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Ecological implications of push-net fisheries on demersal fish biodiversity and bycatch in Banyuasin coastal waters, Indonesia

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Abstract. *Septinar H, Fauziyah, Agustriani F, Febrianti AAP, Ningsih EN, Isnaini, Jubaedah D, Bakri, Rozirwan. 2026. Ecological implications of push-net fisheries on demersal fish biodiversity and bycatch in Banyuasin coastal waters, Indonesia. Biodiversitas 27 (2): d270224. https://doi.org/10.13057/biodiv/d270224.* Push-net fisheries are widely practiced in Indonesian coastal waters but often generate substantial bycatch, posing ecological risks to demersal fish communities and near-threatened species. This study examined the catch composition, species diversity, and ecological linkages of push-net fisheries in the Banyuasin coastal waters, South Sumatra, and assessed the environmental drivers influencing assemblage structure. Seven fishing trips comprising 33 hauls yielded 4,157 individuals (115.87 kg total biomass). Data were analyzed using ecological indices, including Relative Abundance (RA), Occurrence Frequency (F_i), Shannon-Wiener Diversity (H'), Pielou's Evenness (E), Simpson's Dominance (D), and the standardized Morisita Index (I_p). The main catch (*Metapenaeus monoceros*, *Penaeus merguiensis*, *Mierspenaeopsis sculptilis*, *Harpiosquilla raphidea*, and *Macrobrachium rosenbergii*) contributed 51.08% (59.19 kg) of the total catch, while bycatch and discards accounted for 40.33% (46.73 kg) and 8.59% (9.95 kg), respectively. The main catch was dominated by *M. monoceros* (RA = 35.55%, F_i = 100%) and *P. merguiensis* (RA = 21.22%, F_i = 100%), defining the core shrimp assemblage. Among the 20 bycatch species identified, *Johnius carouna* was the most dominant (RA = 21.65%, F_i = 85.71%), while *Clibanarius* spp. and *Lagocephalus spadiceus* dominated the discard fraction. Shannon-Wiener diversity (H' = 0.61-2.08) indicated low to moderate diversity, while evenness (E = 0.17-0.58) and dominance (D = 0.17-0.76) reflected uneven community structure and moderate dominance by a few taxa. The standardized Morisita index (Ip = 0.55-0.87) confirmed clustered distributions. Principal Component Analysis (PCA) explained 68.16% of total variance (F1 = 43.48%, F2 = 24.68%), highlighting strong multivariate associations between environmental variables (dissolved oxygen, temperature, and salinity) and bycatch variation across sampling sites. These findings highlight the influence of environmental variability and fishing pressure on species assemblages and emphasize the need for adaptive, ecosystem-based management to mitigate bycatch and sustain tropical coastal fisheries.

Keywords: Coastal ecosystems, demersal fish, *Metapenaeus monoceros*, Principal Component Analysis, small-scale fisheries

INTRODUCTION

Coastal ecosystems are highly productive marine environments that provide essential habitats, spawning, and nursery grounds for diverse fish and invertebrates, while supporting fisheries and maintaining trophic balance (Cheminée et al. 2021; Lincoln et al. 2024; Putri et al. 2024). However, these ecosystems face increasing pressure from fishing activities, habitat degradation, and unsustainable practices (Gaillet et al. 2022; Hirokawa and Thomps 2023). In tropical regions, the expansion of small-scale and semi-industrial fisheries has intensified bycatch (non-target species) and discard (portion of catch returned to the sea), damaged benthic habitats, and reduced fish stocks (FAO 2022). In shrimp bottom-trawl fisheries of the Tropical Eastern Pacific, for instance, bycatch may reach up to 93% of total catch, including species with moderate to high vulnerability and IUCN threat status (Saul and Claudia 2025).

In Indonesia, coastal ecosystems play a vital role in national food security, supporting millions of small-scale fisheries dependent on nearshore resources (Waldo et al. 2020; García-Lorenzo et al. 2024; Handayati et al. 2025; Rachman et al. 2025). The archipelagic waters accommodate diverse fishing gears (e.g., gillnets, hook-and-line fisheries, lift nets, traps, trammel nets, and various trawl-based gears) adapted to different ecological and socio-economic contexts. Some gears, particularly push nets, trawl, and trammel nets, are associated with high bycatch and discard rates (approximately 5% to over 90% of total catch), posing challenges to ecosystem-based management (Fauziyah et al. 2018; Dineshbabu et al. 2022; Dani et al. 2024; Saul and Claudia 2025).

In South Sumatra, the Banyuasin estuarine system represents one of the most productive fishing grounds, shaped by strong riverine inputs and tidal dynamics (Fauziyah et al. 2022b). Push nets (locally known as *Sondong*) are traditional small-scale fishing gear commonly operated in shallow waters using short tows (Dewi et al., 2022; Hariski and Asshiddiqi, 2022). Despite their socio-economic importance, push nets raise ecological concerns due to high bycatch and discard rates (Pramesthy and Hutapea 2020; Dani et al. 2024).

Previous studies in Indonesia have largely focused on other demersal fishing gears (e.g., gillnets, trawls, and traps), documenting gillnet bycatch, demersal fish composition, and trap bycatch biodiversity (Fitriya et al. 2021; Gautama et al. 2022; Khairunissa et al. 2025). In Banyuasin, research has primarily examined gillnet fisheries (Fauziyah et al. 2022a), while studies on push-net fisheries remain limited. In Riau, investigations of push-net have mainly addressed benthic disturbance (Pramesthy and Hutapea 2020; Dani et al. 2024). Comprehensive analyses integrating ecological indices (diversity, dominance, evenness, and spatial distribution), species composition, and species-environment relationships are still lacking.

This gap highlights the need for systematic ecological assessments of push-net fisheries. Despite their widespread use, their impacts on species diversity, bycatch dynamics, and demersal community structure remain insufficiently understood. The absence of robust ecological evidence constrains the development of science-based management strategies and limits policymakers' capacity to evaluate the sustainability of this widely used gear.

Indonesia's regulatory framework further underscores this need. Push nets are classified as destructive gears under the Ministry of Marine Affairs and Fisheries (MMAF) Regulation No. 2/2015, reflecting ecological concerns (Dani et al. 2024). However, the implementation has been challenged by limited site-specific ecological data, leading to policy conflicts and resistance from fishing communities (Apriliyana et al. 2024; Septinar et al. 2025). Establishing ecological baselines in areas such as Banyuasin is therefore essential to support evidence-based fisheries management.

This study presents the first integrated ecological assessment of push-net fisheries in Banyuasin, combining catch composition, ecological indices, and multivariate analyses to evaluate how environmental conditions shape species distribution and bycatch patterns. By linking community structure, species abundance, and environmental gradients, this study provides a comprehensive scientific basis for sustainable management of small-scale demersal fisheries. Specifically, this study aims to analyze catch composition and demersal fish biodiversity in push-net fisheries, and assess bycatch patterns in relation to environmental gradients. The findings contribute baseline ecological data to support ecosystem-based fisheries management (EBFM), inform adaptive regulatory measures, and promote the sustainability of coastal fisheries in Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted in the coastal waters of Banyuasin, South Sumatra, Indonesia (Figure 1), one of the key fishing grounds supporting small-scale marine capture fisheries in the region. The study area extends between 2°16′00″-2°30′00″S and 104°49′20″-104°56′20″E, encompassing both nearshore and offshore zones. The general bathymetry of Banyuasin coastal waters ranges from approximately 0.6 to 33 m, with a mean depth of about 9 m (Akbarimansyah et al. 2023). However, push-net fishing is primarily conducted in shallow waters, typically at depths of 2-5 m.

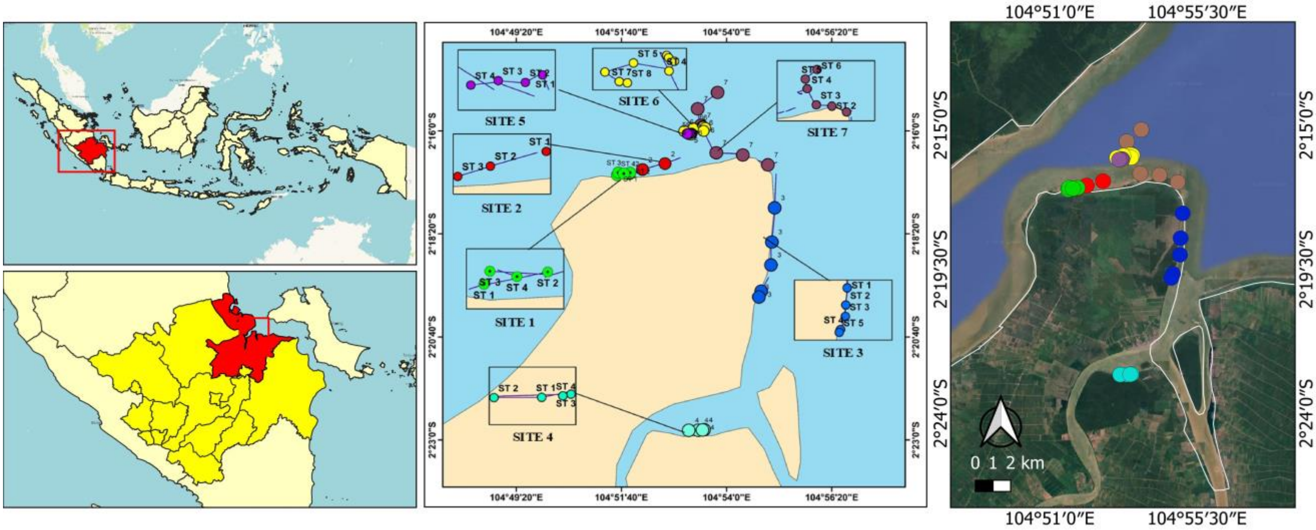

Figure 1. Map of Banyuasin coastal waters, South Sumatra, Indonesia, showing the distribution of 33 sampling stations across sampling sites. Zoomed-in boxes are included to illustrate station distribution and minimize overlap, covering both nearshore and offshore fishing grounds used by local fishermen

The seabed in this estuarine system is predominantly characterized by fine-grained sediments, ranging from clay to sandy clay and clayey sand, with clay-dominated substrates prevailing across the area, indicating generally soft and muddy bottom conditions typical of estuarine environments (Fauziyah et al. 2020; Akbarimansyah et al. 2023). These sediment characteristics are strongly influenced by riverine sediment inputs and tidal dynamics, providing suitable habitats for penaeid shrimps (Fauziyah et al. 2019a; Pratiwi et al. 2023). The coastal waters are strongly influenced by freshwater discharge from two major rivers, the Banyuasin and Musi Rivers, which form an extensive estuarine system and play a key role in shaping local hydrological conditions, including salinity, turbidity, and nutrient dynamics. Field sampling was conducted in November 2024 during the Transitional II monsoon season (September-November), characterized by variable hydrodynamic conditions and active fishing operations.

Fishing gear and sampling procedure

Data collection employed push nets, a bottom fishing gear commonly used by local fishermen (Figure 2). Each net consists of a conical frame supported by outriggers and equipped with a fine-mesh cod end (mesh size 1.5 inches). The gear was operated from a 5 GT wooden vessel moving at a steady 2 knots along the seabed in shallow waters. Each fishing cycle, including setting, pushing, and hauling, lasted approximately 20-30 minutes within a total operation time of 6-8 hours. However, hauling duration was not recorded separately for each haul. Water depth was recorded during each operation, ranging from 1 to 5 m (mean ± SD: 1.86±1.14 m).

A survey-fishing approach was adopted to replicate local fishing practices and capture representative data on demersal fish communities. A total of 33 hauls were conducted across seven fishing sites (one site per trip), with 3-8 randomly selected stations per site, based on fishermen's predictions of target species distribution. The main catch, bycatch, and discards were sorted on board during fishing operations. Upon landing, all specimens were sorted, counted, and identified to the lowest possible taxonomic level using standard guides (Hussin et al. 2019). Catches were then categorized as main catch, bycatch, or discards, following commonly applied FAO-based classifications and adapted to prevailing local fishing practices. In this context, the main catch (target species) refers to species intentionally targeted by fishermen and retained for sale or consumption; bycatch includes non-target species incidentally captured during fishing operations that are retained for economic or subsistence use; whereas discards comprise non-target species or individuals that are returned to the sea due to low economic value, undersized condition, or damage during capture (FAO 2011; Saul and Claudia 2025).

Environmental parameters

To complement sampling, key environmental parameters (temperature, salinity, dissolved oxygen (DO), pH, and current velocity) were measured in situ at each site. Measurements were taken near the seabed (~1 m above the bottom) to reflect conditions relevant to demersal fish assemblages. Water samples were collected from the bottom layer and analyzed on board. Temperature, DO, and pH were measured using a portable multiparameter probe (YSI ProDSS), while salinity was determined with a handheld refractometer (Atago S-28E). Current velocity was estimated using a drift-based method: a floating marker was released, and its displacement was measured over time to calculate surface current speed. This method is less accurate than standard hydrological instruments (e.g., current meters) and may introduce measurement uncertainty. Its use was dictated by logistical constraints during fieldwork and is acknowledged as a methodological limitation. Each parameter was measured in triplicate per station to ensure data accuracy, precision, and statistical reliability. These variables were selected because of their well-documented influence on fish community structure, species distribution, and habitat suitability in shallow tropical coastal ecosystems.

Data analysis

Species diversity and community attributes were quantified using several ecological indices, namely occurrence frequency (F_i), relative abundance (RA), Shannon-Wiener diversity (H′), Pielou's evenness (E′), Simpson's dominance (D), and Morisita's indices (Id and Ip), to characterize the structure and spatial distribution of demersal fish assemblages (Table 1). These indices provide complementary insights into species composition, dominance, and distributional patterns within the assemblage.

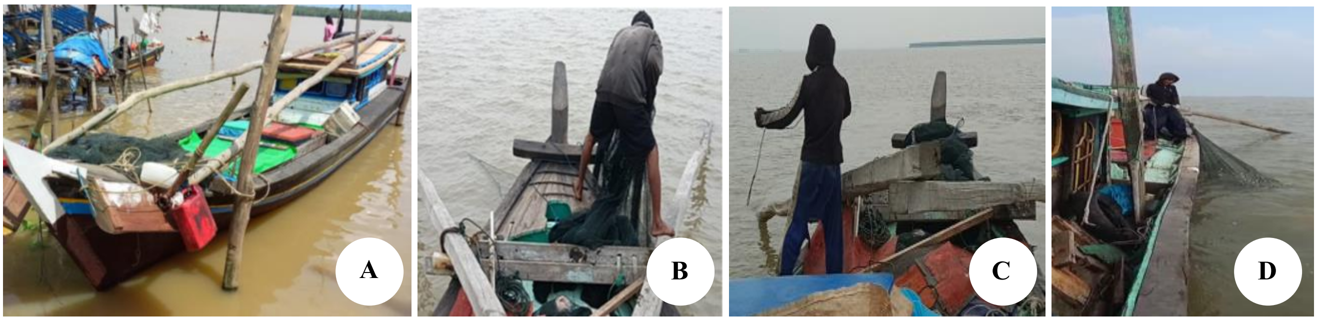

Figure 2. Push-net fishing operations in the Banyuasin coastal waters, Indonesia: A. a 5 GT wooden vessel with outriggers supporting the push-net frame and ice boxes for catch storage; B. preparation before gear setting; C. setting phase, with the net pushed forward at about 2 knots; and D. hauling phase, when the catch is retrieved onto the vessel

Multivariate analysis

Principal Component Analysis (PCA) was conducted using XLSTAT software to explore relationships among ecological indices, catch composition, and environmental parameters. PCA was selected for its ability to reduce data dimensionality and identify dominant gradients shaping variations across biological and environmental datasets. The analysis was based on a correlation matrix because the variables were measured in different units.

Before PCA, all variables were evaluated for skewness and normality. Positively skewed variables were square-root transformed [√(x)], while negatively skewed variables were reflected and then square-root transformed [√(k − x)], where k exceeds the maximum observed value, following established statistical guidelines (Tabachnick and Fidell 2019; Lee 2020). Normality was reassessed after transformation to ensure that PCA assumptions were met. Because the PCA was based on a correlation matrix, XLSTAT automatically standardized the variables (z-scores). The PCA was conducted on a data matrix consisting of seven sites (rows) and the full set of biological and environmental variables (columns). The analysis used site-averaged values for environmental parameters, calculated as the mean of measurements across all stations within each site, to ensure a consistent unit of analysis. Biodiversity indices were calculated based on species composition aggregated at the site level. This analytical structure aligns with the fishing operation unit and minimizes potential pseudo-replication by treating sites rather than individual stations as the primary unit of analysis.

Table 1. Biodiversity indices, formulas, and classification criteria were applied in this study

Index	Formula	Classification criteria	References
Occurrence Frequency (F_i)	$F_i = \frac{(T_i)}{T}\ x\ 100\%$	Common: $F_i \geq 40\%$ Occasional: $10\% \leq F_i < 40\%$ Rare: $F_i < 10\%$	Chen et al. (2019)
Relative Abundance (RA)	$RA = \frac{(n_i)}{N}\ x\ 100\%$	Dominant: $RA \geq 5\%$ Non-dominant: $RA < 5\%$	Ma et al. (2024)
Shannon-Wiener Diversity (H′)	$H' = -\sum_{n}^{i=1} p_i \ln p_i$	High: $H' > 3$ Moderate: $1 < H' \leq 3$ Low: $H' \leq 1$	Odum (1971); Atlanta et al. (2022); Mawardi et al. (2023)
Pielou's Evenness (E′)	$E = \frac{H'}{H_{max}} = \frac{H'}{\ln S}$	Stable: $0.75 < E' \leq 1$ Unstable: $0.5 < E' \leq 0.75$ Depressed: $0 < E' \leq 0.5$	Krebs (1998); Ulfah et al. (2019); Sharashy (2022)
Simpson's Dominance (D)	$D = \sum_{n}^{i=1} {p_i}^2$	High: $0.6 < D \leq 1.0$ Moderate: $0.3 < D \leq 0.6$ Low: $0.0 < D \leq 0.3$	Odum (1971); Atlanta et al. (2022); Mawardi et al. (2023)
Morisita's Index (I_d) and Standardized Morisita Index (Ip)	$I_d = n\left[\frac{\sum X_i^2 - \sum X_i}{(\sum X_i)^2 - \sum X_i}\right]$ $M_u = \frac{X_{0.975}^2 - n + \sum X_i}{(\sum X_i) - 1}$ $M_c = \frac{X_{0.025}^2 - n + \sum X_i}{(\sum X_i) - 1}$ $If I_d \geq M_c > 1: I_p = 0.5 + 0.5\left(\frac{I_d - M_c}{n - M_c}\right)$ $If I_d > M_c \geq 0: I_p = 0.5\left(\frac{I_d - 1}{M_c - 1}\right)$ $If 1 > I_d > M_u: I_p = -0.5\left(\frac{I_d - 1}{M_c - 1}\right)$ $If 1 > M_u > I_d: I_p = -0.5 + 0.5\left(\frac{I_d - M_u}{M_u}\right)$	Ip ≈ 0: Random Ip > 0: Clustered Ip < 0: Uniform	Krebs (1998); Cantillanez and Avendaño (2013); Hasyiati et al. (2023)

Notes: p_i : proportion of individuals of species *i*; S : total number of species; n : number of samples; X_i : number of individuals of species *i*; N : total number of individuals; T_i : the number of sampling trips where species *i* was present; T : the total number of sampling trips; M_u and M_c indicate the Morisita's index limits for uniform and clustered patterns, determined using chi-square values at 97.5% and 2.5% confidence levels

Environmental parameters (temperature, salinity, dissolved oxygen, pH, and current velocity), catch composition (main catch, bycatch, and discards), and ecological indices (RA, H′, E′, and D) served as active variables, while sites were treated as observations. The procedure followed standard multivariate ecological approaches as outlined by Legendre and Legendre (2012) and Jolliffe and Cadima (2016) to ensure analytical robustness and consistency in interpretation.

The first two principal components (F1 and F2) were examined to identify the dominant environmental and biological gradients within the dataset. Variables with loading values of $|r| \geq 0.5$ were considered to have strong contributions to each axis, and scatter plots of trips were used to visualize grouping patterns and associations. This analytical framework provides an integrated basis for interpreting how environmental variability, catch composition, and ecological indices interact in push-net fisheries. The subsequent section presents the empirical results derived from these analyses, beginning with catch composition and abundance patterns, followed by variations in ecological indices and their relationships with environmental parameters.

RESULTS AND DISCUSSION

Catch composition and abundance

The total catch from seven sites using push nets amounted to 115.87 kg, consisting of 59.19 kg (51.08%) of main catch, 46.73 kg (40.33%) of bycatch, and 9.95 kg (8.59%) of discards (Table 2). On average, each trip yielded 16.55 kg, comprising 8.46 kg of main catch, 6.68 kg of bycatch, and 1.42 kg of discards. Catch composition varied among sites, with the highest total catch recorded in Site 4 (25.32 kg) and the lowest in Site 6 (9.61 kg). The main catch peaked in Site 3 (11.20 kg), while bycatch was most abundant in Site 4 (16.71 kg). Discards were consistently low, ranging from 0.73 kg in Site 7 to 2.76 kg in Site 3.

A total of 36 taxa (4,157 individuals) were identified, comprising five species in the main catch, 20 in the bycatch, and 11 in the discards (Table 3). The main catch was dominated by *Metapenaeus monoceros* (35.55%) and *Penaeus merguiensis* (21.22%), both showing 100% occurrence frequency and classified as common and dominant species. Other shrimp species, such as *Mierspenaeopsis sculptilis* (0.58%), *Harpiosquilla raphidea* (0.46%), and *Macrobrachium rosenbergii* (0.05%) were common to occasional and non-dominant.

The bycatch consisted of diverse finfish families, with *Johnius carouna* (21.65%) being the most abundant and dominant species. Other frequently encountered taxa included *Bothus* sp. (1.64%), *Eleutheronema tetradactylum* (1.13%), *Drepane punctata* (0.91%), *Platycephalus indicus* (0.53%), *Hemiramphus brasiliensis* (0.22%), and *Congresox talabon* (0.17%), which were generally common but non-dominant. Discards were dominated by *Clibanarius* spp. (4.67%) and *Lagocephalus spadiceus* (2.67%), both occurring in all samples but remaining non-dominant due to their relatively low abundance. Similarly, *Tetraroge barbata* (0.29%), *Scatophagus argus* (0.12%), and *Tachypleus gigas* (0.1%) were common but non-dominant species. In contrast, other discarded species were occasional and non-dominant.

In general, species classified as common (Fi ≥ 40%) accounted for a substantial portion of the assemblage, indicating the broad habitat utilization and moderate selectivity of push nets in capturing both target and non-target species in shallow coastal waters. The presence of sensitive and non-target taxa highlights the ecological risks associated with unselective fishing gears. Notably, the catch included *T. gigas*, a species protected under Indonesian government regulation, underscoring the conservation concerns associated with incidental capture. Their observations provide empirical evidence supporting bycatch management strategies and directly contribute to the study's conservation-oriented objectives.

Table 2. Catch composition of push nets in Banyuasin coastal waters, South Sumatra, Indonesia, expressed as total weight (kg), mean weight per site, standard deviation, and percentage contribution

Sites	**Catch composition (kg)**			**Total catch (kg)**
	MC	**BC**	**DC**	
1	10.50	10.93	0.88	22.31
2	6.80	2.47	1.00	10.27
3	11.20	1.19	2.76	15.15
4	6.91	16.71	1.70	25.32
5	9.01	4.16	1.85	15.02
6	4.71	3.87	1.03	9.61
7	10.06	7.40	0.73	18.19
Total	59.19	46.73	9.95	115.87
Mean	8.46	6.68	1.42	16.55
Standard Deviation	2.37	5.50	0.73	5.84
%	51.08	40.33	8.59	100

Note: MC: Main catch, BC: Bycatch, DC: Discard. Values are expressed in kilograms (kg). Percentages are calculated relative to the total catch

Table 3. Species composition of push-net catches in the coastal waters of Banyuasin, South Sumatra, Indonesia. The table presents family, species, occurrence frequency, and relative abundance, calculated from a total of 4,157 individuals

Family	**Species**	**Occurrence Frequency (Fi)**		**Relative Abundance (RA)**	
		%	**Criteria**	**%**	**Criteria**
Main catch					
Penaeidae	*Metapenaeus monoceros* (Fabricius, 1798)	100.00	Common	35.55	Dominant
Penaeidae	*Penaeus merguiensis* De Man, 1888	100.00	Common	21.22	Dominant
Penaeidae	*Mierspenaeopsis sculptilis* (Heller, 1862)	42.86	Common	0.58	Non-dominant
Squilidae	*Harpiosquilla raphidea* (Fabricius, 1798)	57.14	Common	0.46	Non-dominant
Palaemonidae	*Macrobrachium rosenbergii* (De Man, 1879)	28.57	Occasional	0.05	Non-dominant
Bycatch					
Sciaenidae	*Johnius carouna* (Cuvier, 1830)	85.71	Common	21.65	Dominant
Sciaenidae	*Nibea soldado* (Lacepède, 1802)	14.29	Occasional	1.71	Non-dominant
Bothidae	*Bothus* sp.	71.43	Common	1.64	Non-dominant
Sillaginidae	*Sillago sihama* (Forsskål, 1775)	14.29	Occasional	1.40	Non-dominant
Polynemidae	*Eleutheronema tetradactylum* (Shaw, 1804)	57.14	Common	1.13	Non-dominant
Scatophagidae	*Drepane punctata* (Linnaeus, 1758)	42.86	Common	0.91	Non-dominant
Carangidae	*Selaroides leptolepis* (Cuvier, 1833)	28.57	Occasional	0.84	Non-dominant
Trichiuridae	*Trichiurus lepturus* Linnaeus, 1758	28.57	Occasional	0.55	Non-dominant
Platycephalidae	*Platycephalus indicus* (Linnaeus, 1758)	42.86	Common	0.53	Non-dominant
Stromateidae	*Pampus argenteus* (Euphrasen, 1788)	28.57	Occasional	0.34	Non-dominant
Spratelloididae	*Spratelloides gracilis* (Temminck & Schlegel, 1846)	14.29	Occasional	0.29	Non-dominant
Hemiramphidae	*Hemiramphus brasiliensis* (Linnaeus, 1758)	42.86	Common	0.22	Non-dominant
Muraenesocidae	*Congresox talabon* (Cuvier, 1829)	42.86	Common	0.17	Non-dominant
Plotosidae	*Plotosus lineatus* (Thunberg, 1787)	14.29	Occasional	0.17	Non-dominant
Cyprinidae	*Thryssa hamiltonii* Gray, 1835	28.57	Occasional	0.12	Non-dominant
Ambassidae	*Ambassis nalua* (Hamilton, 1822)	28.57	Occasional	0.12	Non-dominant
Stromateidae	*Parastromateus niger* (Bloch, 1795)	14.29	Occasional	0.02	Non-dominant
Mugilidae	*Moolgarda pedaraki* (Valenciennes, 1836)	14.29	Occasional	0.02	Non-dominant
Engraulidae	*Setipinna tenuifilis* (Valenciennes, 1848)	14.29	Occasional	0.02	Non-dominant
Portunidae	*Portunus pelagicus* (Linnaeus, 1758)	14.29	Occasional	0.02	Non-dominant
Discards					
Diogenidae	*Clibanarius* spp.	100.00	Common	4.67	Non-dominant
Tetraodontidae	*Lagocephalus spadiceus* (Richardson, 1845)	100.00	Common	2.67	Non-dominant
Portunidae	*Charybdis hellerii* (A.Milne-Edwards, 1867)	14.29	Occasional	1.80	Non-dominant
Thalassinidae	*Thalassina anomala* (Herbst, 1804)	14.29	Occasional	0.38	Non-dominant
Tetrarogidae	*Tetraroge barbata* (Cuvier, 1829)	57.14	Common	0.29	Non-dominant
Scatophagidae	*Scatophagus argus* (Linnaeus, 1766)	42.86	Common	0.12	Non-dominant
Limulidae	*Tachypleus gigas* (O.F.Müller, 1785)	57.14	Common	0.10	Non-dominant
Nereididae	*Nereis* sp.	14.29	Occasional	0.10	Non-dominant
Triacanthidae	*Triacanthus nieuhofii* Bleeker, 1852	14.29	Occasional	0.07	Non-dominant
Tetraodontidae	*Dichotomyctere nigroviridis* (Marion de Procé, 1822)	28.57	Occasional	0.05	Non-dominant
Gobiidae	*Periophthalmus chrysospilos* Bleeker, 1853	14.29	Occasional	0.02	Non-dominant

Note: Species are categorized as common if $F_i \geq 40\%$, occasional if $10\% \leq F_i < 40\%$, and rare if $F_i < 10\%$. Species are considered dominant if $RA \geq 5\%$, and non-dominant if $RA < 5\%$

Ecological indices

Ecological indices for the catch assemblage were calculated using the Shannon-Wiener diversity index (H′), Pielou's evenness index (E), Simpson's dominance index (D), and the Standardized Morisita Index (I_p), providing insights into species diversity, balance, and spatial distribution (Table 4).

Values of H′ ranged from 0.61 to 2.08, reflecting low to moderate diversity across sites. The lowest diversity was recorded in Site 3 (H′ = 0.61), whereas the highest was observed in Site 1 (H' = 2.08). Evenness was generally low to moderate (E = 0.17-0.58), suggesting that the catch assemblage was unevenly distributed and dominated by a few abundant taxa. Site 3 exhibited the most uneven distribution (E = 0.17), while Site 1 had the most balanced catch (E = 0.58).

The variability in diversity and evenness among trips may reflect short-term environmental fluctuations, particularly changes in salinity and dissolved oxygen, which affect species composition and stress tolerance. Lower diversity values were associated with higher dominance in Site 3, suggesting ecological stress or selective capture under suboptimal environmental conditions.

Dominance values (D = 0.17-0.76) showed considerable variation across trips. Site 3 (D = 0.76) was largely dominated by one or two taxa, whereas Sites 1, 5, and 7 exhibited relatively low dominance (<0.25), reflecting a more balanced species composition. This pattern suggests that transient aggregations of target species or reduced availability of other demersal taxa, possibly driven by short-term environmental changes, influenced some trips.

The Standardized Morisita's index (Ip = 0.55-0.87) consistently indicated clustered spatial distributions across all fishing trips, demonstrating that species were aggregated rather than randomly or uniformly distributed within the fishing area. This pattern aligns with the commonly reported patchiness of benthic habitats in shallow estuarine systems, where demersal species tend to form localized groups in response to microhabitat structure and resource availability. The presence of clustered aggregations also implies that localized concentrations of species may be more susceptible to concentrated fishing effort, which is relevant to understanding the ecological implications of push-net operations.

Overall, the catch assemblage showed moderate diversity, low evenness, and variable dominance, with clustered spatial patterns observed across all sites. These findings highlight the ecological concern that this gear type may disproportionately impact localized populations. These patterns of spatial clustering and low evenness support the study's aim of assessing the ecological implications of push-net fishing on demersal biodiversity and bycatch.

Environmental conditions

Environmental parameters measured during the sampling sites showed moderate spatial and temporal variation among sites (Table 5). Water temperature ranged from 27.30 to 29.40°C (mean: 28.64±0.77°C), indicative of the stable thermal regime typical of tropical coastal waters. Such narrow temperature fluctuations suggest minimal thermal stress on benthic and demersal assemblages during the sampling.

Salinity showed a wider range (20.63-28.70 ppt; mean: 26.83±2.82 ppt), likely driven by freshwater input from nearby estuaries and tidal mixing. This variation reflects a moderate estuarine gradient, affecting species distribution —particularly euryhaline taxa such as penaeid shrimps and sciaenid fishes that tolerate intermediate salinity.

The pH values ranged from 6.30 to 7.53 (mean 6.99±0.48) and remained close to neutral, within the optimal range for most estuarine organisms, supporting balanced physiological processes. DO concentrations ranged between 5.18 and 7.53 mg/L (mean: 6.35±0.85 mg/L), reflecting well-oxygenated conditions suitable for demersal fishes and crustaceans. Slightly higher DO levels at some sites coincided with lower temperatures and increased water movement, suggesting mild vertical mixing. Water depth ranged from 1.03 to 4.11 m (mean: 1.86±1.14 m), indicating that sampling encompassed the shallow nearshore zones relevant to the habitat distribution of local fish and shrimp.

Table 4. Ecological indices of push net catches in Banyuasin coastal waters, South Sumatra, Indonesia

Sites	Diversity index (H')		Evenness index (E)		Dominance index (D)		Standardized Morisita index (I_p)	
	Value	Category	Value	Value	Category	Value	Category	Value
1	2.080	Moderate	0.580	Moderate	0.217	Low	0.591	Clustered
2	1.294	Moderate	0.361	Low	0.423	Moderate	0.686	Clustered
3	0.606	Low	0.169	Low	0.760	High	0.869	Clustered
4	1.049	Moderate	0.293	Low	0.596	Moderate	0.784	Clustered
5	2.049	Moderate	0.572	Moderate	0.174	Low	0.548	Clustered
6	1.391	Moderate	0.388	Low	0.346	Moderate	0.641	Clustered
7	1.785	Moderate	0.498	Low	0.220	Low	0.561	Clustered

Note: Diversity was classified as High ($H' > 3.0$), Moderate ($1.0 < H' \leq 3.0$), or Low ($H' \leq 1.0$). Evenness was classified as Stable ($0.75 < E \leq 1.0$), Moderate ($0.50 < E \leq 0.75$), or Low ($E \leq 0.50$). Dominance was classified as High ($0.60 < D \leq 1.0$), Moderate ($0.30 < D \leq 0.60$), or Low ($D \leq 0.30$). Morisita's index (I_p) values close to 0 indicate random distribution, $I_p > 0$ indicates clustered distribution, and $I_p < 0$ indicates uniform distribution

Table 5. Environmental parameters recorded across seven sampling sites in Banyuasin coastal waters, Indonesia, including temperature, pH, dissolved oxygen (DO), salinity, current velocity, and depth. Values represent site-averaged summaries, with minimum, maximum, mean, and standard deviation (SD) describing variability among sites

Sites	Temperature (°C)	pH	DO (mg/L)	Salinity (ppt)	Current velocity (m/s)	Depth (m)
1	29.35	7.33	5.18	28.55	0.33	1.40
2	28.13	7.53	7.53	20.63	0.30	1.33
3	29.40	7.11	5.98	27.88	0.33	2.64
4	28.50	7.29	5.98	27.65	0.22	4.11
5	28.53	6.30	6.78	26.58	0.24	1.20
6	27.30	6.37	7.24	27.80	0.22	1.03
7	29.30	7.00	5.75	28.70	0.19	1.25
Max	29.40	7.53	7.53	28.70	0.33	4.11
Min	27.30	6.30	5.18	20.63	0.19	1.03
Mean	28.64	6.99	6.35	26.83	0.26	1.86
SD	0.77	0.48	0.85	2.82	0.06	1.14

Current velocity was consistently low (0.19-0.33 m/s; mean = 0.26 m/s), reflecting weak hydrodynamic conditions that favor sediment deposition and nutrient accumulation in nearshore areas. These conditions can enhance benthic productivity but may also promote fine sediment settlement, potentially altering habitat structure for some species. In general, the measured parameters indicate that the Banyuasin coastal ecosystem provided suitable conditions to support diverse aquatic assemblages. However, variability in salinity and DO likely influenced differences in catch composition and species distribution among trips, aligning with the observed patterns in ecological indices.

Linkages between catch composition, ecological indices, and environmental parameters

The PCA biplot (Figure 3) revealed multivariate relationships among catch composition metrics, ecological indices, and environmental parameters at the site level. The first two PCA axes explained 68.16% of the total variance (F1 = 43.48%, F2 = 24.68%), indicating that most of the variability in the dataset is structured along two primary gradients. Site groupings were interpreted based on their dominant factor (highest squared cosine values) and the direction of their factor scores on the first two axes.

Along Axis 1 (F1), dominance index, Morisita index, main catch, relative abundance, current velocity, and pH showed positive loadings. Sites 3 and 4 exhibited strong positive factor scores and high representation on F1, indicating that these locations are associated with higher dominance and main catch proportions under stronger hydrodynamic conditions. In contrast, Sites 5 and 7, aligned with evenness (E) and Shannon diversity (H'), were positioned on the negative side of F1. This positioning suggests comparatively lower dominance, reduced main catch, and weaker hydrodynamic influence.

On Axis 2 (F2), both DO and salinity showed positive loadings and were aligned with Sites 2 and 6, which exhibited strong representation on this axis. This pattern indicates that these sites are associated with more oxygen-rich and saline conditions. Conversely, temperature, bycatch, and discards showed negative loading on F2 and were primarily associated with Site 1, which was positioned on the negative side of this axis. This positioning suggests that warmer conditions, along with relatively lower DO and salinity, are associated with higher proportions of bycatch and discards.

Overall, the PCA indicates that variation in catch composition and ecological indices is structured by environmental gradients, particularly temperature, DO, salinity, current velocity, and pH. The observed site groupings reflect shared multivariate associations derived from the ordination structure rather than discrete species community classifications or results of a formal clustering procedure. These patterns suggest that environmental conditions and fishing practices jointly influence catch outcomes and provide a basis for adaptive management and bycatch mitigation strategies.

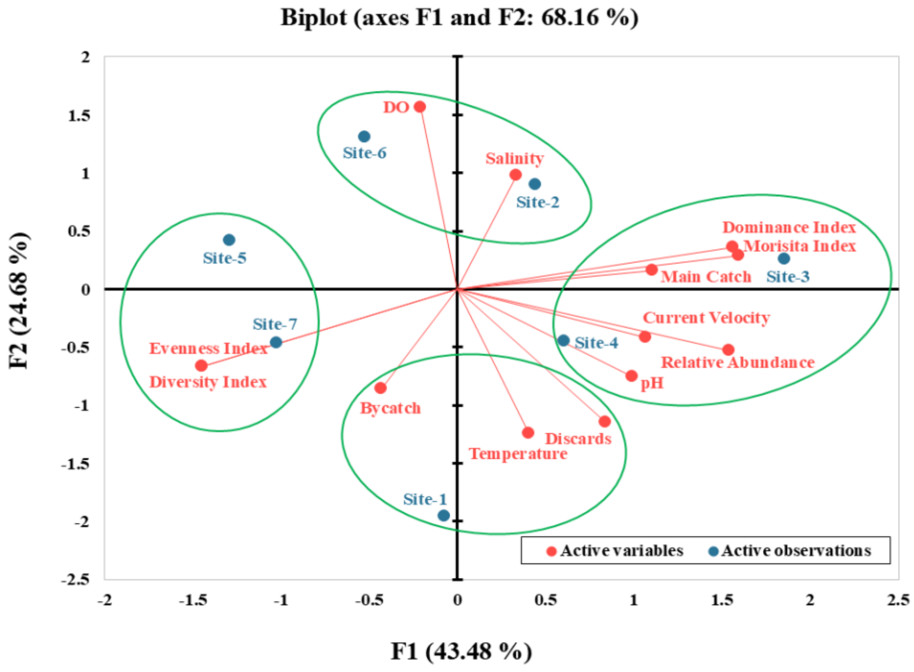

Figure 3. PCA biplot showing relationships among environmental variables (temperature, DO, salinity, current velocity, and pH), catch composition metrics (main catch, bycatch, and discards), and ecological indices across seven sites in Banyuasin coastal waters. Red vectors represent active variables, and blue points represent sites (sampling units). The first two axes (F1 and F2) explain 68.16% of the variance. The green ellipses group sites according to their dominant factor (highest squared cosine values) and the direction of their factor scores on the first two axes, reflecting shared multivariate associations with the active variables rather than results of a formal cluster analysis

Discussion

This study provides new insights into catch composition and demersal fish biodiversity in relation to environmental gradients and fishing impacts in Banyuasin coastal waters, addressing a knowledge gap by linking ecological parameters with bycatch patterns in push-net fisheries. While the gear effectively captured target species (51.08% of total catch), substantial bycatch (40.33%) indicates moderate selectivity and potential ecological risks, particularly for marine protected taxa such as *T. gigas* (Fauziyah et al. 2019b, 2021). These findings highlight how unselective gear can disrupt trophic balance, reduce functional diversity, and threaten vulnerable benthic organisms—patterns consistent with broader evidence that non-selective fishing contributes to biodiversity loss in tropical coastal ecosystems (Ramdhani and Jhonnerie 2019).

From an ecological perspective, the high proportion of bycatch and discards indicates that push-net operations alter species composition not only through physical removal but also by depleting key functional groups such as predators, scavengers, and bioturbators. The loss of these groups can diminish benthic productivity, disrupt nutrient cycling, and weaken sediment stability, thereby intensifying habitat degradation over time (Duque et al. 2020; Park et al. 2024). The recurrent capture of *T. gigas* further heightens conservation concerns, as this species plays a unique ecological role in benthic ecosystems and is legally protected under Indonesian regulations. Its repeated occurrence in catches suggests inadequate spatial exclusion zones or limited enforcement of existing protection measures.

Relative abundance (RA) reflects species dominance within push-net catches, with high RA values indicating either high population density or greater susceptibility to capture due to habitat and behavioral traits. Moderate RA values tend to support community stability, whereas low RA may indicate ecological stress or imbalance. Accordingly, RA serves as a practical ecological indicator for assessing fishery performance, sustainability, and gear selectivity (Diaz et al. 2021; OECD 2025). Species exhibiting moderate RA are often generalists that tolerate variable environmental conditions, whereas highly dominant taxa may signal opportunistic behavior in disturbed habitats, further illustrating the link between fishing pressure and community restructuring.

Variation in ecological indices (H′, E, D, Ip) reflected the combined influence of dissolved oxygen, salinity, and current velocity on demersal assemblages (Duque et al. 2020; Luo et al. 2023; Lai et al. 2024). Moderate diversity and evenness indicate that push-net fisheries shape assemblages that are neither severely degraded nor fully balanced, indicating partial resilience under concurrent environmental and fishing pressures. This trend is consistent with findings from tropical coastal ecosystems, where hydrological fluctuations and localized anthropogenic disturbances drive spatial shifts in community composition and functional diversity (Freitas and Araújo 2025). The negative association of H′ and E with dominance, together with their positive relationship to DO, highlights oxygen availability as a key physiological regulator influencing metabolic performance, foraging dynamics, and stress tolerance in demersal species (Luo et al. 2023; Lei et al. 2025). Moreover, the relatively low dominance index implies that no single taxon monopolized the assemblage, suggesting a partially resilient community capable of maintaining ecological stability despite moderate exploitation and environmental variability (Park et al. 2024).

Physiological and behavioral mechanisms likely underpin these observed patterns. Elevated dissolved oxygen enhances aerobic metabolism, locomotor activity, and foraging efficiency in demersal fishes, facilitating resource partitioning and species coexistence that contribute to higher diversity and evenness (Nodo et al. 2023; Lai et al. 2024). In contrast, increased salinity and stronger current velocity can impose osmotic and energetic stress, potentially reducing prey availability and favoring dominance by tolerant or opportunistic species adapted to suboptimal conditions (Cardoso et al. 2023). This mechanistic perspective provides a comprehensive ecological interpretation beyond simple statistical associations, offering deeper causal insight into how environmental gradients shape assemblage structure under fishing pressure.

Catch composition and biodiversity are shaped by multiple interacting factors, including environmental variability, habitat characteristics, and fishing gear selectivity (Luo et al. 2023; Freitas and Araújo 2025). Local fishers' observations corroborate these findings, noting reduced catches during October-November due to non-peak fishing seasons and adverse hydrodynamic conditions (Fisheries Service of Banyuasin Regency 2020). Environmental factors such as wave exposure, current intensity, and estuarine mixing contributed to lower catch efficiency, consistent with findings from tropical fisheries, where seasonal and hydrodynamic variability drive short-term catch fluctuations (Peng et al. 2023). These results highlight the sensitivity of demersal fish biodiversity and catch composition to both environmental variability and fishing pressure, underscoring the importance of adaptive management in maintaining ecosystem productivity and resilience.

Building upon these ecological interactions, the spatial distribution of the assemblages, as indicated by the standardized Morisita's index, exhibited a predominantly clustered rather than uniform pattern, suggesting aggregation around favorable habitats such as soft-sediment areas and mangrove zones. This spatial clustering likely reflects heterogeneous resource availability and the emergence of fishing hotspots that are repeatedly targeted by push nets, thereby intensifying local depletion. The observed pattern is consistent with PCA results, reinforcing the interpretation of habitat-driven aggregation. The confinement of individuals within limited habitat patches underscores the vulnerability of localized populations to recurrent exploitation, emphasizing the importance of spatially explicit and habitat-sensitive management strategies to sustain ecological integrity and fishery productivity (Cardoso et al. 2023; Ventura et al. 2024).

These spatial patterns are further shaped by the prevailing environmental conditions, which determine habitat suitability and influence species' physiological responses. Average environmental conditions remained within the optimal range for aquatic life, as defined by Ministerial Decree No. 51/2004. However, moderate fluctuations in salinity and DO were sufficient to influence community composition, likely through effects on osmoregulation, prey distribution, and larval dispersal (Baek et al. 2020). Such interactions reinforce the need to monitor short-term environmental variability when assessing demersal assemblage structure and fishery sustainability.

These spatial and environmental patterns collectively highlight the complex interactions shaping demersal fish assemblages in dynamic coastal habitats**.** Building on these insights, this study demonstrates the methodological value of integrating PCA with field-based ecological observations to disentangle the relationships between environmental gradients and fish assemblage composition. The alignment of discard catch, dominance index, and relative abundance with ecological pressure is consistent with recent findings that emphasize the combined effects of environmental stressors and fishing intensity on discarding behavior and benthic assemblages (Barnes et al. 2022). Likewise, the observed association between dissolved oxygen and species aggregation reinforces broader evidence that water quality parameters play a pivotal role in structuring demersal communities (Duque et al. 2020). By explicitly linking environmental conditions to catch composition and bycatch patterns, the results contribute to broader ecological understanding of how gear selectivity and habitat variability jointly shape coastal biodiversity.

From a management perspective, the findings provide clear, evidence-based guidance for improving the sustainability of push-net fisheries in Banyuasin. The consistently clustered spatial distribution of catches and the recurrent capture of horseshoe crab indicate that certain habitat patches function as ecological hotspots vulnerable to repeated exploitation. Accordingly, spatial management should consider designating these areas as conservation zones rather than full closures, allowing focused protection of sensitive taxa while remaining feasible for local authorities. Gear-related measures should also be directly informed by catch patterns, and trialing larger mesh sizes and bycatch-reduction devices is likely to reduce the capture of dominant small-bodied bycatch species that heavily contributed to discards. In addition, sites showing low H’ and E values can serve as indicators of ecological stress and should be considered for seasonal restrictions to prevent further depletion. Integrating continuous monitoring of ecological indices and environmental parameters within a co-management framework aligns with the approach advocated by Boesch and Paul (2001) and Rice (2003), who emphasize the use of measurable ecosystem indicators as decision-support tools for maintaining productivity and resilience in coastal systems. Collectively, these strategies strengthen the ecological and practical foundation for adaptive fisheries management and biodiversity conservation in the region.

While these insights contribute to a stronger scientific and management foundation, several limitations must be acknowledged. Sampling was conducted over a restricted temporal window and spatial scope, which may not fully capture seasonal or interannual variability. In addition, environmental parameters were measured as point observations during fishing operations and therefore represent snapshots of conditions in a highly dynamic shallow coastal system, where variables such as temperature, dissolved oxygen, and pH can vary substantially over short temporal scales. Furthermore, catch-based ecological indices were calculated without haul-level standardization by towing duration or trawled distance, potentially biasing results toward sites with greater effective fishing effort. Although fishing operations were conducted with consistent gear configurations, vessel types, and approximate towing speeds, this approach may not fully account for variability in swept area or effective effort. Moreover, data aggregation at the site level, while necessary to avoid pseudo-replication among stations within the same fishing operation, may reduce fine-scale spatial resolution and mask within-site heterogeneity. Additionally, the correlation-based approach cannot establish causation, highlighting the need for further experimental or modeling studies to clarify underlying mechanisms. Future research should broaden spatial coverage, incorporate multi-seasonal and higher temporal-resolution environmental datasets, apply standardized effort metrics or model-based approaches (e.g., offsets in GLMMs or rarefaction techniques), and consider socio-economic dimensions, including the livelihoods and adaptive strategies of push-net fishers, to enable more comprehensive, evidence-based management.

In conclusion, push-net fisheries in the Banyuasin coastal waters exhibit moderate selectivity but result in substantial bycatch, altering the structure and functioning of demersal assemblages. Dissolved oxygen, salinity, and current velocity are key environmental gradients shaping species composition and biodiversity. These findings underscore the need for adaptive management strategies, including gear modifications, spatial zoning, seasonal closures, and participatory monitoring, to balance fishery productivity with biodiversity conservation. Despite these insights, the study has limitations due to restricted temporal and spatial coverage and the correlative nature of analyses. Future research should expand spatial and multi-seasonal sampling, investigate ecological mechanisms through experimental or modeling approaches, and incorporate socio-economic factors to support evidence-based, ecosystem-oriented management.

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