-subsistence handline fishery in the Persian Gulf. Based on expectations that increasing hook and bait sizes would decrease the catch efficiency of the smaller individuals while maintaining the catch efficiency of larger fish, we investigated the effect of increasing hook and bait sizes. For all three species, the results indicated slightly lower catch efficiency for the smaller fish when larger hooks were used. Furthermore, the results demonstrated a significant increase in catch efficiency for the larger sizes of Spangled Emperor and Orange-spotted Grouper when fished with larger hooks, an effect that increased with fish size for both species. Additionally, the overall catch efficiency did not vary significantly when increasing hook and bait sizes for the three species investigated. This study shows that fishing with larger hooks and larger bait would change the exploitation pattern of these species toward higher proportions of larger fish in the catches. Moreover, based on the size distribution of the species on the fishing grounds during the study period, the use of larger hooks and bait would lead to significant increases in the total number of Spangled Emperor caught (41% increase; 95% confidence interval [CI] = 17–69%) and the total number of Orange-spotted Grouper caught (151% increase; 95% CI = 132–336%), respectively. The results indicated a similar effect for Narrowbarred Mackerel; however, the effect was far less profound than for the two other species and was not significant for any size-classes.

Handlining is one of the most important fishing methods used in the recreational and semi-subsistence sectors in the Persian Gulf. In 2014, 1,370 small boats landed 12,000 metric tons in the handline fishery around Qeshm Island in the northern Persian Gulf (IFO 2014). The dominant species landed in this fishery are the Spangled Emperor

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Lethrinus nebulosus, Orange-spotted Grouper *Epinephelus coioides*, and Narrowbarred Mackerel *Scomberomorus commerson*. Together, these species account for approximately 70% of the total catch in weight (Paighambari and Eighani 2017). In the Persian Gulf handline fishery, there are no management regulations or size limitations, and fish stocks could potentially become depleted due to long-term unsustainable harvesting. Recreational fishing can contribute to declines in both the abundance and biomass of numerous marine species by altering fish population structures (Campbell and Pardede 2006) and reducing the fish biomass within an area (Hawkins and Roberts 2004).

One way to improve the exploitation pattern in the fishery is to adjust hook and bait sizes. However, previous studies into handline fishing have found contradicting results in terms of species selectivity and size selectivity. Nicolaides et al. (2002) and Penaherrera and Hearn (2008) found that handline fishing had very limited species and size selectivity, whereas Ruttenberg (2001) observed handline fishing to be fairly selective. Several studies have also demonstrated the effect of hook and bait sizes for various fish species (Foster et al. 2012; Patterson et al. 2012; Santos et al. 2012; Coelho et al. 2015). Patterson et al. (2012) reported that hook size significantly affected reef fish catch rates as well as the size composition of the catch. Increasing the hook size used in handline fisheries can affect catch efficiency and reduce catches of undersized fish (Otway and Craig 1993; Cooke et al. 2005; Alos et al. 2008a, 2008b; Leaman et al. 2012; Hannan et al. 2013; Campbell et al. 2014; Garner et al. 2014; Ateşşahin et al. 2015). Furthermore, bait size is also regarded as an important factor that affects the size of fish caught by longlines (Lokkeborg and Bjordal 1992; Lokkeborg 1994).

In the Persian Gulf handline fishery, fishers mostly use J-hooks (8/0) for targeting Orange-spotted Grouper and Spangled Emperor, and larger J-hooks (5/0) are used for targeting Narrowbarred Mackerel. However, there are concerns about the exploitation pattern in the handline fishery, particular regarding catches of small fish. Based on expectations that increasing hook size would decrease the catch efficiency of the smaller individuals of these species while maintaining the catch efficiency of larger fish, such a change could potentially improve the exploitation pattern in the handline fishery. However, in this fishery, the fishers tend to adjust the bait size to the hook size, implying that a larger-sized hook would also mean using a larger piece of bait. Therefore, to reflect how fishers deploy different hook sizes, an investigation on how hook size would affect the exploitation pattern in the fishery should also consider a corresponding change in bait size. Based on the above considerations, we sought to assess the effect of increasing hook and bait sizes on the catch efficiency of Orange-spotted Grouper, Spangled Emperor, and Narrowbarred Mackerel in the Persian Gulf handline fishery. Furthermore, we wanted to understand whether differences in catch efficiency are size dependent and whether they can be related to the specific differences in hook and bait sizes.

METHODS

Study area.— The study was conducted in two different fisheries off Qeshm Island in the Persian Gulf during July and September 2016 (Figure 1). The first trial was conducted in the Suza region, while the second trial took place off Greater Tunb Island. Spangled Emperor and Orange-spotted Grouper were targeted during the first trial, close to the Qeshm Island coast in depths from 10 to 65 m. Narrowbarred Mackerel were targeted near Greater Tunb Island, away from the Qeshm Island coastline in depths from 1 to 10 m. These three species are the most abundant and commercially important species in the area and were included in the analysis.

Experimental fishing trials and data collection.— Fishers deployed a handline with a baited hook over the side of the boat, and once a fish was hooked, it was immediately hauled in by hand. The analysis was performed separately for the three species. All characteristics of the fishing gear and practices (e.g., hook placement, deployed number of hooks of each style per set, bait size, setting time, etc.) were standardized throughout the study. Data were recorded by onboard fisheries observers during hauling operations using standard forms and procedures. In the handline fishery targeting Orange-spotted Grouper and Spangled Emperor, a 90-m monofilament mainline with a diameter of 0.8 mm was used. The lead weight (sinker) used at the end of the fishing line was 1.5 kg. Each handline was equipped with a size-7/0 or size-8/0 Mustad (2315-DT) J-hook (Figure 2), hereafter referred to as J7 and J8, respectively. Pieces of squid were used as bait (40 ± 4.5 g for J7; 30 ± 5.1 g for J8 [mean $\pm$ SD]).

In the handline fishery targeting Narrowbarred Mackerel, fishers typically use larger J-hooks with a thicker monofilament line. The handline consisted of a 15-m monofilament mainline with a diameter of 1.5 mm and a 50-cm-long wire trace (3-mm diameter) attached to a swivel at the end of the fishing line to increase the strength. Each handline was equipped with either a size-4/0 or size-5/0 Mustad (2315-DT) J-hook (Figure 2), hereafter referred to as J4 and J5, respectively. Whole Sind Sardinella *Sardinella sindensis* were used as bait (14 ± 2.0 cm for J4; 11 ± 2.0 cm for J5). Fishing trips were carried out daily from dawn to dusk. The duration of each fishing trip varied and depended on fish availability and weather conditions. Two classes of boats (5 and 7 m) typical for the recreational fishery were used. The smaller boats operated near the shore and targeted Orange-spotted Grouper and Spangled Emperor, while the larger boats traveled

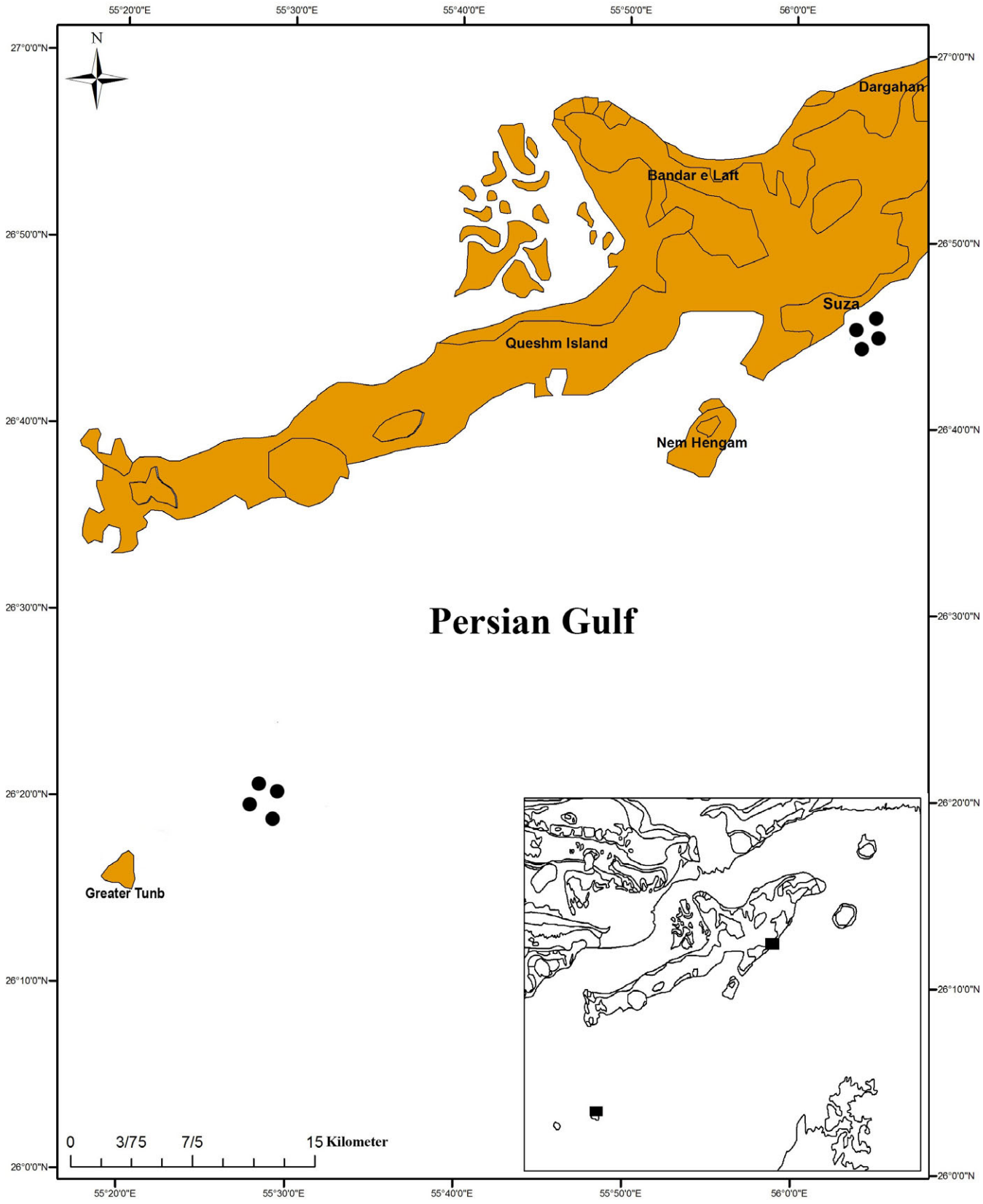

FIGURE 1. Map of the two study areas in the northern Persian Gulf off Qeshm Island. Black circles show the locations of experimental trials.

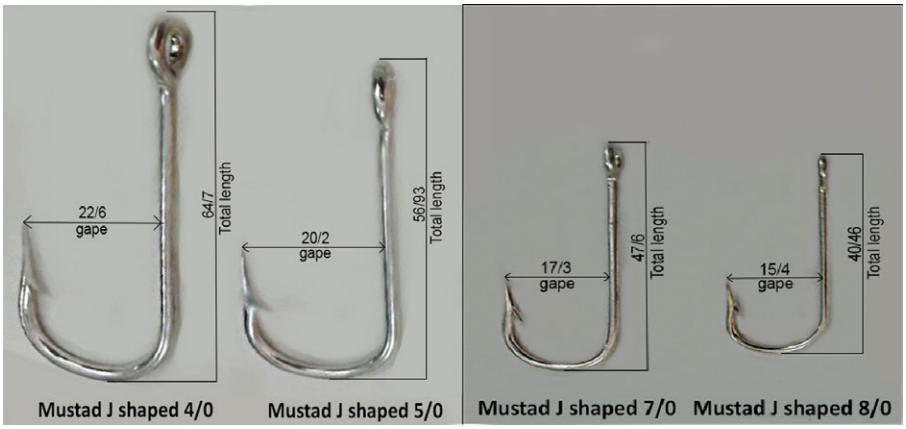

FIGURE 2. Two sets of J-style hook sizes used in a study of the Persian Gulf handline fishery: sizes 4/0 and 5/0 were used to target Narrowbarred Mackerel, whereas sizes 7/0 and 8/0 were used to target Spangled Emperor and Orange-spotted Grouper.

offshore and targeted Narrowbarred Mackerel. Fishers carried one handline set with a specific hook and bait size on each trip and vessel.

For every fish captured, the hook size and bait type were recorded, and the captured species were identified and measured to the nearest centimeter below their TL. Traditional and experimental hook sizes are shown in Figure 2.

Estimation of the catch comparison curve.— Using the catch information (numbers and sizes) on Orange-spotted Grouper, Spangled Emperor, and Narrowbarred Mackerel for each hook and bait size, we determined whether there was a significant difference in catch efficiency among the different hook and bait sizes. Because hook and bait sizes may be size selective, inferences on the catch efficiency between hook and bait sizes needed to explicitly consider fish size. To do this, we adapted the catch comparison methodology for estimating the effect of gear design changes based on unpaired catch data described by Herrmann et al. (2017), and we applied the statistical software SELNET (Herrmann et al. 2012) for the analysis.

This method analyzes the catches of each species individually, where the catches of each species caught using hook *a* (J8 or J5) and hook *b* (J7 or J4) are compared. Each fishing trip was considered a base unit that deployed one specific size of hook and bait (henceforth referred to as hook size). Catch information (numbers and sizes of fish for each of the units) was used to determine whether there was a significant difference in the catch efficiency among the different hook sizes tested. In addition to potential differences in catch efficiency between hook sizes, the catch efficiency of each hook size could be affected by the randomness in numbers and sizes of fish available at the time and location of each fishing trip. However, when averaging over fishing trips, we assumed that the numbers and sizes of fish available to the different hook sizes would be the same, as the different hook sizes were deployed in the same fishing area and during the same period of time. Furthermore, the catch data obtained for hook sizes *a* and *b* were not collected in pairs and did not have the same total number of fishing trips. Therefore, to estimate the functional form of the summed catch comparison rate (expressed in equation 2 below) between hook sizes *a* and *b*, the catch data from the fishing trips of hook size *a* were summed and compared with the summed data of the fishing trips carried out with hook size *b* by minimizing the following equation (Herrmann et al. 2017):

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

where $\boldsymbol{v}$ represents the parameters describing the catch comparison curve defined by $cc(l,\boldsymbol{v})$; na_{li} and nb_{lj} are the numbers of fish measured in each length-class l for hook sizes *a* and *b*, respectively; and sa_i and sb_j are sampling factors for the individual fishing trips that are introduced to account for the fishing trips having different durations. Assuming that, on average, the total catch during a fishing trip i or j will be proportional to trip duration t_i or t_j, then $sa_i = \frac{t_i}{t_{max}}$ and $sb_j = \frac{t_j}{t_{max}}$, here t_{max} is the duration of the longest fishing trip among trips with hook sizes *a* and *b*. In equation (1), *aq* and *bq* are the number of fishing trips carried out with hook sizes *a* and *b*, respectively, and the inner summations in the equation represent the summations of the data from the fishing trips. The outer summation in the equation is the summation over the length-classes l. Equation (1) is equivalent to maximizing the likelihood for the observed data based on a maximum likelihood formulation for binominal data (see Herrmann et al. 2017).

The experimental summed catch comparison rate (cc_l, where l denotes fish length) is given by

$$cc_l = \frac{\sum_{j=1}^{bq} \frac{nb_{lj}}{sb_j}}{\sum_{i=1}^{aq} \frac{na_{li}}{sa_i} + \sum_{j=1}^{bq} \frac{nb_{lj}}{sb_j}}. \quad (2)$$

When both the catch efficiency of hook sizes a and b and the number of fishing trips are equal ($aq = bq$), the expected value for the summed catch comparison rate would be 0.5. In the case of unequal numbers of fishing trips, $bq/(aq + bq)$ would be the baseline to judge whether or not there is a difference in catch efficiency between hook sizes a and b. The experimental cc_l is modeled by the function $cc(l,\boldsymbol{v})$, which has the following form (Herrmann et al. 2017):

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

where f is a polynomial of order k with coefficients v_0 to v_k. Thus, $cc(l,\boldsymbol{v})$ expresses the probability of finding a fish of length l in the catch of one of the fishing trips with hook size b given that it is found in the catch for one of the fishing trips with hook size a or b. The values of the parameters $\boldsymbol{v}$ describing $cc(l,\boldsymbol{v})$ are estimated by minimizing equation (1), equivalent to maximizing the likelihood of the observed data. We considered f of 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 the parameters $v_0,\ldots,v_4$ led to 31 additional models that were also considered as potential models for the catch comparison $cc(l,\boldsymbol{v})$ between a and b. Based on these models, estimations of the catch comparison rate were made using model averaging (Burnham and Anderson 2002) via the procedure described by 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 great of a discrepancy between the experimental data and the model as observed, assuming that the model is correct. Therefore, this P-value, which was calculated based on the model deviance and the degrees of freedom, should not be less than 0.05 for the combined model to describe the experimental data sufficiently well (Wileman et al. 1996).

The confidence limits for the catch comparison curve were estimated using a double-bootstrapping method for unpaired data (Herrmann et al. 2017). The procedure accounted for between-fishing-trip variation in the availability of fish and catch efficiency by random sampling, with replacement, aq and bq from the different hook sizes deployed (a and b, respectively). Furthermore, within-fishing-trip uncertainty in the size structure of the catch data was accounted for by randomly selecting fish with replacement from each of the selected fishing trips separately. The number of fish selected was equal to the number of fish caught within that fishing trip, with the resampling conducted prior to raising the data by the sampling factors sa_i and sb_j to correctly account for the additional uncertainty this causes (Eigaard et al. 2012). These data were then combined as described above, and the catch comparison curves were estimated. We performed 1,000 bootstrap repetitions and calculated the Efron 95% confidence limits (Efron 1982) for the catch comparison curves. By applying the approach described above for each bootstrap repetition, we also accounted for the effect of uncertainty in model selection in the confidence limits for the catch comparison curve. To determine the sizes of fish with significant differences in catch efficiency, we identified length-classes for which the confidence limits around the combined catch comparison curves did not contain $bq/(aq + bq)$.

Estimation of the catch ratio curve.— The catch comparison rate $cc(l,\boldsymbol{v})$ cannot be used to directly quantify the ratio between the catch efficiency of hook size a versus hook size b for a fish of length l. Instead, we used the catch ratio $cr(l,\boldsymbol{v})$. For the experimental data, the average catch ratio for a length-class l is expressed as equation (4)

$$cr_l = \frac{\frac{1}{bq}\sum_{j=1}^{bq} \frac{nb_{lj}}{sb_j}}{\frac{1}{aq}\sum_{i=1}^{aq} \frac{na_{li}}{sa_i}} \quad (4)$$

Simple mathematical manipulation based on equations (2) and (4) yields the following general relationship between the catch ratio and the summed catch comparison:

$$cr_l = \frac{aq \times cc_l}{bq \times (1 - cc_l)}, \quad (5)$$

which also means that the same relationship exists for the functional forms:

$$cr(l,\boldsymbol{v}) = \frac{aq \times cc(l,\boldsymbol{v})}{bq \times [1 - cc(l,\boldsymbol{v})]}. \quad (6)$$

One advantage of using the catch ratio, as defined by equations (4) and (6), is that it gives a direct relative value of the catch efficiency between a and b. Furthermore, it provides a value independent of the number of fishing trips carried out with a and b. Thus, if the catch efficiency is equal between hook sizes a and b, $cr(l,\boldsymbol{v})$ should be 1.0. Therefore, $cr(l,\boldsymbol{v}) = 1.25$ would mean that hook size b is catching, on average, 25% more fish at length l than hook

size a. In contrast, $cr(l,\boldsymbol{v}) = 0.75$ would mean that hook size b caught 25% less fish at length l than hook size a.

Using equation (6) and incorporating the calculation of $cr(l,\boldsymbol{v})$ into the double-bootstrap procedure described for the catch comparison rate, we estimated the confidence limits for the catch ratio. We used the catch ratio analysis to estimate the length-dependent effect on catch efficiency caused by changing from hook size a to hook size b.

Estimation of the length-integrated catch ratio.— A length-integrated average value for the catch ratio can be estimated by

$$cr_{average} = \frac{\frac{1}{bq}\sum_l \sum_{j=1}^{bq} \frac{nb_{lj}}{sb_j}}{\frac{1}{aq}\sum_l \sum_{i=1}^{aq} \frac{na_{li}}{sa_i}} \quad (7)$$

where the outer summation covers the length-classes caught during the trial.

By incorporating $cr_{average}$ into each of the bootstrap iterations described for estimation of the catch comparison curve, 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 hook and bait sizes on catch efficiency. In contrast to the length-dependent evaluation of the catch ratio ("Estimation of the catch ratio curve" section), $cr_{average}$ is specific for the population structure encountered during the sea trials. Therefore, the values obtained are specific for the size structures encountered and cannot be extrapolated to other scenarios in which the size structure of the population is different.

RESULTS

Suza Fishery Trials

In total, 548 Spangled Emperor (length range = 18–80 cm) and 336 Orange-spotted Grouper (15–95 cm) were caught during 103 fishing trips (Table 1). Fishing trip durations ranged from 2 to 12 h. The length-dependent catch comparison rates and catch ratios were estimated and plotted for both species by using the traditional J8 hook as the baseline (Figure 3). The models applied to describe the length-based catch comparison rates explained the main trends in the experimental data sufficiently well (Figure 3). Therefore, the low p-values (Table 2) were probably a result of overdispersion in the catch data.

Use of the larger hook size (J7) resulted in a significant increase in catch performance of Spangled Emperor larger than 40 cm and Orange-spotted Grouper larger than 25 cm (Figure 3). For 40–62-cm Spangled Emperor and 25–43-cm Orange-spotted Grouper, this effect was significant. It was estimated that the catch efficiency of a 40-cm Spangled Emperor when the larger hook is used will be 150% compared to use of the smaller hook (Table 2).

TABLE 1. Main catch data for Persian Gulf handline fishing trips with J-hook sizes 8/0 (J8) and 7/0 (J7).

Variable	J8	J7
Number of fishing trips	67	36
Total fishing time (h)	520	247
Total number of Spangled Emperor caught	329	219
Total number of Spangled Emperor caught[a]	519	392
Mean size of Spangled Emperor caught (cm)	33.7 ± 8.3	40.7 ± 14.1
Minimum size of Spangled Emperor caught (cm)	18.0	20.0
Maximum size of Spangled Emperor caught (cm)	60.0	80.0
Total number of Orange-spotted Grouper caught	150	186
Total number of Orange-spotted Grouper caught[a]	237	320
Mean size of Orange-spotted Grouper caught (cm)	22.1 ± 4.7	28.4 ± 8.6
Minimum size of Orange-spotted Grouper caught (cm)	15.0	15.0
Maximum size of Orange-spotted Grouper caught (cm)	45.0	95.0

[a]Adjusted for trip duration (see Methods).

Additionally, it was estimated that the catch efficiency of 25-cm Orange-spotted Grouper when the larger hook is used will be 234% compared to when fishing with the smaller hook. For 45-, 50-, and 55-cm Spangled Emperor, the relative catch efficiency for the larger hook is 218, 335, and 539%, respectively, of that obtained when fishing with the smaller hook. For 30- and 35-cm Orange-spotted Grouper, the relative catch efficiency for the larger hook is 1,247% and 3,927%, respectively, of that obtained when using the smaller hook. On average, the larger hook size caught significantly more Spangled Emperor (41%) and Orange-spotted Grouper (151%). These results demonstrate that increasing the hook size from J8 to J7, with the accompanying increase in bait size, would increase the catch of the larger Spangled Emperor and Orange-spotted Grouper and would thereby lead to a lower proportion of smaller individuals of these species in the catch. The larger hook is therefore to be preferred with respect to obtaining a higher fraction of larger Spangled Emperor and Orange-spotted Grouper in the catch. The results also demonstrate that the size structure in the catches of Spangled Emperor and Orange-spotted Grouper is affected by hook and bait sizes, which also proves that hooks are size selective, with the larger hook and bait being more likely to catch larger individuals of the two species.

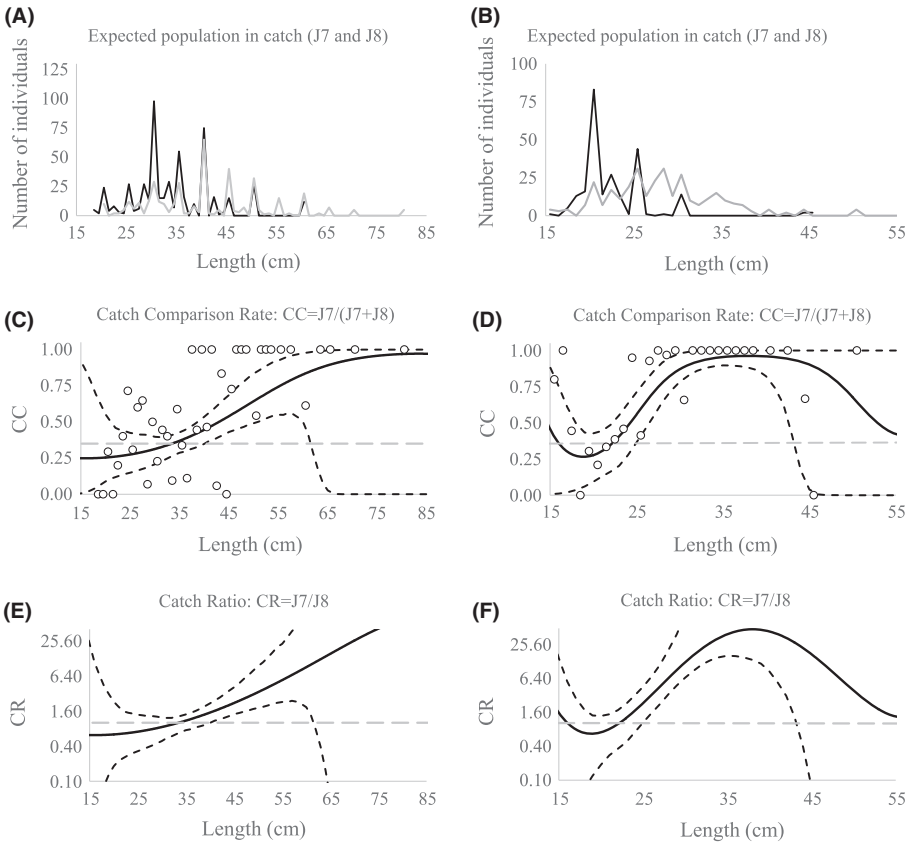

FIGURE 3. Effect of changing hook size (J-hook sizes 8/0 [J8] and 7/0 [J7]) on **(A)** Spangled Emperor expected population in catch; **(B)** Orange-spotted Grouper expected population in catch; **(C)** Spangled Emperor catch comparison (CC) rate; **(D)** Orange-spotted Grouper CC rate; **(E)** Spangled Emperor catch ratio (CR); and **(F)** Orange-spotted Grouper CR. In panels (A) and (B), the gray and black curves represent individuals caught with J7 and J8 hooks, respectively. In the CC curves (panels C and D), the circles represent the experimental rates; thin dashed curves represent the 95% confidence limits for the rate curves; and the horizontal gray dashed line shows the expected CC rate in the case of no effect of the hook size change investigated. For the CR curves (panels E and F), the *y*-axis uses a logarithmic scale (base 2) to enable the whole range of values to be shown in detail. The horizontal gray dashed line at the CR value of 1.0 marks the baseline for no effect of the hook change.

Greater Tunb Fishery Trials

In total, 328 Narrowbarred Mackerel (length range = 60–158 cm) were caught during 89 fishing trips (Table 3). Fishing trip durations ranged from 4 to 16 h. The length-dependent catch comparison rates and catch ratios described the main trends in the experimental data sufficiently well (Figure 4). Therefore, the low *P*-value was probably a result of overdispersion in the catch data (Table 4).

Use of the larger hook (J4) and bait resulted in an increase in catch performance for larger Narrowbarred Mackerel, and the effect was more pronounced with an increase in fish size (Figure 4). However, since the confidence interval included 1.0, the results were not significant and are therefore only indicative. For 110-, 120-, and 130-cm Narrowbarred Mackerel, the relative catch efficiency when using the larger hook was 105, 151, and 256%, respectively, of that obtained when using the smaller hook (Table 4). On average, the larger hook caught 12% more Narrowbarred Mackerel. These results indicate that increasing the hook and bait sizes increases the catch of larger Narrowbarred Mackerel and thereby leads to a lower proportion of smaller individuals in the catch.

DISCUSSION

Improving the exploitation pattern within a fishery can lead to a more efficient exploitation of the stock's growth potential (Macher et al. 2008). This is something that can be achieved through the regulation of fishing gears to ensure the capture of large adult fish while allowing small juveniles to escape (Armstrong et al. 1990). Our results show that by increasing the sizes of hooks and bait employed within the Persian Gulf handline fishery, the exploitation pattern can be optimized. Here, significant increases in the catch efficiency of larger Spangled Emperor and Orange-spotted Grouper were observed. For

TABLE 2. Catch ratio (*cr*) results and fit statistics obtained for J-hook sizes 8/0 (J8) and 7/0 (J7). Values in parentheses represent 95% confidence limits; asterisks indicate no data.

Statistic	Spangled Emperor	Orange-spotted Grouper
$cr(20, \boldsymbol{v})$ (%)	63.22 (18.08–230.24)	71.06 (18.89–138.93)
$cr(25, \boldsymbol{v})$ (%)	70.49 (32.57–137.24)	233.95 (106.39–458.79)
$cr(30, \boldsymbol{v})$ (%)	84.69 (48.61–122.54)	1,246.67 (666.45–8,843.68)
$cr(35, \boldsymbol{v})$ (%)	109.06 (74.77–139.14)	3,927.02 (1,630.55 to >10,000)
$cr(40, \boldsymbol{v})$ (%)	149.81 (99.67–215.40)	4,396.97 (859.22 to >10,000)
$cr(45, \boldsymbol{v})$ (%)	218.30 (140.55–406.45)	*
$cr(50, \boldsymbol{v})$ (%)	335.32 (179.82–933.77)	*
$cr(55, \boldsymbol{v})$ (%)	538.76 (227.06–2,255.82)	*
$cr(60, \boldsymbol{v})$ (%)	896.23 (185.69–7,429.92)	*
$cr_{average}$ (%)	140.57 (116.64–168.89)	251.32 (131.86–435.92)
p-value	$<1 \times 10^{-4}$	$<1 \times 10^{-4}$
Deviance	113.02	93.53
df	37	25

Narrowbarred Mackerel, an increase in the catch efficiency of larger individuals was also observed; however, the effect was nonsignificant. Furthermore, based on the size distributions of the species on the fishing grounds during the trial, the use of larger hooks and baits led to significant increases in the number of Spangled Emperor (41%) and Orange-spotted Grouper (151%) caught. However, for Narrowbarred Mackerel, a nonsignificant increase (12%) in catch rates was observed. These results suggest that hook size regulations could potentially be a useful management strategy to more effectively target desired size-classes. However, this only holds true if fishers simultaneously increase the bait size.

Previous studies investigating the effect of hook and bait sizes have found that increasing hook size results in an increase in the size of individuals caught (Otway and Craig 1993; Erzini et al. 1996, 2003; Yamashita et al. 2009; Campbell et al. 2014; Garner et al. 2014). Conversely, Mapleston et al. (2008) reported that hook size affected catch rate, with smaller hooks yielding higher catch rates in the handline fishery within the Great Barrier Reef, Australia. Similar results with regard to hook size have been reported for handline fisheries in other areas (Ralston and Polovina 1982; Bacheler and Buckel 2004; Mongeon et al. 2013). The effect of bait size on size selectivity may reflect an optimal relationship between a predator's size and the size of its prey (Lokkeborg 1990). A better understanding of the potential impacts of bait modifications on catch efficiency and species selectivity is vital for successful fishing operations (Yokota et al. 2009; Echwikhi et al. 2010). Furthermore, optimization of bait size can also improve species-specific targeting; for example, Haddock *Melanogrammus aeglefinus* are known to take smaller bait than similarly sized Atlantic Cod *Gadus morhua* (Johannessen et al. 1993).

If more than one bait is present, the one that appears largest to the fish is the one likely to be attacked (O'Brien et al. 1976). Bait might be selected in relation to their value to the fish. Bait is chosen to maximize the profitability to the fish; the currency in which the profit is measured is usually assumed to be the net rate of energy gain. This is the total energy gained per unit time

TABLE 3. Main catch data for Persian Gulf handline fishing trips with J-hook sizes 5/0 (J5) and 4/0 (J4).

Variable	J5	J4
Number of fishing trips	45	44
Total fishing time (h)	361	334
Total number of Narrowbarred Mackerel caught	170	158
Total number of Narrowbarred Mackerel caught[a]	306	335
Mean size of Narrowbarred Mackerel caught (cm)	104.6 ± 13.1	110.5 ± 15.5
Minimum size of Narrowbarred Mackerel caught (cm)	60.0	70.0
Maximum size of Narrowbarred Mackerel caught (cm)	135.0	158.0

[a]Adjusted for trip duration (see Methods).

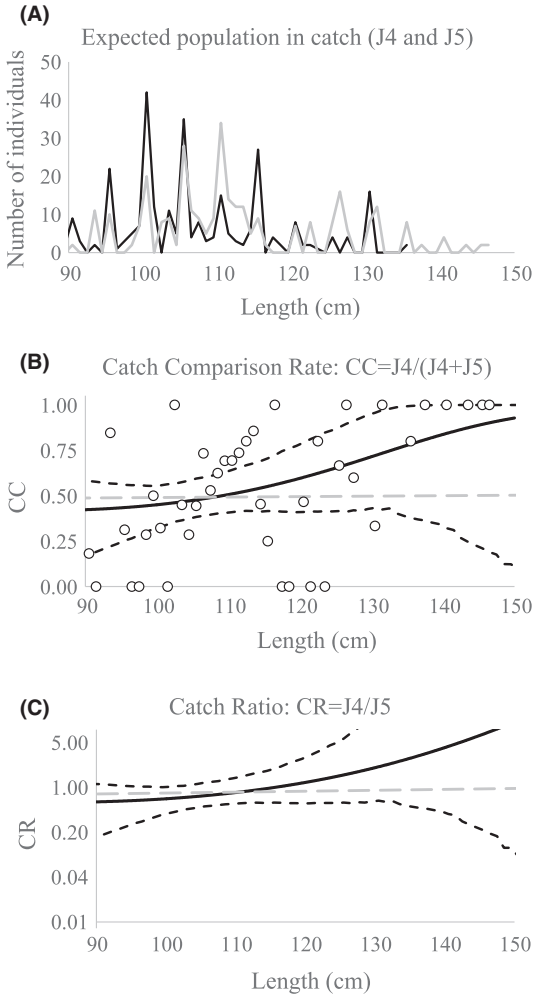

FIGURE 4. Effect of changing hook size (J-hook sizes 5/0 [J5] and 4/0 [J4]) on Narrowbarred Mackerel **(A)** expected population in catch, **(B)** catch comparison (CC) rate, and **(C)** catch ratio (CR). In panel (A), the gray and black curves represent individuals caught with J4 and J5 hooks, respectively. In the CC curve (panel B), the circles represent the experimental rates; the thin dashed curves represent the 95% confidence limits for the rate curve; and the horizontal gray dashed line shows the expected CC rate in the case of no effect of the hook size change investigated. For the CR curve (panel C), the *y*-axis uses a logarithmic scale (base 2) to enable the whole range of values to be shown in detail. The horizontal gray dashed line at the CR value of 1.0 marks the baseline for no effect of the hook change.

TABLE 4. Catch ratio (*cr*) results and fit statistics obtained for J-hook sizes 5/0 (J5) and 4/0 (J4). Values in parentheses represent 95% confidence limits.

Statistic	Narrowbarred Mackerel
$cr(90, \boldsymbol{v})$ (%)	74.94 (22.14–141.84)
$cr(95, \boldsymbol{v})$ (%)	78.23 (34.81–130.50)
$cr(100, \boldsymbol{v})$ (%)	83.76 (50.16–128.87)
$cr(105, \boldsymbol{v})$ (%)	92.26 (63.69–149.87)
$cr(110, \boldsymbol{v})$ (%)	104.84 (71.04–183.09)
$cr(115, \boldsymbol{v})$ (%)	123.34 (72.97–245.86)
$cr(120, \boldsymbol{v})$ (%)	150.73 (71.32–390.89)
$cr(125, \boldsymbol{v})$ (%)	192.06 (72.97–728.96)
$cr(130, \boldsymbol{v})$ (%)	256.02 (78.39–2,261.69)
$cr(135, \boldsymbol{v})$ (%)	358.11 (62.35 to >10,000)
$cr(140, \boldsymbol{v})$ (%)	526.43 (48.55 to >10,000)
$cr(145, \boldsymbol{v})$ (%)	812.83 (27.29 to >10,000)
$cr_{average}$ (%)	111.97 (92.34–136.74)
p-value	$<1 \times 10^{-4}$
Deviance	144.04
df	51

by the fish less the energetic costs of foraging (Stephens and Krebs 1986). When encountering bait sequentially and randomly, the fish should select bait in descending order of profitability until a bait of lesser profitability causes a decline in the overall net energy gain. This may be one of the reasons why larger fish target larger hooks with larger bait.

Fish within an active space respond to baited hooks, strike the bait, and become caught. Large fish have higher swimming speeds and can reach baits more quickly than small fish (Hart 1993). Small hooks with small bait seem to have a narrower active space than large hooks with large bait; this may explain why larger fish were attracted less to the smaller hooks with small bait.

Mouth gape is the one of the limiting factors that regulate the effectiveness of hooks (Yamashita et al. 2009). The problem with small hooks is their inability to hold the larger fish. They may not be large enough to penetrate completely through the mouth. Furthermore, the way in which a species strikes the bait may also influence a hook's effectiveness. For example, Orange-spotted Grouper were observed to swallow the bait and hook, while Narrowbarred Mackerel were observed to hit or strike at the bait and were typically hooked in the mouth.

It is common knowledge among handline fishermen in the Persian Gulf that squid are good bait for Spangled Emperor and Orange-spotted Grouper, whereas Sind Sardinella are considered good bait for Narrowbarred Mackerel. However, no studies have been found that support or explain why these particular baits are used for targeting these species. The method applied here could also be used to assess the effect of different bait types on catch efficiency in handline fisheries. Furthermore, because hook and bait sizes were altered simultaneously, we were not able to determine the extent to which each of these factors contributed to the observed changes in catch efficiency. This could be investigated during a future study in which the same bait size is used on different-sized hooks and/or different bait sizes are used on hooks of the same size.

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