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Abstract: Shrimp trawl fishery is of significant importance in Saudi Arabia's marine capture fishery sector. Al Qunfudhah and Jizan are the only ports along the southern Saudi Arabian coast of the Red Sea dedicated to shrimp fishing. This study evaluates the catch per unit effort (CPUE) of targeted shrimp species along with the associated retained bycatch and discard ratios across these two trawling locations. Using daily catch data from commercial shrimp trawlers specific to each port's vessel type, this research provides the first comprehensive analysis of CPUE dynamics and fishing practices in these fishing grounds. The CPUE of target shrimps exhibited a wide range (0.01 kg h^{-1} to 13.08 kg h^{-1}) with an overall mean of 1.37 ± 0.143 kg h^{-1}. *Penaeus semisulcatus* emerged as the predominant species (mean CPUE: 3.77 ± 0.28 kg h^{-1}), followed by *Metapenaeus monoceros* (mean CPUE: 0.1 ± 0.02 kg h^{-1}). Significant differences in CPUE were observed among species, including *P. semisulcatus*, *Penaeus hathor*, and *Penaeus pulchricaudatus*, although CPUE differences between the two fishing grounds were minor, likely due to their proximity and similar environmental conditions. The bycatch analysis identified a total of 72 species across 28 families, with significant variation in the relative ratios. Sepiidae species constituted 31.8% of the total bycatch, followed by Portunidae species (24.8%). Discard patterns also varied, with *Gerres oyena* being the most commonly discarded species (mean discard ratio: 11.37% ± 1.89%), followed by *Equulites klunzingeri* (mean discard ratio: 8.76% ± 2.00%). While CPUE differences between Al Qunfudhah and Jizan were modest, this study highlights the need for expanded spatial and temporal coverage to enhance future analyses. These findings underscore the importance of integrated data for a comprehensive understanding of fishing effort and bycatch dynamics, supporting sustainable fisheries management in the Red Sea. By addressing bycatch and discard practices, this research contributes to efforts to mitigate ecological impacts and promote sustainable resource use in Saudi Arabia's fisheries sector.

Keywords: CPUE; shrimp trawling; bycatch management; discard analysis; Red Sea; fisheries management; marine ecosystem sustainability; Saudi Arabia

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1. Introduction

Shrimp trawling stands as a cornerstone within global fisheries, serving as a crucial mechanism in satisfying the burgeoning demand for shrimp worldwide. Recent estimates from the Food and Agriculture Organization (FAO) place the global harvest of tropical shrimps at approximately 1.3 million tonnes, with Saudi Arabia contributing around 0.4%

to this total [1]. Although this represents a modest share, the shrimp trawling industry plays a vital role in supporting Saudi Arabia's coastal livelihoods and regional fisheries economy. Achieving sustainability, however, remains challenging for fisheries globally, including those in Saudi Arabia. Advances in fishing technology, expansion into new fishing grounds, and the targeting of previously untapped species have long concealed the depletion of fish stocks. Since the late 1980s, global catch volumes have declined, raising concerns about potential supply shortages and increasing reliance on aquaculture, which itself poses environmental challenges. Ensuring sustainable fisheries requires reducing fishing capacity and cutting subsidies that promote overfishing. Establishing marine reserves and restricting fishing activity in key areas could help fish stocks recover and contribute to developing fisheries that are resilient within their ecosystems [2].

Shrimp fisheries employs various methods, such as trammel nets and seines, yet shrimp trawling remains the predominant technique. This prevalence highlights shrimp trawling's central role in the industry. However, its commercial importance contrasts sharply with concerns about the environmental impacts of shrimp fishery, particularly through the use of bottom trawling methods, which can damage marine ecosystems and affect non-target species [3–6]. Bottom trawls, while effective for harvesting large quantities of shrimp, are widely considered among the most destructive fishing methods. They impact sensitive marine habitats [7–10] and contribute substantially to retained bycatch—species that are not the target of the gear but are retained by fishers for sale or personal consumption—as well as to high discard rates at both regional and global scales [11]. This issue is particularly pronounced in tropical waters, where fisheries are characterized by a high diversity of species and gear types [12–15]. Recent studies estimate that about 46% of global discards originate from bottom trawling methods, including otter, shrimp, pair bottom, twin otter, and beam trawls [16]. In the Western Indian Ocean (FAO Area 51), which includes the Red Sea, an estimated average of 743,352 tonnes of catch is discarded annually [16].

Numerous studies have focused on critical aspects of shrimp trawling, including assessments of catch per unit effort (CPUE) [17–21], biological aspects [22,23], bycatch composition, strategies for reducing retained bycatch and discards [4,5,10,15,24–36], and evaluations of its environmental impacts [37–40]. These investigations play a crucial role in understanding the sustainability and ecological implications of shrimp trawling, aiding in the development of informed management practices that mitigate its adverse effects while maximizing its benefits. Research on the shrimp fishery along the Saudi coast of the Red Sea is scarce. The only available study on this subject, conducted by Ghamrawy [22], focuses solely on the biology of penaeid shrimps.

The Red Sea is an elongated marine system with a high coast-to-sea area ratio and is characterized by several unique oceanographic and biological features [41], such as high levels of salinity, and temperature [41,42], and moderate productivity [43]. It is one of the most important hotspots for coral reef ecology, boasting distinctive physical and biological attributes that foster a rich biodiversity. The region's reef communities are notable for their endemism across diverse species groups and include the world's northernmost coral reefs. Despite its ecological richness, the Red Sea faces numerous anthropogenic pressures, with fishing representing the most direct human impact on its ecosystems [41]. Currently, the Red Sea is an important fishing ground for the seven countries along its coastline [41]. Shrimp fishing grounds are located in the southern part of the Red Sea, where productivity surpasses that of the north. This increased productivity arises from the influx of nutrient-rich waters from the Indian Ocean, coupled with nutrient resuspension from seabed sediments stirred by turbulence over the broad shelf areas [44].

This study seeks to enhance our understanding of shrimp trawl fishing and its consequential impacts in two key fishing grounds, Al Qunfudhah and Jizan, along the southern Red Sea coast of the Kingdom of Saudi Arabia. Evaluating the CPUE of targeted shrimp species and quantifying the rates of retained bycatch and discards provides essential baseline data to support the sustainable management of this fishery. This research represents

the first comprehensive investigation into the CPUE dynamics and bycatch practices in these fishing grounds. Through a detailed analysis of CPUE, bycatch rates, and discard levels across the two regions, this study offers valuable insights into the sustainability and management of shrimp fisheries in the southern Red Sea. These findings are intended to guide fishery management strategies and promote the conservation and responsible utilization of marine living resources in this ecologically important region.

2. Material Methods

2.1. Study Area

Al Qunfudhah and Jizan are the only ports along the Red Sea coast of Saudi Arabia where shrimp trawl fisheries are legally permitted. Al Qunfudhah is one of the important ports in the Red Sea (Figure 1), renowned for its rich shrimp resources [45]. The fleet registered at this port consists of 24 industrial boats and 276 traditional boats [46]. Industrial boats engage in shrimp trawling and purse seining, depending on the closure of the shrimp trawl fishery. Trawling is primarily conducted parallel to the coast, with the fishing grounds varying in depth from 10 to 30 m [45]. Jizan, located near the Farasan Islands, is the largest and most important fishing port on the Red Sea coast in terms of fleet size and fish production (Figure 1). The registered fleet consists of 151 industrial boats and 1658 traditional boats [46]. Unlike Al Qunfudhah, trawling in Jizan is carried out at an acute angle to the coast. The depth of the fishing grounds usually ranges from 10 to 40 m [45]. In both fishing grounds, shrimp trawlers operate seasonally between September and March and remain closed between April and August [45].

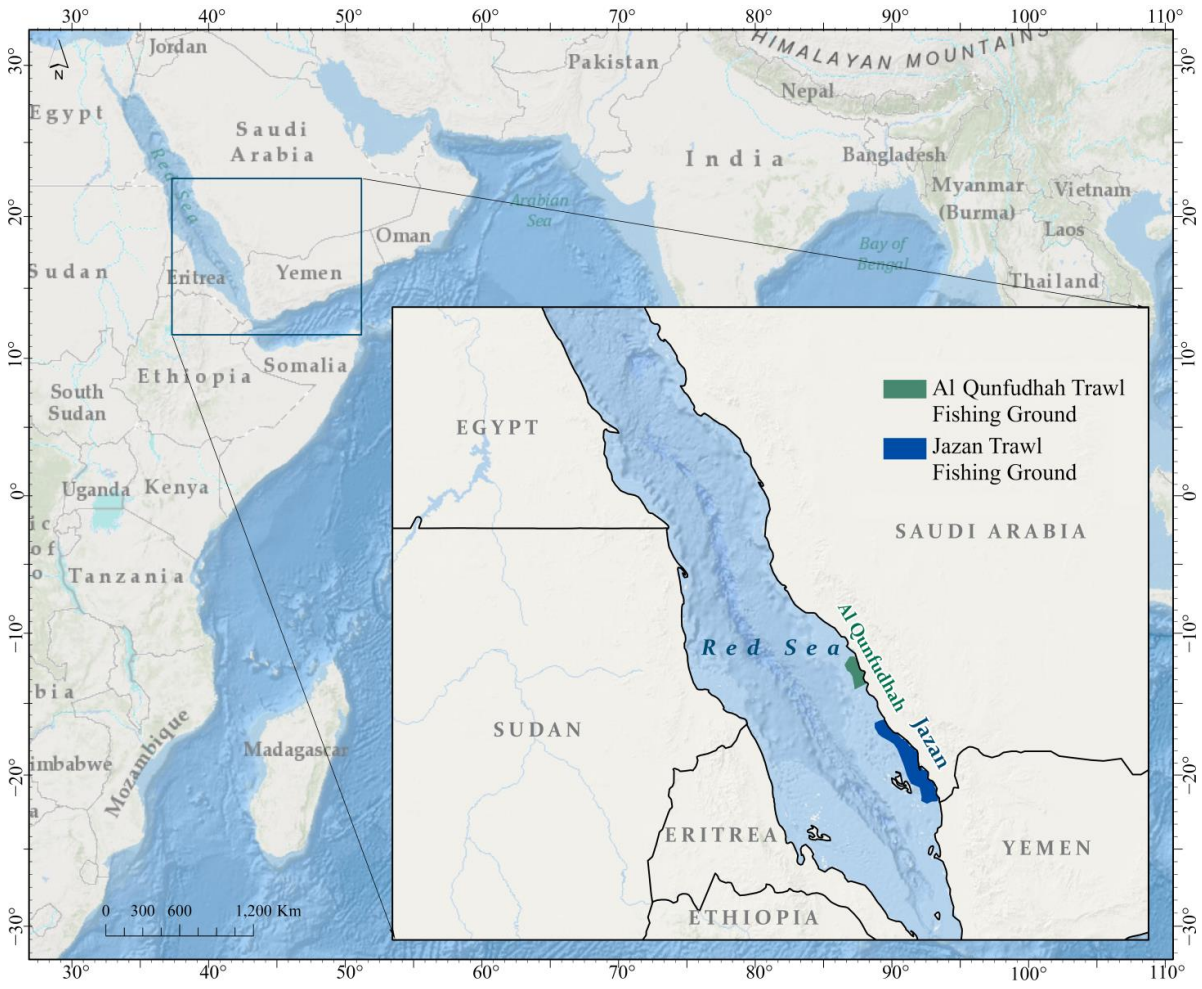


Figure 1. Trawl haul locations in the Red Sea territorial waters of Saudi Arabia.

2.2. Data Collection

The daily catch data were collected from individual commercial shrimp trawler operations conducted at distinct locations in May and June 2023. Specifically, data were obtained from a typical side trawler (16.8 m length overall (LOA), 360 horsepower (HP) engine) operating in Al Qunfudhah and a stern trawler (17.0 m LOA, 550 HP engine) in Jizan. Active participation in each operation enabled the authors to gather pertinent information.

Trawl hauls were consistently executed under standardized fishing conditions, including location, haul duration, towing speed, and trawl net specifications. The trawl used in Al Qunfudhah was of medium size, measuring 34.8 m, while the one employed in Jizan was larger, measuring 49.9 m. Both trawl nets were constructed using multi-monofilament polyethylene (PE) netting material. Additionally, the otter boards on the trawler in Al Qunfudhah weighed 130 kg each, in contrast to approximately 300 kg for those utilized in Jizan.

The trawl hauls conducted in these trials closely replicated commercial fishing operations in terms of trawl net specifications, locality, haul duration, towing speed, etc. All hauls were performed at night at an average speed of 3.0 knots, with each tow lasting approximately 3 h. A total of 12 valid hauls were conducted in Al Qunfudhah and 21 in Jizan. Each haul employed the current 40 mm diamond mesh codend commonly used in existing shrimp trawls.

2.3. Data Analyses

The target species for shrimp trawlers operating within the Saudi Arabian territorial waters of the Red Sea were identified as *Penaeus semisulcatus*, *Metapenaeus monoceros*, *Penaeus pulchricaudatus*, *Penaeus indicus*, and *Penaeus hathor*. Any species retained for sale or personal consumption that did not belong to these target groups were classified as commercial or retained bycatch. Species of little to no commercial value, or those deemed inedible, damaged, and thrown back at sea, were categorized as discards. The discard category also included vulnerable species such as sharks, rays, and turtles, which are legally protected, and their capture is prohibited [47]. The catch weight (kg) of the target species, retained bycatch, and discards was recorded for each haul.

The assessment of CPUE for each net haul was conducted following the method outlined by Gulland [48]. The CPUE was calculated using the formula:

$$\mathrm{CPUE} = \mathrm{C}\cdot\mathrm{f}^{-1} \quad (1)$$

where C denotes the catch (in kg) of the target species and f represents the fishing effort, defined as the tow duration (the total time the trawl net is actively fishing on the seabed) [49]. CPUE is thus expressed in kg per unit of tow duration.

The retained bycatch ratio (RBCR) represents the proportion of retained bycatch relative to the total catch per haul. In this context, the total catch included targeted catch (TC), retained bycatch (RBC), and discard (D) for each haul on a fishing day [50,51]. The formula for calculating %RBCR is:

$$\%\mathrm{RBCR} = \left(\frac{\sum \mathrm{RBC}}{\sum(\mathrm{TC} + \mathrm{RBC} + \mathrm{D})}\right)\cdot 100 \quad (2)$$

The discard rate (%DR) represents the proportion of D relative to the total catch, following the methodology outlined by Kelleher [13]. This rate offers insight into the portion of the catch that is discarded rather than retained or targeted:

$$\%\mathrm{DR} = \frac{\mathrm{D}}{\sum(\mathrm{TC} + \mathrm{RBC} + \mathrm{D})}\cdot 100 \quad (3)$$

The data were assessed for normal distribution both visually, through QQ plots and histograms, and statistically, utilizing tests such as Shapiro–Wilk and Kolmogorov–Smirnov

tests. For non-normally distributed data, various transformation processes were applied, including an inverse of the sine function (arcsin), Box–Cox, center, scale, double reversed logarithmic, exponential, logarithmic, ordered quantile (ORQ), square, and Yeo–Johnson. The selection of the best transformation was based on the Pearson P statistic, and normality checks were reiterated on the transformed data. If the normality criteria were met, parametric tests such as ANOVA, Student's t-test, and Tukey's honestly significant difference (HSD) were conducted for targeted CPUE. Otherwise, non-parametric tests such as the Kruskal–Wallis H test were applied for bycatch and discard ratios.

The analyses were conducted within the R language environment [52] with the utilization of various packages, including but not limited to "tidyverse" [53] and "bestnormalize" [54].

3. Results

The CPUE of the target shrimps exhibited a wide range of values, varying from 0.001 kg h^{-1} to 13.08 kg h^{-1}, with an overall mean of 1.37 ± 0.143 kg h^{-1}. In this fishery, five species were targeted, with *P. semisulcatus* emerging as the predominant species, boasting a mean CPUE of 3.77 ± 0.28 kg h^{-1}. Closely following is *M. monoceros*, accounting for an average of 0.1 ± 0.02 kg h^{-1}. The species with the lowest CPUE in this dataset is *P. hathor*, recording a mere 0.001 kg h^{-1} (Table 1). Statistical analysis reveals significant differences ($p < 0.05$) between the CPUE of species. Notably, *P. semisulcatus* has a significantly higher CPUE compared with all other species, and *P. hathor* differs significantly from *M. monoceros* (Figure 2).

Table 1. The descriptive statistics of CPUE for targeted shrimp species in the trawl fishery of the Kingdom of Saudi Arabia in the Red Sea.

Species	Min	Max	Mean	se
Penaeus indicus	0.004	0.164	0.048	0.015
Penaeus pulchricaudatus	0.002	0.288	0.049	0.009
Metapenaeus monoceros	0.004	0.921	0.106	0.022
Penaeus hathor	0.001	0.176	0.022	0.005
Penaeus semisulcatus	0.090	13.081	3.765	0.275

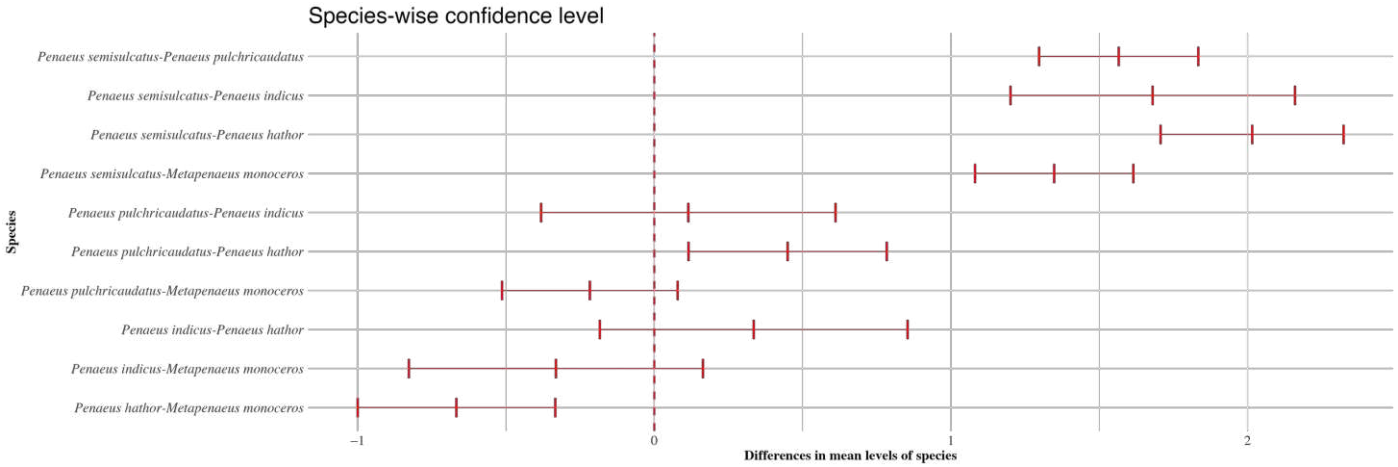


Figure 2. Tukey's HSD test results showing 95% confidence intervals for the mean-wise differences in CPUE of targeted species.

Two major ports were investigated in this study, each encompassing distinct fishing grounds. Jizan displayed significantly higher CPUE, ranging from 0.01 kg h^{-1} to 13.08 kg h^{-1} with an average of 8.06 ± 2.84 kg h^{-1} compared with Al Qunfudhah, where CPUE values fell between 0.02 kg h^{-1} and 3.45 kg h^{-1} with an average of 0.53 ± 0.85 kg h^{-1}. *P. semisulcatus*, the dominant species, displayed varying CPUE values within the 25th and

75th percentiles (interquartile range—IQR). In Jizan, the IQR ranged from 3.05 kg h^{-1} to 7.07 kg h^{-1}, while the IQR in Al Qunfudhah spanned from 0.43 kg h^{-1} to 1.91 kg h^{-1}. *M. monoceros*, the second most prevalent species, exhibited CPUE values of 0.01 kg h^{-1} 1 to 0.09 kg h^{-1} in Jizan and 0.01 kg h^{-1} to 0.39 kg h^{-1} in Al Qunfudhah, within their respective IQRs (Figure 3). These findings suggest differences in the distribution and abundance patterns of these shrimp species across regions. Statistical analysis revealed no significant differences between the two ports regarding the CPUE values of *P. semisulcatus*, *M. monoceros*, and *P. pulchricaudatus* ($p > 0.05$), while CPUE values for *P. hathor* differed significantly ($p < 0.05$). Notably, only one record of *P. indicus* exists in Al Qunfudhah, precluding statistical analysis at this time.

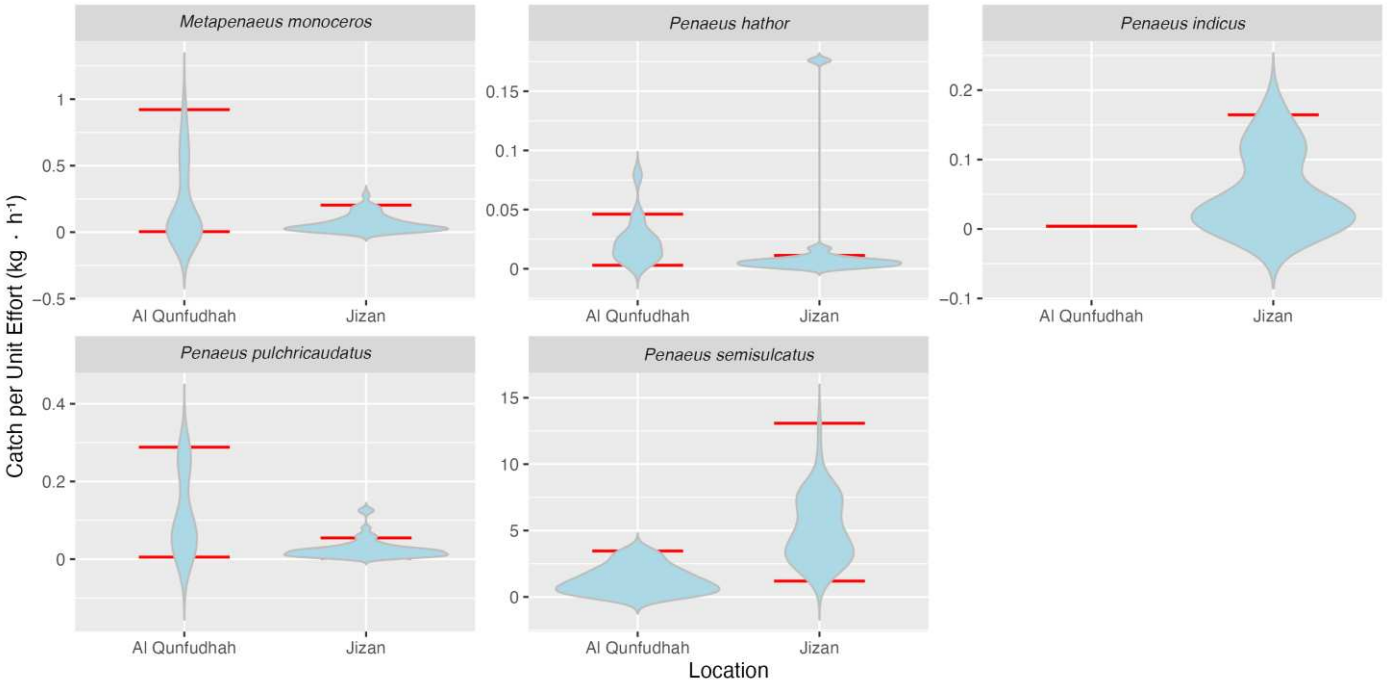


Figure 3. Violin plots showing CPUE variations of targeted shrimp species across Jizan and Al Qunfudhah fishing ports. Red lines represent the whiskers, which extend to 1.5 times the IQR from the first and third quartiles.

In this study, 72 retained bycatch species, representing 28 families, were identified. The retained bycatch ratios for each family (i.e., the percentage of a family's total catch that constituted bycatch) ranged from 0.01% to 32.3%, with a mean of 1.3% ± 0.14%. Notably, species from the molluscan family Sepiidae constituted 31.8% of the total bycatch, followed by species from the crustacean family Portunidae, which accounted for approximately 24.8% of the total retained bycatch (Figure 4). Furthermore, *Portunus segnis* exhibited the highest mean retained bycatch ratio at 4.68% ± 0.69%. The second highest mean retained bycatch ratio was observed in *Scomberoides commersonnianus*, ranging from 2.91% to 5.55%, despite this species being observed only twice during the study period. Statistical analysis revealed significant differences in the retained bycatch ratios of species ($p < 0.05$).

A comprehensive survey of the discards in the shrimp trawl fishery in this region revealed a total of 177 fish species across 77 different families. The discard ratio for each species (i.e., the percentage of the total catch of each species that was discarded) varied with catch frequency, with *Gerres oyena* emerging as the most frequently discarded species, exhibiting a mean discard ratio of 11.37% ± 1.89%, followed closely *by Equulites klunzingeri* with a mean discard ratio of 8.76% ± 2.00%. The third most frequently discarded species was *Himantura uarnak*, with discard ratios ranging from 0.31% to 27.22%, depending on haul frequency. Statistical analysis indicated significant differences in discard ratios among

species ($p < 0.05$). In terms of overall contribution to total discards, *G. oyena* accounted for 17% of all discarded species (Figure 5).

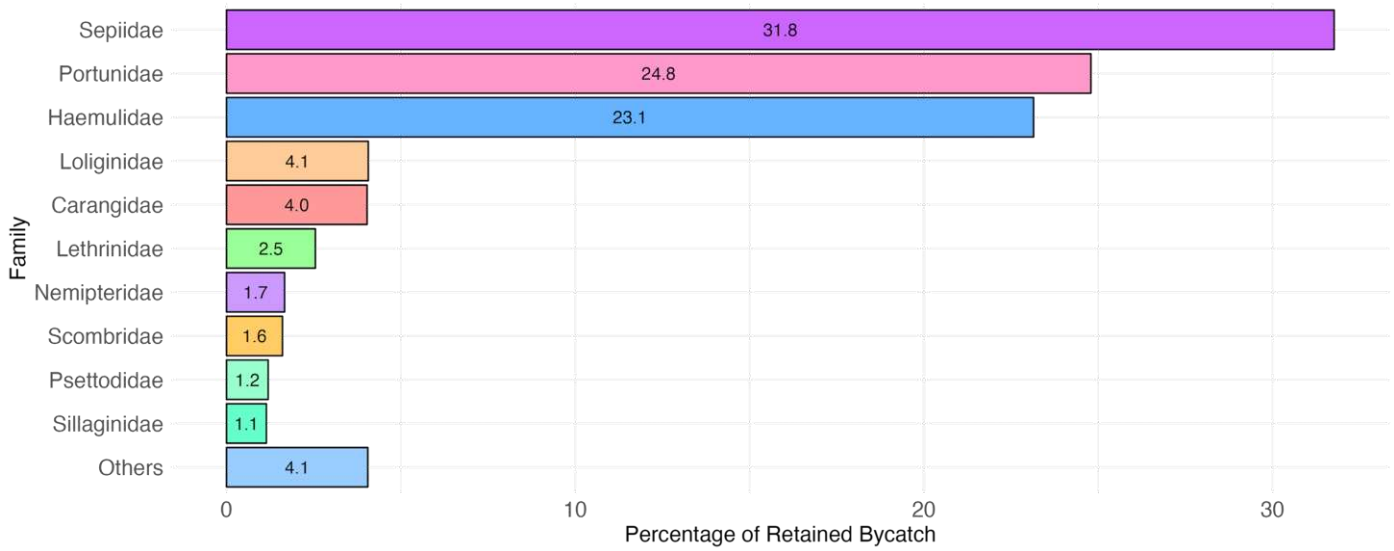


Figure 4. Percentage distribution of the ten most common retained bycatch species families.

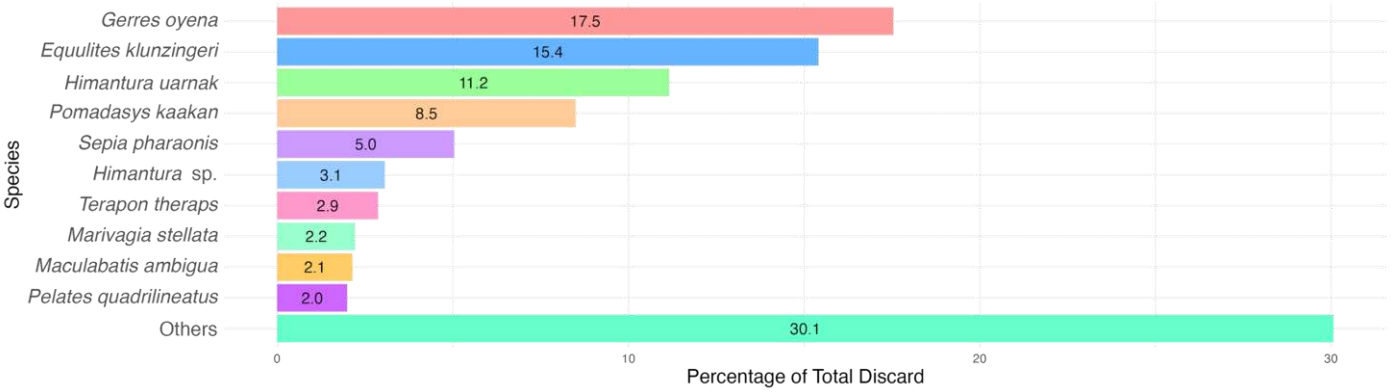


Figure 5. Percentage distribution of the top ten discarded species.

4. Discussion

The CPUE values observed for *P. semisulcatus* in this study ranged from 0.090 to 13.081 kg·h^{-1} with an average of 3.765 ± 0.275 kg·h^{-1}, exhibiting significant variability. This variability may stem from differences in local environmental factors, such as depth, salinity, and temperature, as demonstrated in previous studies [20,55,56]. It is important to note, however, that this study was limited to two vessels operating out of Al Qunfudhah and Jizan ports that serve as critical hubs for the shrimp trawl fishery in the Red Sea. These vessels were among the few legally authorized to conduct trawling in the Saudi Arabian waters. Therefore, while the findings offer valuable insights into CPUE in these regions, they may not fully represent the broader fishing area of the southern Red Sea.

The data collection period for this study was limited to two months (May and June), which may not fully capture the seasonal and annual variability of shrimp populations in the region. Consequently, caution is advised when generalizing these results, as broader temporal and spatial coverage is required to account for seasonal variability and more extensive geographic patterns. Additionally, the ongoing conflict in the region has presented substantial challenges to data collection in the southern Red Sea. The proximity of the Jizan fishing grounds to areas affected by the conflict has raised logistical and safety concerns, further restricting the temporal and spatial scope of this study. In light of these constraints,

future research will need to address these limitations by expanding vessel participation, incorporating additional sampling locations, and capturing seasonal variations in fishing effort. Such efforts will be essential for ensuring a more comprehensive understanding of the shrimp trawl fisheries in the region.

The observed variability in trawl CPUE can be attributed to a range of factors related to fishing gear. Variations in mesh size, net length and width, distance between trawl doors, lengths of bridles and foot ropes, float line length and depth, trawling duration, codend mesh size, and configuration all play critical roles in influencing catch rates [57]. Additionally, factors such as environmental conditions, fleet dynamics, and trawling duration can significantly impact CPUE, as reported by Maunder et al. [58] and Karakulak and Ceyhan [59].

We acknowledge that comparing CPUE between the two fishing grounds is complicated by differences in vessel power and gear configurations, which may influence catch efficiency. Vessels with greater power typically yield higher catches, and variations in gear setup can lead to different CPUE outcomes, even under similar environmental conditions. Ideally, CPUE comparisons should be standardized for both gear and vessel power to provide a more accurate reflection of relative abundance across regions. While efforts were made to standardize CPUE data to better reflect abundance [60], the inherent complexities of gear performance and environmental interactions added challenges to the analysis. Future studies should aim to control for these variables by employing consistent gear across multiple vessels and incorporating temporal factors, such as monthly or seasonal catch data, to enhance the robustness of the findings.

The higher CPUE values observed in Jizan compared with Al Qunfudhah may be influenced by subtle differences in environmental factors, such as depth and habitat characteristics, as well as potential variations in species distribution between the regions. Additionally, differences in retained bycatch and discard ratios between the two fishing grounds may reflect localized fishing practices or habitat conditions that influence species composition. However, given the limited data from only two vessels and the descriptive nature of this study, a more detailed analysis of these differences would require further research. Future studies should aim to incorporate data from multiple vessels operating across both grounds and capture seasonal variations to develop a more comprehensive understanding of these spatial differences.

Bycatch remains a critical global issue in fisheries, with shrimp trawl fisheries being particularly notorious for high bycatch rates, which pose threats to species diversity and ecosystem integrity [61,62]. Trawling with bottom-contact gear is recognized as one of the most environmentally impactful fishing methods due to its effects on benthic habitats, high bycatch rates, and associated carbon emissions. Consequently, some countries have banned or strictly limited the use of trawls, and other regions are considering similar restrictions [63]. Comparative studies on trawl fisheries and other food production systems indicate that well-managed trawl fisheries can sustainably maintain fish stocks with potentially lower environmental impacts than certain land-based protein sources, such as beef [64]. Effective management practices—such as spatial protections, species-specific safeguards, and gear modifications—can reduce the environmental footprint of trawling. For the Red Sea shrimp fishery, the integration of bycatch reduction devices (BRDs) and turtle excluder devices (TEDs) could significantly minimize bycatch, aligning the fishery with global best practices. This study identified 72 retained bycatch species across 28 families, with bycatch ratios ranging from 0.01% to 32.3% at the family level, averaging 1.3% $\pm$ 0.14%, consistent with findings from other regions (e.g., Abdulqader et al. [33]). Many of the bycatch species, including *P. semisulcatus*, *Nemipterus japonicus*, and *Carangoides bajad*, were juveniles, raising concerns about the sustainability of the fishery.

The high proportion of juveniles in the catch, particularly for commercially valuable species such as *Lethrinus lentjan* and *Scomberomorus commerson*, mirrors patterns observed in the Kuwait shrimp fishery [29]. The unintended capture of juveniles emphasizes the need for more effective bycatch reduction strategies, as juvenile depletion can lead to diminished

future stocks and disruptions to ecosystem balance. Notably, the bycatch also included endemic species such as *Diagramma punctatum*, with juveniles frequently caught in both Al Qunfudhah and Jizan, further raising conservation concerns.

Discards further exacerbate the problem, as evidenced by our findings of 177 discarded fish species across 77 families, with *G. oyena* emerging as the most frequently discarded species. Mendo et al. [35] shed light on the alarming extent of bycatch and discards in shrimp trawl fisheries of Northern Peru, reporting that only about 18% of the overall catch consisted of the targeted shrimp species. The remaining 82% was bycatch, with nearly half (51%) being discarded. Such profound levels of discards raise grave concerns for marine ecosystem sustainability, potentially precipitating overfishing and the depletion of non-target species.

This study also recorded the incidental catch of several non-target charismatic species, including *Chelonia mydas*, *Stegostoma tigrinum*, and *H. uarnak*, all currently listed as "Endangered" on the International Union for the Conservation of Nature (IUCN) Red List [65]. Sea turtles are particularly at risk as they may drown when forcibly submerged by trawl nets [66]. Nonetheless, the vast majority of sea turtles that encounter trawls equipped with turtle excluder devices (TEDs) were found to escape quickly and surface to breathe [67]. Shrimp trawling, which involves dragging large nets across the seabed, not only harms marine life and habitats but also contributes significantly to global carbon emissions [68]. Mitigating the impact on these species is crucial for maintaining marine biodiversity.

Given the high rates of unintended bycatch observed in this study, particularly the large proportion of juvenile and non-target species (e.g., *G. oyena*, *E. klunzingeri*), the adoption of bycatch reduction devices (BRDs) is critical for mitigating these impacts. Devices such as turtle excluder devices (TEDs), shark-excluding grids, and square mesh codends have been shown to be effective in reducing unintended catches [61,66,69]. The high discard ratios observed in species like *G. oyena* and *H. uarnak* further underscore the need for BRDs to reduce unnecessary mortality. Additionally, implementing temporal management measures, such as tow time restrictions [70], could further reduce bycatch, particularly for vulnerable species like sea turtles and juvenile fish. Modifications to net design aimed at reducing the capture of smaller, non-target fish and juveniles would also contribute to more sustainable fishing practices in this region.

An ecosystem approach to fisheries management is essential to ensure the long-term sustainability of Red Sea trawl fisheries. This participatory approach should include systematic monitoring, scientific assessments, and the enforcement of regulations aimed at minimizing bycatch and reducing ecosystem impacts. In accordance with the FAO Code of Conduct for Responsible Fisheries, ongoing monitoring and further research into gear innovations and management strategies are critical for safeguarding marine ecosystem health.

Author Contributions: S.T.K.: Writing—original draft, data curation, formal analysis, investigation. T.C.: Writing—original draft, writing—review and editing, conceptualization, formal analysis, methodology, visualization. Z.T.: Writing—review and editing, conceptualization, investigation, methodology, validation. S.G.: Writing—review and editing, investigation. R.G.S.: Writing—review and editing, data curation, investigation. A.M.S.A.: Writing—review and editing, investigation, supervision. S.K.C.: Writing—review and editing, investigation. E.M.T.: Writing—review and editing, conceptualization, methodology, supervision, project administration, resources. V.Ü.: Writing—review and editing, conceptualization, investigation, supervision. M.D.: Writing—review and editing, conceptualization, funding acquisition, supervision, project administration, resources. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study did not involve the use of live animals in a laboratory setting. The research was conducted onboard a commercial shrimp trawler, and only the animals caught by this commercial gear were studied. All sampling was performed in accordance

with local and international regulations governing fishing practices, ensuring that the areas where the species were caught were designated for legal fishing activities.

Data Availability Statement: The data presented in this study are available on request from the corresponding author (The data are not publicly available due to privacy restrictions set by the funding institution).

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Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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