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Diversity and Seasonal Variation in Live Baits Caught in Hann Bay, Dakar, Senegal

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Abstract

Live bait fishing, which was initiated around the 1950s on the coast of Dakar for the exploitation of tropical tunas, remains poorly studied. This study aims to examine the ichthyological diversity in Hann Bay and analyze the seasonal variation in species used as live bait. Ten experimental fishing campaigns were conducted between February and November 2023, using a beach seine and a purse seine. Captured individuals were sorted by species, counted, and weighed. Salinity and temperature drive seasonal changes in live bait fish communities in Hann Bay. Beach seine captured 389,171 individuals from 65 species, representing a biomass of 1743 kg. Purse seine yielded 9408 individuals from 62 species, representing a total of 306 kg. Ten species were identified as live bait, ten of which were caught with beach seine (*Engraulis encrasicolus* dominated) and eight with purse seine (*Sardinella maderensis* dominated). Eight of the ten live bait species were caught by both purse seine and beach seine. For beach seine, Shannon's index was higher during the cold season, indicating a better distribution of species abundance. For purse seine, species abundance was lower in the cold season. Pielou's evenness index indicated a more balanced assemblage in the cold season for beach seine (0.65) and in the warm season for purse seine (0.74). The number and weight of live baits did not vary significantly between seasons. These results may support the sustainable management of coastal small pelagics, whose juveniles are used as live bait.

Keywords: live bait; diversity; seasonal variation; Hann Bay; Senegal

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1. Introduction

Senegal's fishing sector benefits from favorable natural conditions, including a 718 km coastline and a 200-nautical-mile EEZ rich in marine resources [1].

The sustainability of fisheries in Senegal largely depends on the productivity of marine ecosystems, particularly coastal ecosystems. These ecosystems serve mainly as nursery grounds and spawning areas for numerous species, notably small coastal pelagic fish.

Rod fishing for tuna is generally considered to have many virtues, particularly in social and ecological terms. Indeed, one of the main characteristics of this type of fishing is

the use of live bait, the capture of which represents both an economic opportunity and a constraint [2]. Many species, especially sardinellas, horse mackerels, and anchovies, which form the basis of food webs, inhabit these ecosystems [3]. In pole-and-line fishing, which primarily targets schools of tropical tunas (yellowfin, bigeye, and skipjack) concentrated between 22° and 8° N [4], live bait is a key component. Senegal and Ghana are countries where live bait is available in sufficient quantity and quality for tuna fishing purposes [4]. Live bait is collected at the beginning of each pole-and-line fishing trip from coastal areas such as beaches and bays [3]. Thus, various small coastal pelagic species are potentially usable as live bait, including *Sardina pilchardus*, *Sardinella maderensis*, *Sardinella aurita*, *Engraulis encrasicolus*, *Boops boops*, *Caranx rhonchus*, *Ethmalosa fimbriata*, etc. The biomass of these small coastal pelagics is particularly significant in Senegal [5,6].

Live bait fishing is allowed throughout Senegalese jurisdictional waters, except in the area defined by the line connecting the following coordinates: L = 14°40′08″ N and G = 17°25′02″ W and L = 14°44′18″ N and G = 17°21′00″ W. According to Senegalese fishing regulations (Decree 2016–1804 of 22 November 2016, Article 51), live bait fishing is only authorized for pole-and-line tuna vessels holding a valid fishing license. Live bait is caught by artisanal fishers under contract, while domestic plants use it as raw material for fishmeal, fish oil, and other vitamin and mineral complexes for animal feed (poultry, pigs), as well as aquaculture [7].

Hann Bay is preferred for this activity due to its configuration (a closed bay that retains juveniles), its proximity to the Port of Dakar, and the most attractive selling price of bait compared with other sites [8]. The juveniles of small pelagics may also be self-consumed or sold to individuals with a habit of consuming fry or with low purchasing power [9]. Additionally, some fishing activities operating in Hann Bay catch juveniles not for pole-and-line fishing, but for markets oriented more toward human consumption and fishmeal production, which raises concerns such as resource depletion [10,11] or biodiversity loss [11].

In this context of the unregulated exploitation of juveniles for various purposes, it becomes necessary to characterize the ichthyological diversity of live bait and examine its seasonal variations in Hann Bay.

2. Materials and Methods

2.1. Study Area

Hann Bay is located about 6 km from downtown Dakar, between 14°43′21″ N and 17°23′12″ W. It covers an area of 1.4 km^2 [12]. Located on the eastern maritime façade of Cape Verde Peninsula, Hann Bay stretches from Bel-Air Point to Mbao village (Figure 1) [13]. Hann is a major landing site for artisanal fisheries, comparable to Saint-Louis and Kayar on the Grande Côte, and Mbour and Joal on the Petite Côte of Senegal [9].

2.2. Sampling Strategy

Experimental fishing was carried out using two types of fishing gear: a beach seine and a purse seine. Each month, two purse seine hauls were performed on the sampling day, followed by one beach seine haul the next day, during the last week of each month from February to November 2023. Sampling campaigns were conducted once per month during the second half of each month, over a period of ten months. Although this strategy may not capture certain intramonthly or sub-seasonal variations, it ensures temporal consistency and comparability across months, with the aim of analyzing broader seasonal patterns in the diversity of live bait species. A total of 20 purse seine hauls and 10 beach seine hauls were conducted. Fishing took place between 8:00 and 12:00 each day. Fishing depths ranged from 3 to 7 m for the beach seine and from 2.5 to 13.3 m for the purse seine.

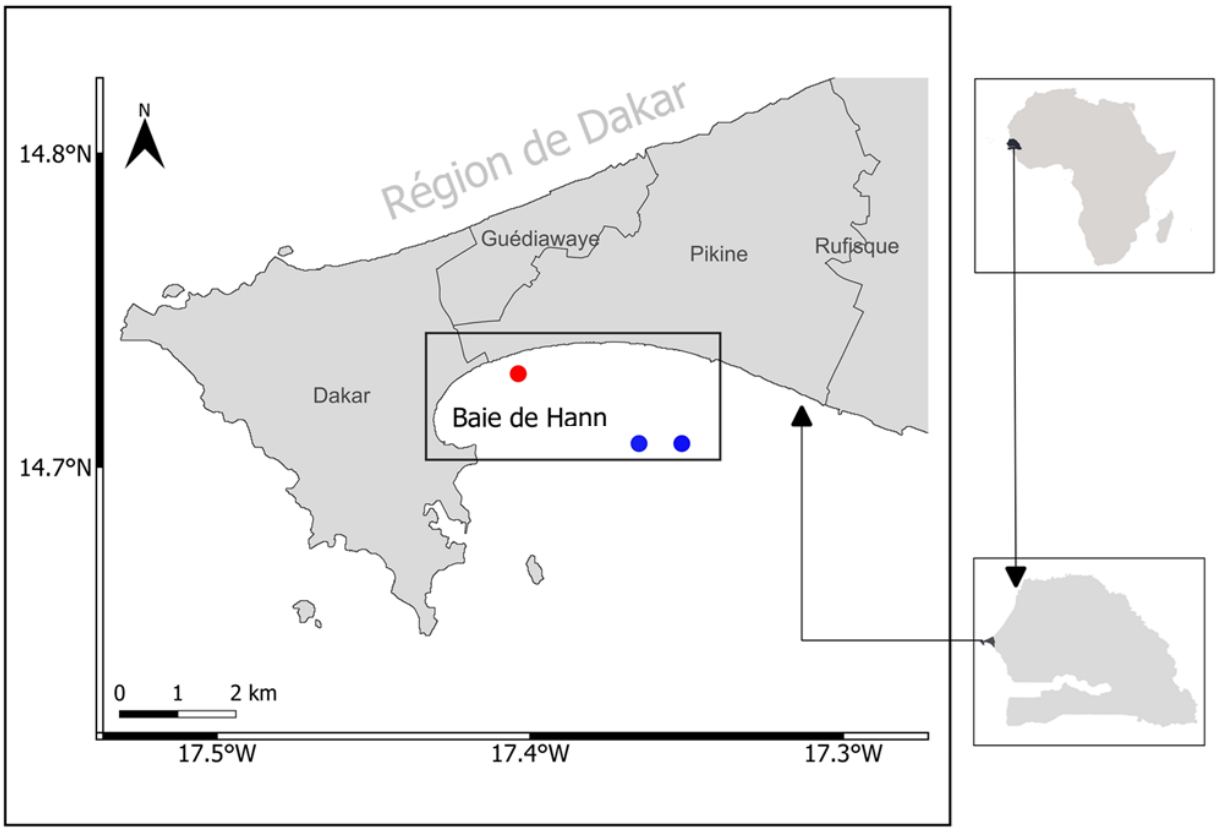

Figure 1. Map showing the location of Hann Bay, and the sampling stations for beach seine (red point) and purse seine (blue points).

The beach seine was 250 m long with a drop of 21.5 m. The purse seines measured either 400 m in length with a 50 m drop or 350 m in length with a 16 m drop, all equipped with 12 mm stretch mesh. The beach seines had mesh sizes of either 12 mm or 20 mm. Both types of gear had the same characteristics as those used by artisanal fishers targeting live bait. These gears allow a wide range of fish sizes to be caught. It is important to note that this study does not aim to compare the efficiency or performance of the two fishing gears used. Rather, the aim is to assess the contribution of each gear to the diversity of live bait species caught in Hann Bay. The difference in the number of hauls per gear is due to practical constraints: beach seining is more labor-intensive and time-consuming, allowing only one haul per morning, while purse seining is easier to operate, permitting two hauls during the same period.

The physico-chemical parameters measured included Salinity (ppt, parts per thousand, ‰) measured using a handheld refractometer (0–10 Brix; 0–100% salinity; ATC; supplied in a case, Dongguan, China), temperature measured using a digital thermometer (HANNA CHECKTEMP IP65 with remote probe, model HI98509, Villafranca Padovana, Italy), water transparency (using a Secchi disk locally manufactured, Senegal), and depth (using a depth sounder, Plastimo, Lorient, France). Captured individuals were sorted by species, count ed, and weighed using an electronic scale. For species used as live bait, individuals were brought to the laboratory, measured with an ichthyometer, weighed, and sexed.

Individuals were considered juveniles if their size did not reach the length at first sexual maturity (L_{50}) of the species. Species not used as live bait were grouped under the Miscellaneous category.

2.3. Data Analysis

Statistical analyses were performed separately for each gear type. Seasonal analyses were conducted, distinguishing the cold season (October to March) from the warm season (April to September). Seasonal comparisons of environmental parameters, the number of individuals, and total weight were carried out using the non-parametric Wilcoxon test. The Wilcoxon test was chosen due to either the non-normality of variable distributions or the lack of homogeneity in variance.

To identify the main environmental drivers shaping the composition of fish communities targeted as live bait, a redundancy analysis (RDA) was conducted based on species abundance data and measured abiotic variables from each sampling campaign. RDA is a constrained ordination method that allows for the assessment of linear relationships between species composition and environmental gradients [14,15]. Separate RDAs were performed for samples collected with beach seines and purse seines, using the rda() function from the "vegan" package in R [16]. Prior to the analysis, species abundances were Hellinger-transformed to reduce the influence of double zeros and fulfill the linearity assumptions of RDA [14]. Environmental variables were standardized by centering and scaling. The significance of the relationships between environmental predictors and species composition was evaluated using permutation tests with 999 iterations. For each gear type, the proportion of variance explained by the first two RDA axes was reported, along with the orientation of species and environmental vectors on the ordination plot, allowing for the identification of species–environment associations and seasonal patterns in community structure.

The Shannon diversity index (H') is a measure of biological diversity within a community. This index allows for the measurement of the complexity of an assemblage by considering the distribution of individuals among different species. The Shannon index is calculated using the following formula:

$$H' = -\sum_{i=1}^{S} p_i * \log_i * (p_i) \quad (1)$$

For $P_i = n_i/Np$, N is the total number of individuals for all species, n_i is the number of individuals per species, pi is the relative abundance of each species, and log is the logarithm to base e [17]. The Pielou's evenness index (J'), defined as the ratio of actual diversity to maximum diversity, is obtained by dividing the Shannon diversity index by the logarithm base 2 of species richness [18], to assess whether the station or living conditions are optimal for the different species. The Pielou's evenness index (J') is calculated using the following formula:

$$J' = H'/\ln(S) \quad (2)$$

where H' is the Shannon diversity index, S is the total number of species, and ln(S) is the logarithm base 2 of S.

All analyses were conducted using R software, version R-4.4.2 [19], with a significance threshold of 0.05.

3. Results

3.1. Aquatic Environment of Hann Bay

During the cold season, salinity ranged from 31 to 37 ppt (mean ± SD: 34.08 ± 1.80 ppt; median: 35 ppt), while in the warm season it ranged from 30 to 36 ppt (33.92 ± 1.68 ppt; median: 35 ppt) (Figure 2a). The seasonal differences were not statistically significant (Wilcoxon, W = 143,653, p = 0.227). Water temperature varied from 17.50 °C to 30.70 °C in the cold season (24.49 ± 3.90 °C; median: 25 °C) and from 18.30 °C to 31.40 °C in the

warm season (27.30 ± 3.60 °C; median: 25 °C) (Figure 2b), with a significant seasonal difference (Wilcoxon, W = 211,433, $p < 0.001$). Transparency ranged from 1.10 to 6.50 m in the cold season (2.80 ± 1.40 m; median: 2.65 m) and from 0.80 to 4.50 m in the warm season (mean 2.57 ± 0.80 m; median: 2.38 m) (Figure 2c), with no significant variation (Wilcoxon, W = 143,550, $p = 0.242$). Fishing depth ranged from 2.50 to 10.40 m in the cold season (4.43 ± 1.90 m; median: 3.90 m) and from 2.10 to 13.30 m in the warm season (4.54 ± 1.80 m; median: 3.90 m) (Figure 2d), with no significant seasonal difference (Wilcoxon, W = 158,466, $p = 0.095$).

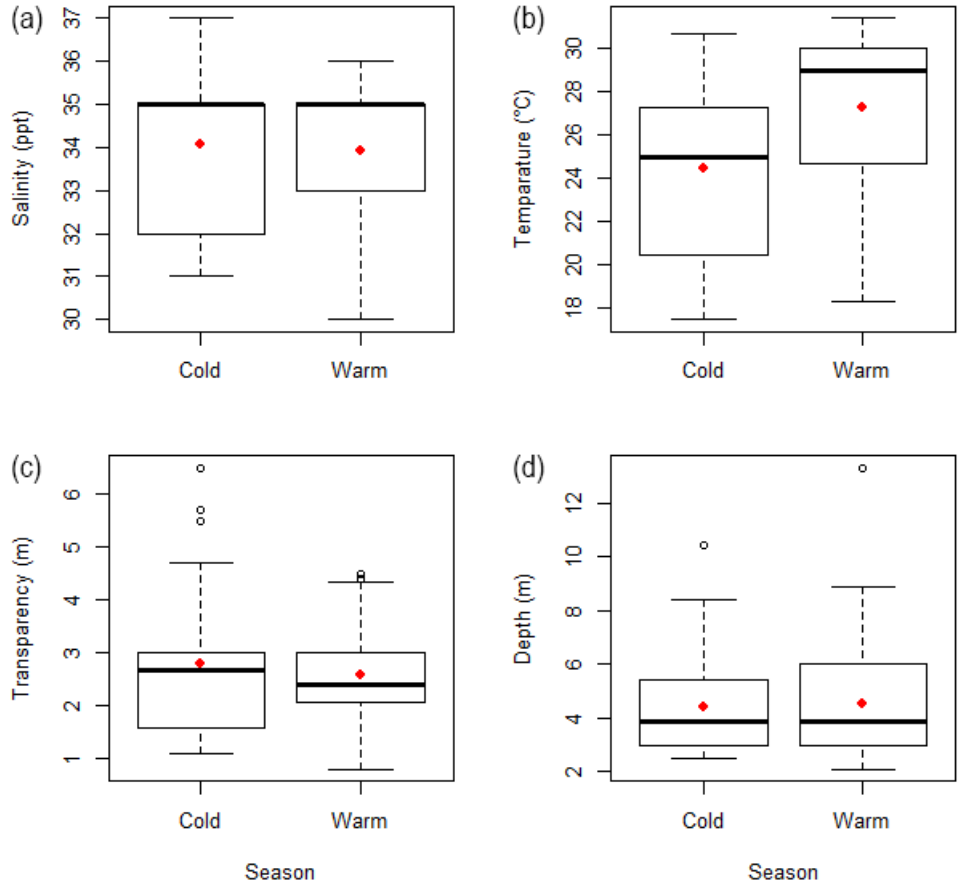

Figure 2. Seasonal variation in environmental parameters in Hann Bay. (**a**) Salinity; (**b**) temperature; (**c**) transparency; (**d**) depth. Red dots represent mean values, and horizontal bars represent medians.

3.2. Environmental Drivers of Live Bait Fish Assemblages

The redundancy analysis (RDA) revealed that temperature, depth, salinity, and transparency significantly influence the structure of fish communities targeted as live bait and captured using beach seines. The first two RDA axes explained 32.4% of the total variance, with temperature and depth emerging as the most influential environmental variables. *S. maderensis* was associated with higher temperatures, while *Mugil curema* and *Mugil cephalus* were linked to cooler and less saline conditions (Figure 3). *Trachurus trecae* and *E. fimbriata* were more closely associated with salinity and transparency, reflecting distinct ecological niches among bait species. A clear seasonal pattern was observed, with thermophilic species dominating during the summer months (June–August), a shift toward species associated with higher salinity and transparency in November, and distinct winter conditions in February–March affecting community composition (Figure 3).

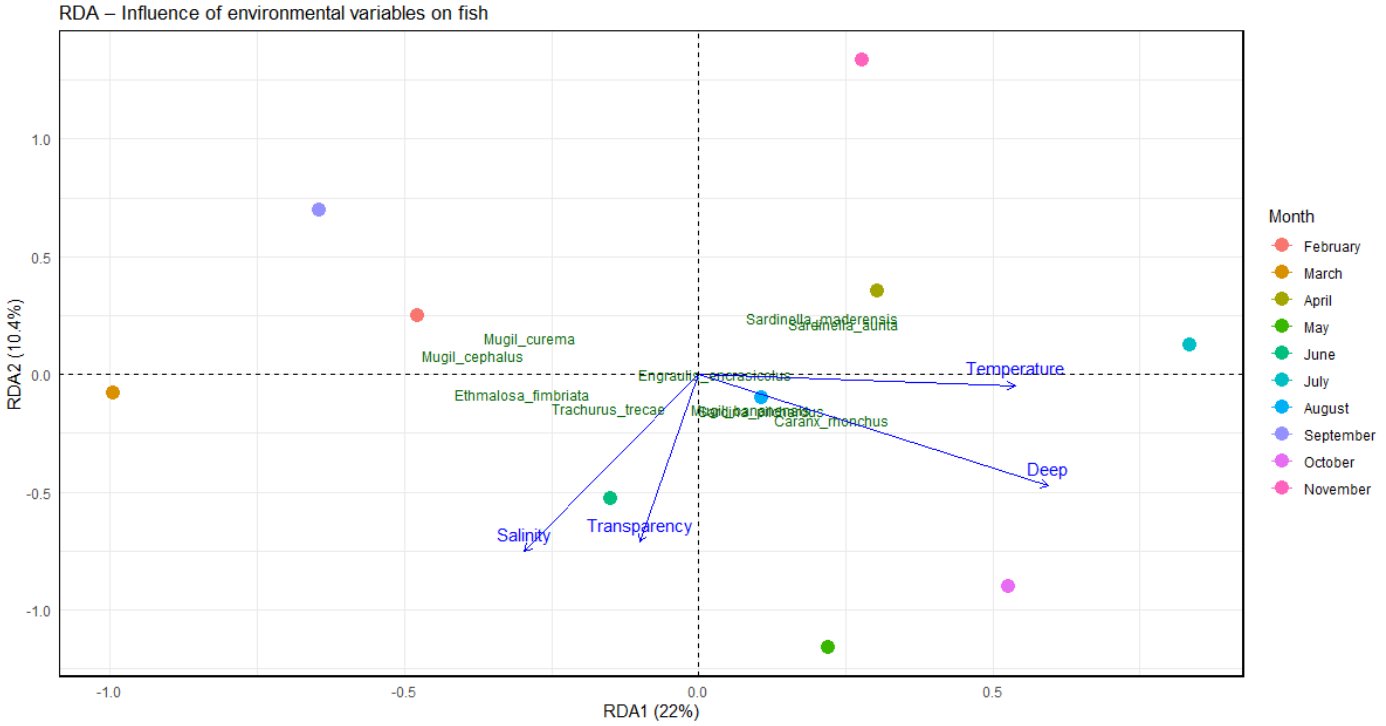

Figure 3. Redundancy analysis (RDA) of baitfish communities caught by beach seine and environmental variables in Hann Bay.

The redundancy analysis (RDA) reveals that the composition of fish communities caught with the purse seine is primarily influenced by salinity and temperature, as indicated by RDA axis 1 (39.2% of explained variance) and axis 2 (11.5%). The lengths of the environmental vectors confirm the predominant role of these two variables. *T. trecae* and *M. bananensis* are associated with more saline and clearer waters, whereas *C. rhonchus* appears to prefer opposite conditions (Figure 4). *S. maderensis* is positioned on the opposite side of the temperature vector, suggesting an affinity for cooler waters. A seasonal pattern is evident, with the months of March, September, October, and November grouped in the high-salinity zone, while May, June, and July correspond to different species assemblages, likely influenced by lower temperatures or other environmental factors (Figure 4).

3.3. Species Composition of Catches

Beach seine fishing operations led to the capture of 389,171 individuals representing a total weight of 1743 kg across 65 fish species (Table 1). Among the species identified, only 10 were used as live bait: *C. rhonchus*, *E. encrasicolus*, *E. fimbriata*, *M. bananensis*, *M. cephalus*, *M. curema*, *S. pilchardus*, *S. aurita*, *S. maderensis*, and *T. trecae*. The most abundant species was *E. encrasicolus*, accounting for 83% of the total number of individuals. The other bait species each represented less than 5% of the total. In terms of biomass, *T. trecae* and *E. encrasicolus* made up 31.5% and 24% of the total weight, respectively. The species not used as bait (Appendix A) accounted for 33.85% of the total weight.

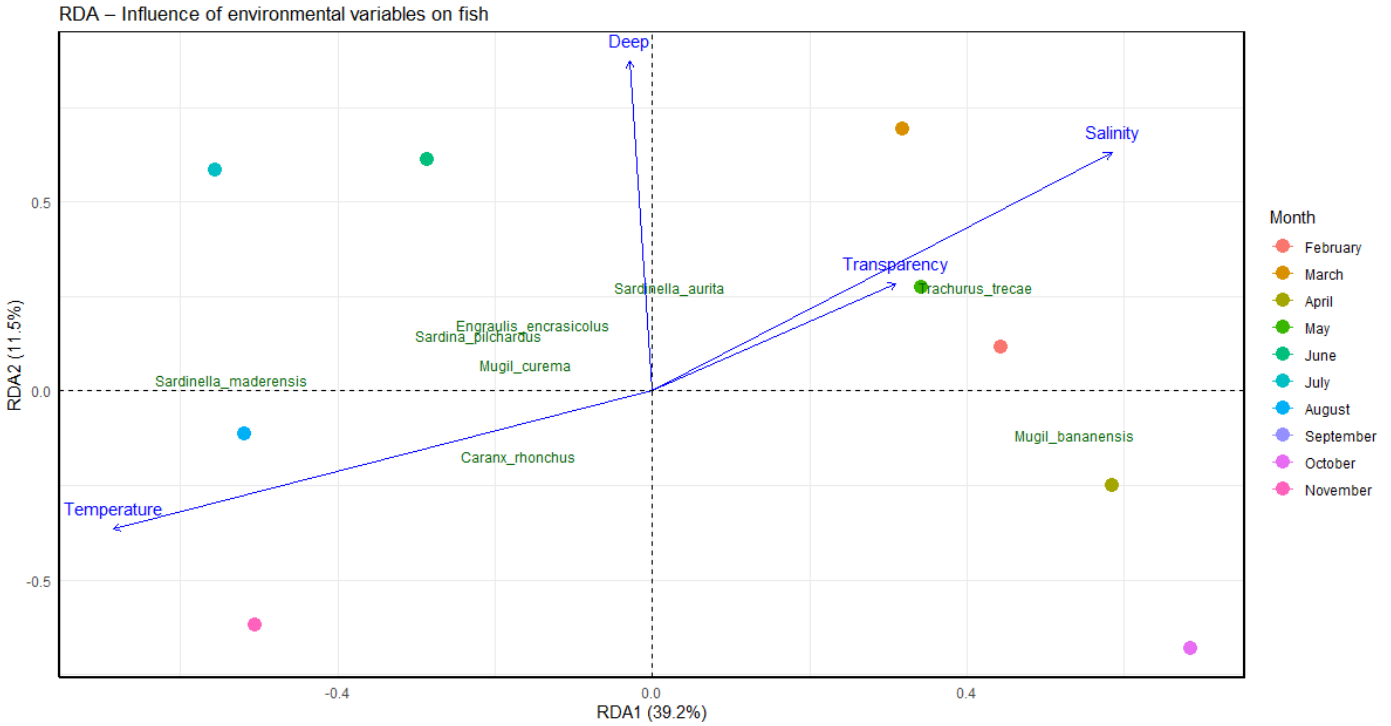

Figure 4. Redundancy analysis (RDA) of baitfish communities caught by purse seine and environmental variables in Hann Bay.

Table 1. Distribution of number of individuals, percentage (%) of number individuals, percentage (%) of weight, and total weight by species caught with beach seine and purse seine in Hann Bay.

Species	Beach Seine		Purse Seine		Beach Seine		Purse Seine	
	Number of Individuals	% Number of Individuals	Number of Individuals	% Number of Individuals	Weight of Individuals (kg)	% Weight of Individuals	Weight of Individuals (kg)	% Weight of Individuals
Caranx rhonchus	1138	0.29	158	1.68	37.66	2.16	17.73	5.80
Engraulis encrasicolus	325,168	83.55	6	0.06	419.10	24.05	0.06	0.02
Ethmalosa fimbriata	481	0.12			4.89	0.28		
Mugil bananensis	35	0.01	14	0.15	2.25	0.13	2.32	0.76
Mugil cephalus	3	0.00			1.54	0.09		
Mugil curema	289	0.07	9	0.10	4.30	0.25	2.20	0.72
Sardina pilchardus	2214	0.57	109	1.16	11.35	0.65	2.53	0.83
Sardinella aurita	4201	1.08	113	1.20	55.26	3.17	1.37	0.45
Sardinella maderensis	5466	1.40	2651	28.18	66.35	3.81	87.36	28.57
Trachurus trecae	18,346	4.71	36	0.38	550.21	31.57	1.12	0.37
Miscellaneous category	31,830	8.18	6312	67.09	589.83	33.85	191.11	62.50
Total	389,171		9408		1743		306	

Purse seine fishing resulted in the capture of 9408 individuals from 62 species, totaling 306 kg. Of the 62 species captured, 8 were used as live bait: *C. rhonchus*, *E. encrasicolus*, *M. bananensis*, *M. curema*, *S. pilchardus*, *S. aurita*, *S. maderensis*, and *T. trecae*. *S. maderensis* was the most abundant species, representing 28% of individuals. The remaining species used as live bait accounted for less than 2% of the total number of individuals. Non-bait species (Appendix A) represented 67% of individuals. In terms of weight, *S. maderensis* dominated with 28.5% of the total biomass, followed by *C. rhonchus* (5.8%). The other bait species each represented less than 1% of the total biomass.

3.4. Seasonal Variation in Diversity Indices

For the beach seine, the number of individuals was lower during the cold season and higher in the warm season. A similar pattern was observed for biomass, which was higher in the warm season. Shannon's diversity index ranged from 0.77 (warm season) to 2.96 (cold season). The lower values during the warm season suggest a community dominated by a few abundant species, whereas higher values during the cold season indicate a more even species distribution (Table 2). Pielou's evenness index for the beach seine was lower (0.19) in the warm season, reflecting a community dominated by a few species, and higher (0.65) in the cold season, indicating a more balanced community.

Table 2. Seasonal variation in abundance, biomass (kg), species richness, Shannon's diversity index, and Pielou's evenness index for fish communities caught with beach and purse seines in Hann Bay. ln(S), logarithm to base e of the total richness (S), and standard deviation (SD).

Gear	Season	Individuals	Biomass (kg)	Seasonal Species Richness (S)	Shannon's Index (H)		Pielou's Evenness (J′)	
					H (0–ln(S))	Mean ± SD	J′	Mean ± SD
Beach Seine	Warm	385,301	1578	53	0.77 (0–3.97)	1.59 ± 1.15	0.19	0.42 ± 0.32
	Cold	3890	165	40	2.4 (0–3.68)		0.65	
Purse Seine	Warm	2347	132	53	2.96 (0–3.97)	2.15 ± 1.14	0.74	0.56 ± 0.34
	Cold	7061	174	30	1.34 (0–3.40)		0.39	

Conversely, purse seine catches showed fewer individuals and a lower biomass during the warm season, and higher numbers during the cold season. More species were encountered during the warm season and fewer during the cold season for both fishing gears (Table 2). Shannon's index ranged from 1.34 (cold season) to 2.96 (warm season), with a greater diversity and more even abundance distribution during the warm season. Pielou's evenness was higher (0.74) in the warm season and lower (0.39) in the cold season (Table 2).

The K-dominance curves of beach seine catches reveal distinct seasonal patterns in species dominance and diversity. In both the warm and cold seasons, the rapid initial rise in the dominant curves indicates that a small number of species contribute disproportionately to total abundance. However, this effect is more pronounced during the warm season, where the top 10 ranked species account for more than 95% of the total catch, compared with just over 85% during the cold season. The dominance curve for the warm season reaches the asymptote more quickly, suggesting a high degree of dominance by few species and, consequently, lower species evenness and diversity. This pattern reflects a community structure strongly influenced by a few opportunistic or highly abundant species during this period. In contrast, the curve for the cold season rises more gradually, indicating a more even distribution of individuals across species. This reflects relatively lower dominance and greater species evenness, which is consistent with higher species diversity (Figure 5).

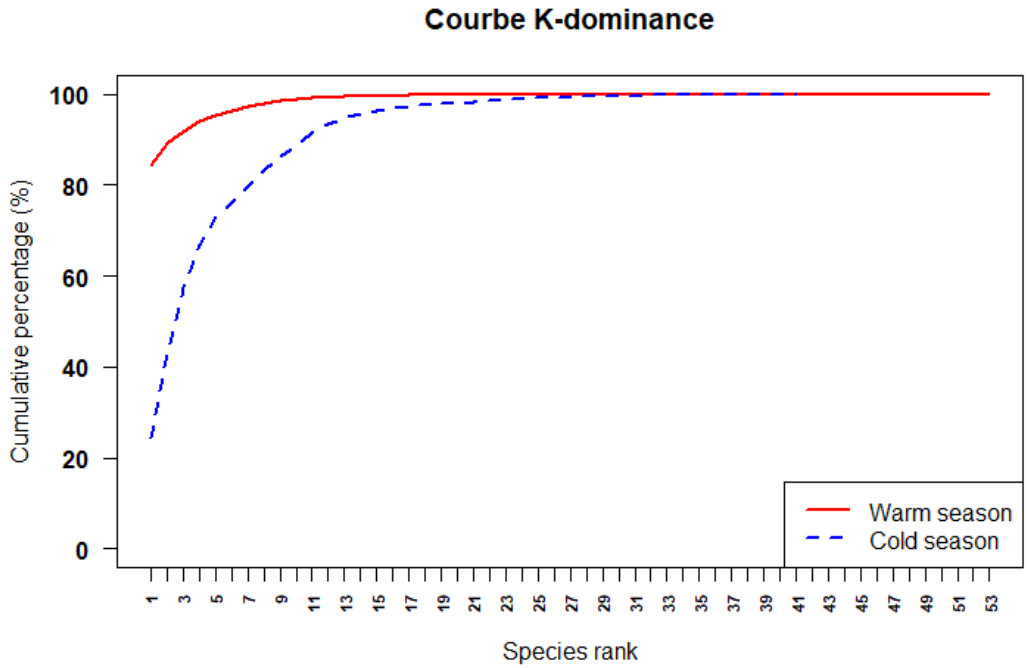

Figure 5. Seasonal variation in the K-dominance curve for beach seine data. The solid blue line represents the warm season; the dashed red line represents the cold season.

For purse seine catches, the K-dominance curve for the cold season rises sharply and reaches nearly 100% cumulative abundance within the first 10 species, highlighting a high degree of dominance by a small number of taxa. This steep profile reflects very low species evenness and reduced diversity during the cold season, where just a few species dominated the catches almost entirely (Figure 6). In contrast, the dominance curve for the warm season is more gradual and extends over a larger number of species before approaching an asymptote. This indicates a more balanced distribution of individuals across species and, consequently, higher species evenness and diversity (Figure 6).

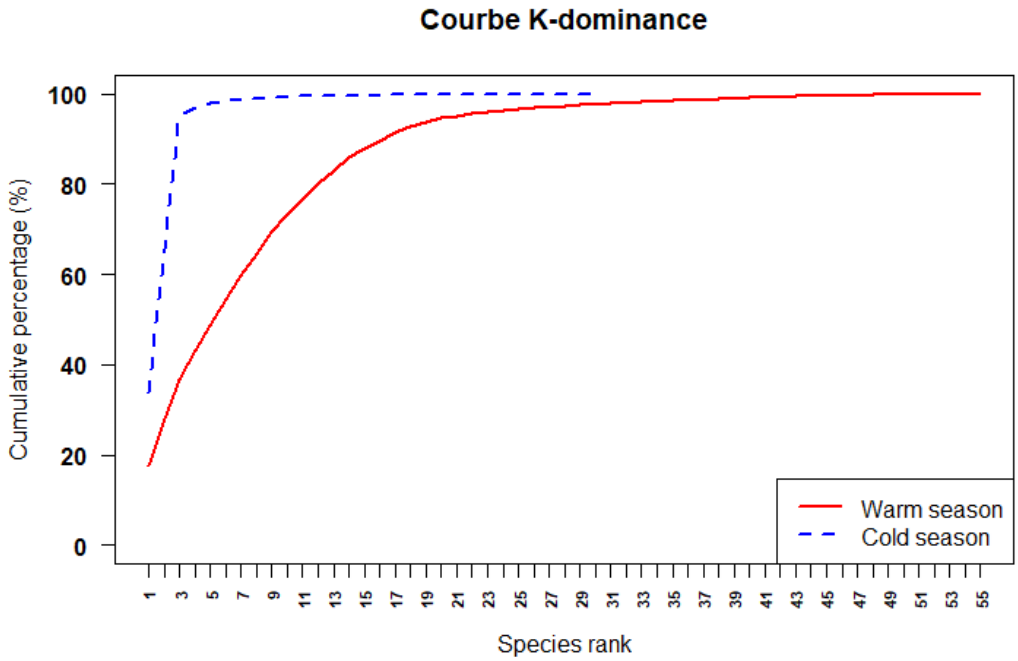

Figure 6. Seasonal variation in the K-dominance curve for purse seine data. The solid blue line represents the warm season; the dashed red line represents the cold season.

3.5. Seasonal Variation in the Number and Weight of Live Baits

During the cold season, the number of individuals caught per fishing haul with beach seine and used as live bait ranged from 1 to 912 (mean ± SD: 64.83 ± 166.40; median: 9), while in the warm season it ranged from 1 to 270,200 (3132.36 ± 24,852.90; median: 8) (Figure 7a). There was no significant seasonal difference in the number of individuals caught (Wilcoxon, W = 4022.5, $p = 0.319$). The weight of bait caught per haul varied between 0.003 and 95.40 kg in the cold season (2.75 ± 12.70 kg; median: 0.22 kg) and between 0.003 and 550 kg in the warm season (12.83 ± 57.60 kg; median: 0.26 kg) (Figure 7b). Seasonal differences in bait weight were not statistically significant (Wilcoxon, W = 4314.5, $p = 0.063$).

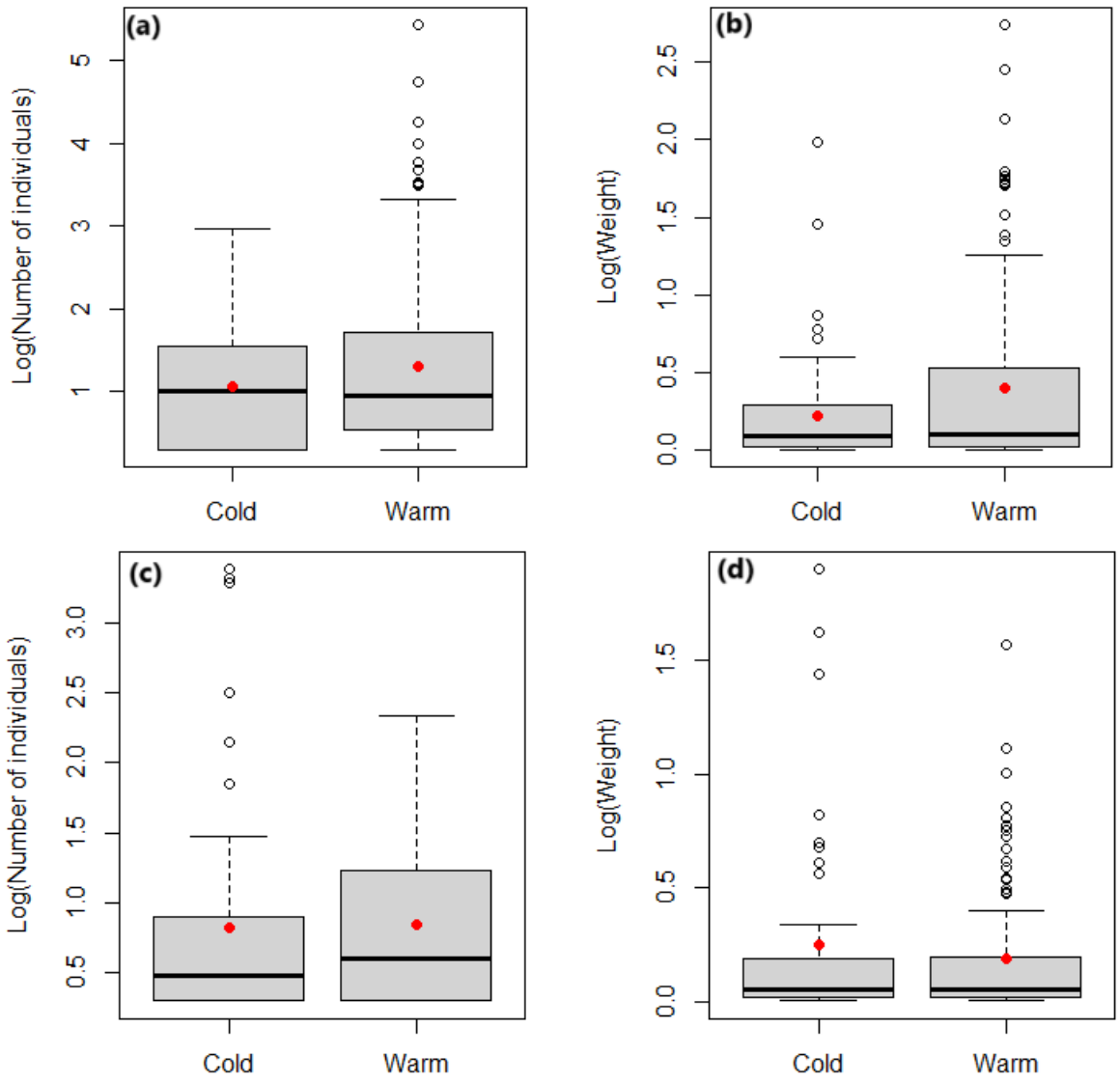

Figure 7. Seasonal variation in the number and weight of live bait per fishing haul using beach seine (**a**,**b**) and purse seine (**c**,**d**) in Hann Bay. Red dots represent mean values, and horizontal bars represent medians.

During the cold season, the number of individuals caught per fishing haul with purse seine and used as live bait ranged from 1 to 2381 (mean ± SD: 156.91 ± 538.10; median: 2), whereas in the warm season it ranged from 1 to 216 (21.53 ± 43.19; median: 3) (Figure 7c). No significant seasonal difference was observed (Wilcoxon, W = 2774.5, $p = 0.190$). The weight of live bait per haul ranged from 0.005 to 78.85 kg in the cold season (3.86 ± 13.5 kg;

median: 0.13 kg) and from 0.002 to 36.38 kg in the warm season (1.21 ± 3.90 kg; median: 0.12 kg) (Figure 7d), with no significant seasonal variation (Wilcoxon, W = 2349, $p = 0.682$).

3.6. Proportion of Juvenile Live Baits in the Catches

The number of individuals of species used as live bait and caught with beach seine ranged from 18 individuals (*M. curema*) to 496 individuals (*E. encrasicolus*). Size varied from 42 mm (*M. curema*) to 233 mm (*E. fimbriata*). The percentage of juveniles was over 82% for all species, except for *M. curema*, which was present in Hann Bay with more adults than juveniles (Table 3).

Table 3. Number of individuals, minimum size (mm), maximum size (mm), L_{50} (mm), and percentage of juveniles of target species caught with beach seine and purse seine in Hann Bay. Gear codes: PS = purse seine, BS = beach seine.

Species	Gear	Numbers	Minimum (mm)	Maximum (mm)	L_{50} (mm)	Juvenile (%)
Caranx rhonchus	PS	158	100	275	200 [20]	32
	BS	490	103	295		83
Engraulis encrasicolus	PS	7	75	130	96 [21]	69
	BS	496	55	127		82
Mugil curema	PS	2	211	224	220 [22]	50
	BS	18	205	247		22
Sardina pilchardus	PS	108	96	155	133 [23]	79
	BS	99	74	125		100
Sardinella aurita	PS	100	60	150	181 [24]	100
	BS	300	61	150		100
Sardinella maderensis	PS	987	80	322	166 [12]	89
	BS	427	35	210		99
Trachurus trecae	PS	36	102	210	168 [20]	98
	BS	345	40,4	222		99
Ethmalosa fimbriata	BS	435	54	287	172 [25]	99
Mugil bananensis	PS	1	316	316	180 [20]	0
Mugil cephalus	BS	72	45	230	390 [26]	100

Regarding the beach seine, the number of individuals ranged from 1 individual (*M. bananensis*) to 987 individuals (*S. maderensis*). Size varied from 13 mm (*M. curema*) to 242 mm (*S. maderensis*). The percentage of juveniles was 100% in *S. aurita* and 98% in *T. trecae*. It ranged from 50% to 89% in three species (*M. curema*, *S. pilchardus*, and *S. maderensis*) and was below 50% in two species (*C. rhonchus* and *M. bananensis*) (Table 3).

4. Discussion

The objective of this study was to analyze the diversity of fish species used as live bait and to evaluate their seasonal variations using two different fishing techniques. This approach aimed to examine the potential effects of live bait fishing on fish diversity in Hann Bay. This study is among the first recent investigations on live bait fisheries in Senegal, following earlier work such as [27].

4.1. Aquatic Environment

The environmental parameters in Hann Bay revealed generally stable salinity and water transparency across seasons, while temperature showed expected seasonal variation. Salinity remained around 34 ppt throughout the study period, consistent with typical marine conditions suitable for most coastal fish species [28,29]. Seasonal temperature differences, with warmer values during the warm season (mean between 24 and 28 °C), reflect a tropical coastal environment favorable to a wide range of fish assemblages, particularly small pelagics [21]. Notably, the consistently high turbidity reflected by mean transparency values below 3 m suggests a highly productive and organically enriched ecosystem, likely influenced by both terrestrial runoff and phytoplankton blooms [30,31]. These conditions can have direct implications for species distribution and gear selectivity. For example, reduced visibility may favor the efficiency of purse seines that rely on fish schooling behavior in the upper water column, while potentially reducing the capture rates of more visually oriented predatory species by line gear. Although fishing depths reached up to 13.3 m, the shallow and turbid character of the bay, coupled with tidal dynamics, limits vertical stratification and may enhance the spatial overlap between fish schools and fishing gears. Rather than describing the environment in isolation, these parameters must be interpreted as influencing the observed patterns of species dominance and gear-specific catches discussed below.

4.2. Drivers of Community Structure in Live Bait Fish

For beach seine, the RDA showed that temperature, depth, salinity, and transparency influence baitfish communities. *S. maderensis* preferred warmer waters, while *Mugil* spp. thrived in cooler, less-saline conditions. T. trecae and E. fimbriata responded to salinity and transparency [32,33]. These patterns reflect ecological niche separation [34]. Seasonal shifts were clear, with thermophilic species in summer and hydrological changes shaping winter communities [35,36]. The findings underscore the importance of integrating environmental variability into fishery management under climate change [37,38].

For purse seine, the RDA highlights salinity and temperature as key drivers of baitfish assemblages caught by beach seine, aligning with previous studies on estuarine fish communities [39,40]. *T. trecae* and *M. bananensis* are associated with saline, clear waters, suggesting seasonal abundance during dry periods [41,42]. Conversely, *C. rhonchus* appears linked to turbid, brackish conditions, possibly reflecting freshwater inputs. The position of *S. maderensis* relative to the temperature vector may indicate a preference for cooler waters during upwelling or transitional seasons [43,44]. The temporal clustering observed confirms the influence of seasonal hydrology on fish composition [40,45].

4.3. Variation in Species Richness

The high species richness reflects the low selectivity of both gears, especially the beach seine, which is widely recognized as being effective for sampling shallow coastal biodiversity. Despite this overall richness, only a limited number of species were retained for live bait, highlighting a narrow selection of species targeted for bait relative to the full spectrum of fish present. Among these, *E. encrasicolus* and *S. maderensis* emerged as the dominant bait species in beach seines and purse seines, respectively. Their dominance likely reflects a combination of ecological traits such as schooling behavior, tolerance to high turbidity, and seasonal abundance that enhance their vulnerability to fishing gears. In the case *of E. encrasicolus*, persistent dominance may also indicate high exploitation levels, potentially affecting stock sustainability. These patterns are consistent with the findings of [46], who reported clupeids and engraulids as the primary components of live bait catches, and [4], who emphasized the prevalence of *S. maderensis* in Senegalese artisanal

fisheries. While gear type and spatial heterogeneity (e.g., greater distance between purse seine sites) contribute to observed diversity, the functional role and abundance of just a few species underscore the ecological and fishery importance of dominant bait taxa.

4.4. Variation in Diversity Indices

The seasonal variations in catch composition and diversity differed between beach seine and purse seine fisheries. Beach seine catches were notably higher in both abundance and biomass during the warm season, whereas purse seine catches peaked in the cold season. Although species richness increased during the warm season for both gears, diversity indices revealed contrasting community structures. The lower Shannon diversity observed in beach seine catches during the warm season suggests dominance by a few species, reflecting a less even distribution, while the cold season supported a more balanced assemblage. In contrast, purse seine catches exhibited greater species dominance in the cold season, with a more equitable community in the warm season. These patterns likely arise from seasonal shifts in environmental factors and fishing pressure, as reported in previous studies [47,48]. The consistent dominance of a limited number of species across seasons and gear types may indicate underlying ecological imbalances, potentially driven by overfishing or anthropogenic impacts such as pollution, particularly within the turbid waters of Hann Bay [30]. Additionally, the differences in selectivity between gear types contribute to the observed patterns: beach seines capture a broader range of coastal species, resulting in lower evenness during periods of species dominance, while purse seines preferentially target schooling pelagic fish, which may explain their relatively higher evenness during the warm season. This interpretation is supported by evenness indices, suggesting temporal fluctuations in community stability [49].

4.5. Seasonal Variation in Species Dominance

The K-dominance curves from Hann Bay reveal clear seasonal shifts in live bait fish assemblages, with warmer periods showing higher evenness and species diversity, while colder seasons are dominated numerically by a few species, particularly *E. encrasicolus* in beach seine catches and *S. maderensis* in purse seine samples [50,51]. These patterns align with ecological theory and observations from tropical and subtropical estuarine systems, where temperature, salinity, and productivity regulate community composition [39,52,53]. The dominance of *E. encrasicolus* (83% in beach seine catches) reflects its pelagic schooling behavior and preference for plankton-rich shallow coastal waters, increasing its susceptibility to beach seines [39,54]. Its population dynamics are influenced by coastal upwelling, seasonal productivity, and reproductive synchrony, which can amplify dominance during specific periods [55]. Similarly, *S. maderensis* dominates purse seine catches due to dense surface schooling and diel vertical migrations that enhance vulnerability to this gear [55,56]. These ecological traits explain catch dominance but also highlight the need for gear-specific management strategies [57,58]. However, such extreme dominance raises concerns for ecosystem resilience and fishery sustainability. Assemblages dominated by one or two species exhibit lower evenness and functional diversity, increasing vulnerability to environmental changes and fishing pressure [59,60]. Both *E. encrasicolus* and *S. maderensis* are short-lived and highly productive species, heightening the susceptibility to recruitment overfishing without adequate management. Therefore, beyond documenting species abundance, these findings stress the importance of ecosystem-based approaches that consider seasonal assemblage dynamics, dominant species' traits, and long-term community stability [51,61].

4.6. Variation in Abundance and Biomass

The lack of significant seasonal variation in the abundance and biomass of live bait caught with beach seines in Hann Bay suggests a relatively stable year-round availability of these resources. This stability may be attributed to favorable environmental conditions throughout the year, despite known seasonal fluctuations in the bay [62,63]. The average weights per fishing haul indicate that, although large numbers of individuals are caught, many of the fish are small, consistent with their use as live bait. Similarly, no significant seasonal variation was observed in the abundance or biomass of live bait caught using purse seines. This stability likely reflects the relatively constant distribution and availability of *S. maderensis*, which was the most abundant species in terms of both number and biomass. It also suggests that seasonal environmental changes in Hann Bay may have a limited impact on pelagic live bait species targeted by purse seines. However, this finding contrasts with previous studies reporting strong seasonal effects on fish assemblages. For instance, ref. [64] highlighted significant seasonal influences on the abundance and biomass of demersal fish populations. In contrast, our results suggest that live bait populations dominated by small pelagic or coastal species may be less sensitive to such seasonal shifts in Hann Bay.

4.7. Juvenile Exploitation and Implications for Sustainability

The high proportion of juveniles observed in live bait catches often exceeding 80% and reaching 100% in species such as *S. aurita* and *T. trecae* is a critical finding with direct implications for fisheries sustainability. These empirical results reveal that the live bait fishery is not simply harvesting surplus individuals, but is disproportionately removing immature fish from the population. For instance, juvenile proportions were particularly high in key small pelagic species such as *S. maderensis* (89%) and *S. pilchardus* (70%), indicating a pattern of consistent juvenile targeting. This raises major concerns regarding recruitment overfishing and the long-term viability of these stocks. Juveniles play a pivotal role in maintaining population replenishment, and their removal before reaching reproductive maturity can significantly reduce spawning stock biomass (SSB), thereby impairing future recruitment [44,65]. Furthermore, as small pelagics form the base of the food web in coastal ecosystems, such selective removal may also alter trophic dynamics and reduce ecosystem resilience [66,67]. These issues are exacerbated in data-limited contexts where management measures (e.g., minimum mesh size or seasonal closures) are weakly enforced or absent. While the discussion previously highlighted concerns about bait use conflicting with fishmeal production or food security, it is now evident that the unsustainable removal of juveniles is itself a key driver of ecological and economic risk. Strengthening regulations to protect juvenile fish particularly during peak recruitment seasons is therefore essential to ensure the sustainability of both bait fisheries and broader ecosystem functions.

4.8. Impacts of Fishing on Biodiversity

Live bait fishing targets not only the intended bait species but also captures a considerable number of non-target species as bycatch. This low selectivity is a known characteristic of many artisanal fishing techniques, especially when operating in biodiverse coastal ecosystems [68,69]. The presence of a high proportion of bycatch underscores the potential ecological impact of live bait fisheries, particularly when small or juvenile individuals are involved. Regardless of gear type, the results indicate that live bait fishing significantly alters the species composition in Hann Bay. The structure of fish populations is visibly disrupted, leading to imbalances in community organization. The substantial proportion of juveniles in the catch raises particular concern, as it undermines population renewal and long-term sustainability [70,71]. The selective pressure on juvenile stages distorts natural age structures, potentially shifting population dynamics toward older cohorts and reducing

reproductive output over time. These patterns reflect unsustainable practices that threaten both biodiversity and fisheries' resilience. By removing large quantities of small forage fish and juvenile individuals' key prey for higher trophic levels, live bait fishing also risks disrupting food web dynamics and essential ecological functions [72–74]. This can degrade the integrity of coastal ecosystems such as Hann Bay and ultimately affect the livelihoods of local communities that rely heavily on these resources for food and income.

5. Conclusions

This study offers valuable insights into the species composition and seasonal dynamics of fish used as live bait in Hann Bay, based on monthly experimental fishing with both beach and purse seines. Analyses highlight the significant role of seasonal hydrological factors, particularly salinity and temperature, in shaping baitfish communities. A redundancy analysis reveals strong correlations between these variables and baitfish assemblages, which are clearly adapted to environmental conditions fluctuating throughout the year. This seasonal variability influences the availability and distribution of live bait species, underlining the importance of incorporating such dynamics into sustainable management and conservation plans.

Although water temperature exhibited some seasonal changes, other physico-chemical parameters remained fairly stable year-round. Hann Bay hosts a diverse fish fauna, with 65 species caught by beach seines and 62 by purse seines. Species such as *E. encrasicolus* and *S. maderensis* dominated catches, likely due to their ecological traits and vulnerability to fishing gears. Live bait mainly targets small-sized individuals, with no significant seasonal variation in bait abundance or biomass, suggesting relatively stable bait availability. However, the heavy reliance on a few dominant species, especially *E. encrasicolus* and *S. maderensis*, and frequent capture of juveniles raise concerns about the fishery's long-term sustainability. The effective management of fishing effort and targeted stocks is therefore critical to preserve fish populations, maintain ecological balance in Hann Bay, and secure the livelihoods of dependent local communities.

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Appendix A

Table A1. Group and family of all species identified during this study and captured using purse seine and beach seine in Hann Bay. The Miscellaneous category refers to species considered as part of the 'Various' group. *, the presence of the species.

Group	Family	Species	Beach Seine	Purse Seine
Live baits	Alosidae	*Sardina pilchardus* (Walbaum, 1792)	*	*
	Carangidae	*Caranx rhonchus* (Geoffroy Saint-Hilaire, 1817)	*	*
		Trachurus trecae (Cadenat, 1950)	*	*
	Dorosomatidae	*Ethmalosa fimbriata* (Bowdich, 1825)	*	
		Sardinella aurita (Valenciennes, 1847)	*	*
		Sardinella maderensis (Lowe, 1838)	*	*
	Engraulidae	*Engraulis encrasicolus* (Linnaeus, 1758)	*	*
	Mugilidae	*Mugil bananensis* (Pellegrin, 1927)	*	*
		Mugil cephalus (Linnaeus, 1758)	*	
		Mugil curema (Valenciennes, 1836)	*	*
Miscellaneous category	Ariidae	*Carlarius parkii Cuvier, 1833* (Günther, 1864)	*	
	Batrachoididae	*Halobatrachus didactylus* (Bloch & Schneider, 1801)		*
	Belonidae	*Ablennes hians* (Valenciennes, 1846)	*	
		Tylosurus Acus Rafale (Collette & Parin, 1970)	*	*
	Carangidae	*Caranx crysos* (Mitchill, 1815)	*	*
		Caranx hippos (Linnaeus, 1766)	*	
		Caranx senegallus (Cuvier, 1833)	*	*
		Chloroscombrus chrysurus (Linnaeus, 1766)	*	*
		Hemicaranx bicolor (Günther, 1860)	*	
		Lichia amia (Linnaeus, 1758)	*	
		Selene dorsalis (Gill, 1863)	*	*
		Trachinotus ovatus (Linnaeus, 1758)	*	*
	Centrolophidae	*Schedophilus pemarco* (Poll, 1959)	*	
	Cichlidae	*Coptodon guineensis* (Günther, 1862)	*	*
		Sarotherodon melanotheron (Rüppell, 1852)	*	*
	Cyclopsettidae	*Citharichthys stampflii* (Steindachner, 1894)		*
		Syacium guineensis (Bleeker, 1862)	*	*
	Cynoglossidae	*Cynoglossus senegalensis* (Kaup, 1858)	*	*
	Dactylopteridae	*Dactylopterus volitans* (Linnaeus, 1758)		*
	Diodontidae	*Chilomycterus spinosus* (Linnaeus, 1758)	*	*
	Drepaneidae	*Drepane africana* (Osório, 1892)	*	*
	Epinephelidae	*Epinephelus aeneus* (Geoffroy Saint-Hilaire, 1817)	*	*
	Exocoetidae	*Exocoetus volitans* (Linnaeus, 1758)	*	*
		Fodiator acutus (Valenciennes, 1847)	*	*
	Fistulariidae	*Fistularia petimba* (Lacepède, 1803)	*	*
		Fistularia tabacaria (Linnaeus, 1758)	*	*
	Gerreidae	*Eucynostomus melanopterus* (Bleeker, 1863)	*	*
		Gerres Nigri (Günther, 1859)	*	*

Table A1. *Cont.*

Group	Family	Species	Beach Seine	Purse Seine
Miscellaneous category	Haemulidae	*Brachydeuterus auritus* (Valenciennes, 1832)	*	*
		Pomadasys incisus (Bowdich, 1825)	*	*
		Pomadasys jubelini (Cuvier, 1830)	*	
		Pomadasys peroteti (Cuvier, 1830)	*	*
		Pomadasys rogeri (Cuvier, 1830)	*	
	Hemiramphidae	*Hemiramphus brasiliensis* (Linnaeus, 1758)	*	*
	Monacanthidae	*Stephanolepis hispidus* (Linnaeus, 1766)	*	*
	Mugilidae	*Chelon dumerili* (Steindachner, 1870)	*	
		Neochelon falcipinnis (Valenciennes, 1836)	*	*
		Parachelon grandisquamis (Valenciennes, 1836)	*	
		Mullus barbatus (Linnaeus, 1758)		*
		Pseudupeneus prayensis (Cuvier, 1829)	*	*
	Polynemidae	*Galeoides decadactylus* (Bloch, 1795)	*	
	Priacanthidae	*Priacanthus arenatus* (Cuvier, 1829)		*
	Scaridae	*Scarus hoefleri* (Steindachner, 1881)		*
	Sciaenidae	*Pseudotolithus senegallus* (Cuvier, 1830)	*	*
		Umbrina canariensis (Valenciennes, 1843)	*	*
	Scombridae	*Auxis thazard* (Lacepède, 1800)	*	
		Euthynnus alletteratus (Rafinesque, 1810)	*	*
		Scomberomorus tritor (Cuvier, 1832)	*	
	Soleidae	*Pegusa lascaris* (Risso, 1810)		*
		Solea senegalensis (Kaup, 1858)	*	
		Synaptura cadenati (Chabanaud, 1948)		*
	Sparidae	*Boops boops* (Linnaeus, 1758)		*
		Diplodus bellottii (Steindachner, 1882)	*	*
		Diplodus cervinus (Lowe, 1838)		*
		Diplodus sargus (Linnaeus, 1758)	*	
		Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	*	*
		Lithognathus mormyrus (Linnaeus, 1758)	*	*
		Pagellus bellottii (Steindachner, 1882)	*	*
		Pagrus auriga (Valenciennes, 1843)	*	
		Pagrus caeruleostictus (Valenciennes, 1830)	*	*
		Spondyliosoma cantharus (Linnaeus, 1758)	*	*
	Sphyraenidae	*Sphyraena afra* (Peters, 1844)		*
		Sphyraena guachancho (Cuvier, 1829)	*	
	Synodontidae	*Trachinocephalus myops* (Forster, 1801)		*
	Tetraodontidae	*Ephippion guttifer* (Bennett, 1831)	*	*
		Lagocephalus laevigatus (Linnaeus, 1766)	*	*
		Sphoeroides marmoratus (Lowe, 1838)	*	*
		Sphoeroides pachygaster (Müller & Troschel, 1848)		*
	Torpedinidae	*Torpedo mackayana* (Metzelaar, 1919)		*
		Torpedo marmorata (Risso, 1810)		*
		Torpedo torpedo (Linnaeus, 1758)		*

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