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Habitat Heterogeneity Influences Intertidal Fish Biodiversity and Ecological Functions in Chabahar County, Sea of Oman

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ABSTRACT

Aims: This study examines the biodiversity and ecological importance of intertidal fish communities across three distinct habitats in Chabahar County, Sea of Oman.
Materials & Methods: Sampling was conducted in the intertidal zone at three stations in Chabahar during low tide using hand nets and waiting nets in summer/June 2023.
Findings: Sampling at Darya-Bozorg, Tis Fishing, and Tis Recreational Beaches revealed 22 species from 9 families, with Blenniidae and Gobiidae dominating the permanent resident community. Darya-Bozorg's supratidal pools, characterized by vertical walls and wave exposure, support blennies with specialized morphological adaptations for clinging and aerial respiration, while Tis Fishing Beach's sandy and gravel pools favor gobiid species that remain mostly submerged. Tis Recreational Beach, with large boulder formations, supports fewer cryptic species but provides habitat for transient juveniles of families such as Epinephelidae, Apogonidae, and Pomacentridae. Transient species utilize intertidal zones as nurseries and feeding grounds, linking coastal ecosystems and contributing to trophic dynamics.
Conclusion: Ecological roles of resident and transient fishes include regulating invertebrate populations, nutrient cycling, and maintaining reef community structure. Habitat heterogeneity, substrate type, and microhabitat availability strongly influence species composition and abundance. The findings underscore the ecological significance of intertidal fish assemblages for biodiversity conservation, fisheries, and the aquarium trade. Given the distinct ichthyofaunal assemblages and habitat characteristics among the studied sites, habitat-specific management and protection strategies are essential. This research provides a baseline for understanding intertidal fish diversity in Chabahar, an area facing increasing industrialization pressures, and highlights the need to preserve diverse intertidal habitats.

Keywords: Biodiversity; Blenniidae; Ecological Conservation; Gobiidae; Habitat Adaptation; Sea of Oman.

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Introduction

Macrophytes and invertebrates in intertidal ecology research have historically overshadowed tidepool fishes. Yet, they exhibit remarkable biodiversity and perform essential ecological functions, including mediating energy transfer between marine and terrestrial ecosystems. These habitats face significant threats: climate-driven sea-level rise results in coastal squeeze, endangering specialist species, while anthropogenic pressures contribute to the degradation of these critical zones [1]. The intertidal zone is characterized by a diverse array of organisms adapted to fluctuating conditions, such as immersion in water, exposure to air, and temperature changes, making it a biodiversity hotspot [2]. Within this zone, a rich assemblage of prey species, including crustaceans, mollusks, and small fishes, thrives. However, the predation pressure on these rocky intertidal fish communities is predominantly exerted by large subtidal predators, such as *Scorpaenichthys marmoratus* (Jordaniidae), *Enophrys bison* (Cottidae), and *Ophiodon elongatus* (Hexagrammidae) [3,4]. Additionally, intertidal habitats provide vital resources, including food through shellfish harvesting, recreational opportunities, and tourism, all of which contribute to local economies [5]. Due to their sensitivity to environmental changes, intertidal communities serve as important indicators of the impacts of climate change, pollution, and ocean acidification [6].

Fishes inhabiting the intertidal zone can be categorized as either residents, which spend their entire life within this habitat, or transients, which occupy it only for part of their life cycle [3]. Many fish species utilize intertidal areas as safe nursery grounds, where juveniles benefit from reduced predation pressure and abundant food sources [7].

In southern Iran, intertidal fish communities have been extensively studied, particularly in mudflats and mangroves, which are primarily inhabited by three resident mudskipper species [8]. Species in the Gobiidae and Blenniidae families are permanent tidepool residents. In the rocky intertidal habitats of the Persian Gulf and Sea of Oman, several blenniid genera-including *Alticus, Antennablennius, Entomacrodus, Istiblennius, Omobranchus, Parablennius*, and *Salarias*-have been documented [9-14]. Similarly, gobiid genera such as *Bathygobius, Coryogalops, Cryptocentroides, Favonigobius*, and *Istigobius* are also reported in these habitats [9, 10, 15].

Diversity indices indicate that the Persian Gulf generally hosts lower fish diversity than the Sea of Oman, with the notable exception of Qeshm Island, which exhibits higher diversity due to its proximity to the open ocean and enhanced ecological connectivity with the Sea of Oman. This contrast is attributed to extreme seasonal temperature fluctuations and elevated salinity levels in the Persian Gulf, which limit faunal diversity [9].

The composition of fish communities in intertidal rockpools is influenced by various factors, including rockpool characteristics (size, depth, complexity, and sea exposure), environmental conditions (volume, intertidal height, and substrate complexity), habitat features (microhabitats and species-specific preferences), and physicochemical factors (temperature, salinity, and dissolved oxygen, which vary seasonally). Additionally, the morphological and behavioral adaptations of resident fishes are crucial to their survival in these dynamic environments [10]. For

instance, the distinct shape of the urohyal bone in resident species such as *Istigobius ornatus* and *Bathygobius meggitti* is linked to their feeding regimes [16]. This study aims to 1) examine the intertidal ichthyofauna from three different habitats along the Chabahar coast and 2) assess their ecological values for the conservation of natural resources.

Materials & Methods

In June 2023, sampling was conducted at three stations in Chabahar city. Sampling from the intertidal zone was carried out during low tide using hand nets and waiting nets. The waiting net was deployed during low tide and retrieved at high tide. The sampled stations include Darya-Bozorg Beach (25°16'37.8"N 60°40'10.3" E) (Figures 1, 2), Tis Fishing Beach (25°21'00.7"N 60°36'00.0"E) (Figures 1, 3), and Tis Recreational Beach (25°21'58.3"N 60°36'28.8" E) (Figures 1, 4). The samples were transferred and deposited in the Zoological Museum of the University of Sistan and Baluchestan (ZMUSB). All specimens were identified using taxonomic keys relevant to the region [17–20], and individuals ≈2 cm were classified and counted as adults [9]. The three studied sampling areas are carefully examined and described. All statistical analyses have been conducted by PAST version 4.16c [21].

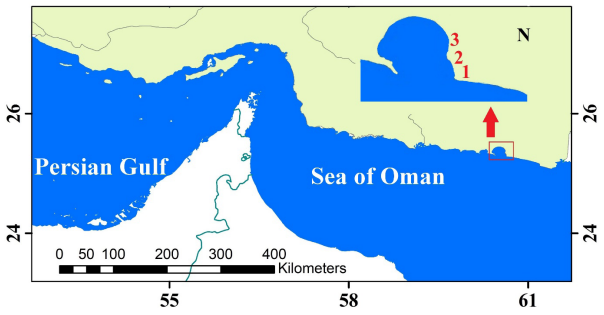

Figure 1) The sampled stations consist of Darya-Bozorg Beach (1), Tis Fishing Beach (2), and Tis Recreational Beach (3).

Figure 2) Darya-Bozorg Beach features vertical walls, above which lies the supratidal zone that is never submerged by the tide.

Figure 3) Tis Fishing Beach has intertidal pools made up of gravel and sand, with no large boulders.

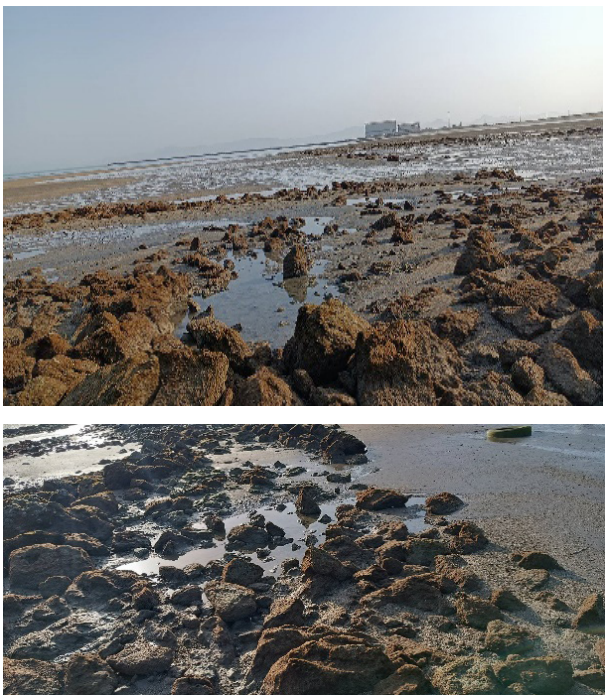

Figure 4) Tis Recreational Beach features large boulders that create intertidal pools during low tide, where fish wait for the tide to rise again.

Findings

Three distinct sampling stations were delineated based on systematic field observations and standardized ecological assessments of habitat heterogeneity. The substrate type and slope of the stations vary, and they can be considered different habitats for fish. Darya-Bozorg Beach (Figure 2) has vertical walls, above which lies the supratidal zone. Although the tide never submerges this area, these supratidal pools are constantly exposed to sea waves and remain full of water, providing a suitable environment for fish. Particular fish species have evolved specialized morphological adaptations that enable adhesion to vertical substrates and sustained aerobic respiration despite persistent hydration from wave-induced hydrodynamic forces.

Additionally, intertidal ecosystems universally contain crevices and boreholes that serve as vital cryptic microhabitats, providing shelter for small benthic fish populations within these dynamic environments. Supratidal pools (high intertidal zone) at the Darya-Bozorg exhibit smoother and more polished substrate textures compared to intertidal pools at the Tis Fishing Beach. At Tis Fishing Beach (Figure 3), the intertidal pools consist of gravel and sand, with no large boulders. The pool areas range from approximately 1 m^2 with a depth of about 10 cm to large pools around 50 m^2 in area and 50 cm deep. At Tis Recreational Beach (Figure 4), large boulders form intertidal pools during low tide, where fish wait for the tide to rise again. The bottom of these pools also contains medium-sized pebbles. The intertidal zone at this station has a gentle slope.

Ichthyofaunal sampling in the coastal intertidal zone of Darya-Bozorg Beach yielded 223 specimens representing eight teleost species across two families. Blenniidae (*Istiblennius pox*, n=146; *Antennablennius bifilum*, n=54;

Alticus kirkii, n=11; *Istiblennius lineatus*, n=4; *Istiblennius edentulus*, n=2; *Omobranchus mekranensis*, n=2) exhibited the highest relative abundance, followed by Gobiidae (*Bathygobius meggitti*, n=3). Taxonomic composition and numerical distributions are detailed in supplementary appendices (Table 1; Figure 5). Ichthyofaunal sampling conducted along the Tis Fishing Beach yielded 563 specimens representing 15 teleost species across eight families. Gobiidae (*Istigobius ornatus*, n=411; *Bathygobius meggitti*, n=58; *Cryptocentroides arabicus*, n=5; *Callogobius* sp., n=4) and Blenniidae (*Antennablennius variopunctatus*, n=24; *Antennablennius bifilum*, n=2; *Istiblennius pox*, n=3; *Istiblennius edentulus*, n=2) demonstrated the highest relative abundance. Subordinate taxa included representatives from Apogonidae, Pomacentridae, Terapontidae, Mugilidae, Lutjanidae, and Labridae, with complete systematic enumeration provided in supplementary datasets (Table 1; Figure 6).

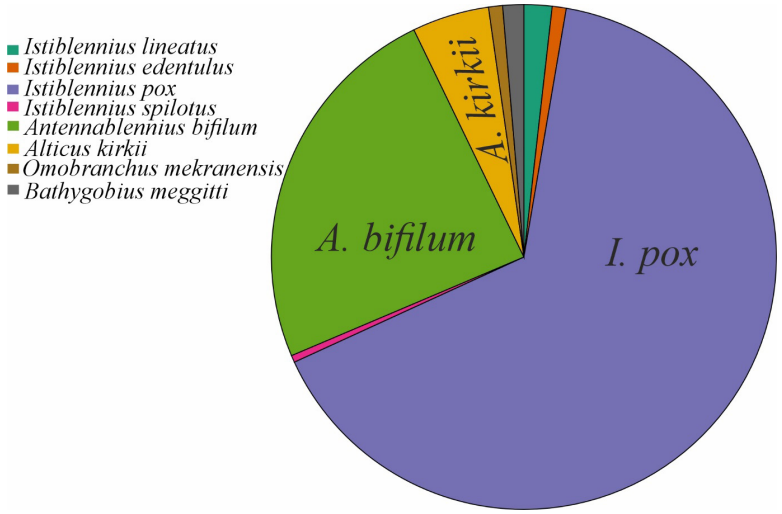

Figure 5) Intertidal ichthyofauna of Darya-Bozorg yielded 223 specimens, including *Istiblennius pox*, *Antennablennius bifilum*, and *Alticus kirkii*.

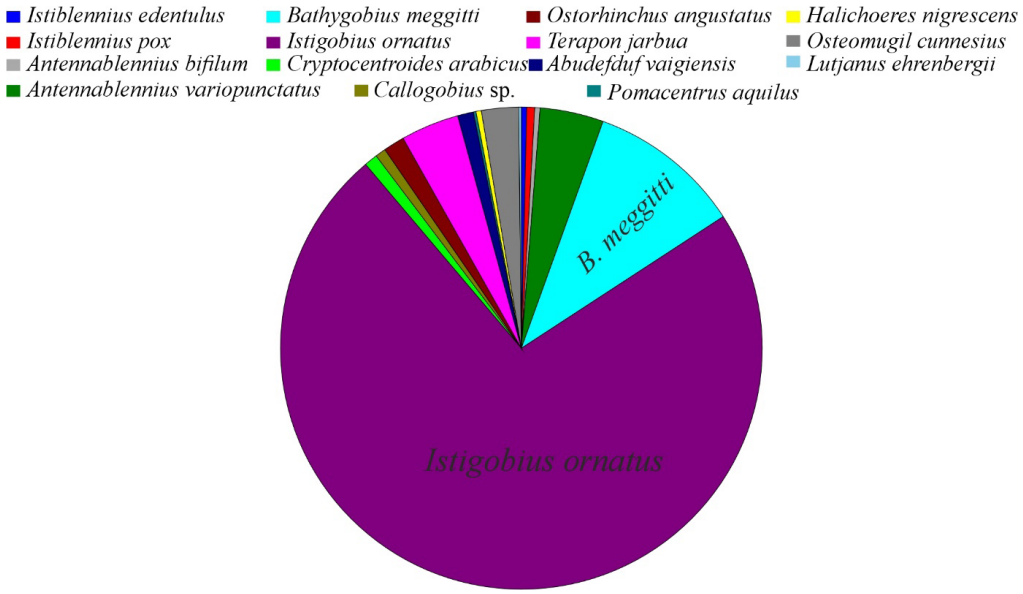

Figure 6) Tis Fishing Beach yielded 563 specimens, including *Istigobius ornatus*, *Bathygobius meggitti*, *Antennablennius variopunctatus*, and *Terapon jarbua*.

Sampling in the intertidal zone at Tis Recreational Beach yielded 24 specimens representing six teleost species across five families. Apogonidae (*Apogonichthyoides taeniatus*, n=9; *Ostorhinchus angustatus*, n=1) and Gobiidae (*Istigobius ornatus*, n=7) constituted the dominant taxa by abundance. Subsidiary captures comprised representatives of Epinephelidae, Terapontidae, and Pomacentridae, with complete taxonomic and numerical data tabulated in supplementary materials (Table 1; Figure 7).

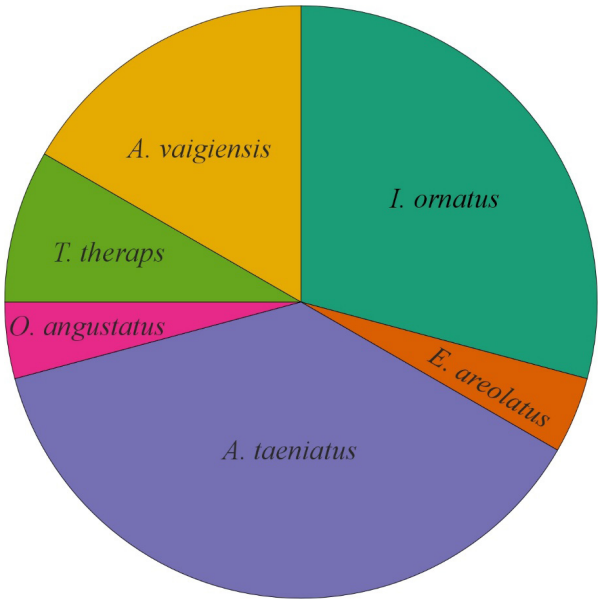

Figure 7) Tis Recreational Beach intertidal zone yielded 24 specimens, including *Apogonichthyoides taeniatus*, *Istigobius ornatus*, *Abudefduf vaigiensis, Terapon theraps, Epinephelus areolatus,* and *Ostorhinchus angustatus.*

Ichthyofaunal sampling across three coastal stations yielded 810 specimens representing 22 teleost species within nine families. Gobiidae (4 species; n = 488) dominated the assemblage in relative abundance, while Blenniidae (8 species; n = 251) exhibited the most species richness, reflecting divergent ecological niche specialization within the intertidal zone (Figure 8).

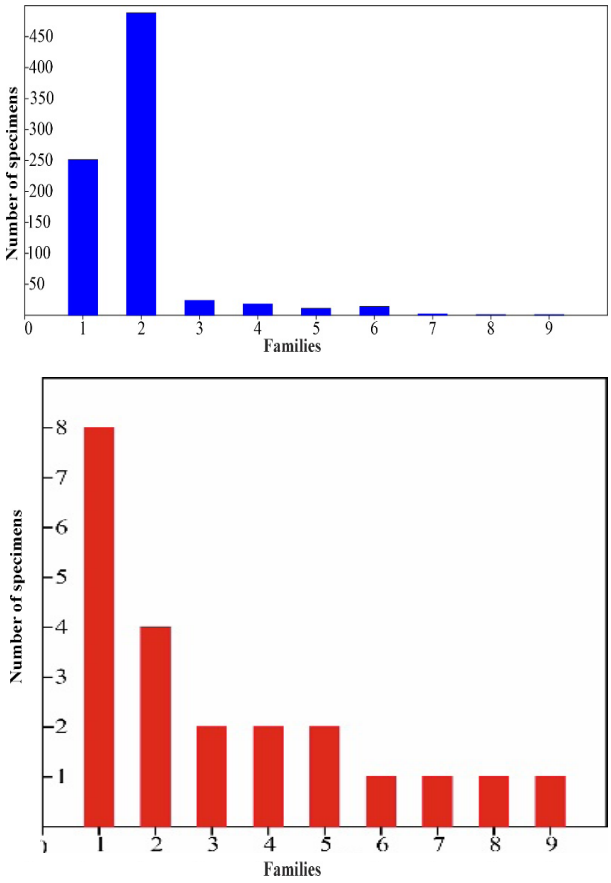

Figure 8) The blue columns represent the number of specimens in each family, while the red columns indicate the number of species in each family. The numbers on the x-axis correspond to 1) Blenniidae, 2) Gobiidae, 3) Terapontidae, 4) Apogonidae, 5) Pomacentridae, 6) Mugilidae, 7) Labridae, 8) Lutjanidae, 9) Epinephelidae. Blenniidae displayed the highest species richness, whereas Gobiidae dominated the assemblage in relative abundance.

Discussion

Intertidal fish in the Sea of Oman have evolved a diverse array of adaptations that enable them to survive and thrive in the fluctuating conditions of their habitat. These adaptations encompass specialized body shapes, modified fins, air-breathing capabilities, metabolic adjustments, and distinct behavioral strategies that help them cope with environmental changes. The diversity and composition of intertidal fish species in this region reflect these unique adaptations [9, 22, 23].

Fish species residing in intertidal rockpools

Table 1) Taxonomic composition (family-level) and numerical abundance of ichthyofauna across sampled coastal stations

Species	Family	Darya-Bozorg	Tis Fishing Beach	Tis Recreational Beach
Istiblennius lineatus	Blenniidae	4	0	0
Istiblennius edentulus	Blenniidae	2	2	0
Istiblennius pox	Blenniidae	146	3	0
Istiblennius spilotus	Blenniidae	1	0	0
Antennablennius bifilum	Blenniidae	54	2	0
Alticus kirkii	Blenniidae	11	0	0
Omobranchus mekranensis	Blenniidae	2	0	0
Antennablennius variopunctatus	Blenniidae	0	24	0
Bathygobius meggitti	Gobiidae	3	58	0
Istigobius ornatus	Gobiidae	0	411	7
Cryptocentroides arabicus	Gobiidae	0	5	0
Callogobius sp.	Gobiidae	0	4	0
Epinephelus areolatus	Epinephelidae	0	0	1
Apogonichthyoides taeniatus	Apogonidae	0	0	9
Ostorhinchus angustatus	Apogonidae	0	8	1
Terapon jarbua	Terapontidae	0	22	0
Terapon theraps	Terapontidae	0	0	2
Abudefduf vaigiensis	Pomacentridae	0	6	4
Pomacentrus aquilus	Pomacentridae	0	1	0
Halichoeres nigrescens	Labridae	0	2	0
Osteomugil cunnesius	Mugilidae	0	14	0
Lutjanus ehrenbergii	Lutjanidae	0	1	0

exhibit strong habitat associations. For example, larger rockpools with minimal biological cover and higher salinity tend to support greater fish abundance and species richness [24]. Our findings align with prior ichthyological studies that identify Blenniidae and Gobiidae as core components of the ichthyofauna within the intertidal ecosystems of the Persian Gulf and Sea of Oman [9, 10]. However, at Darya-Bozorg Beach, Blenniidae emerged as the dominant taxon, while Gobiidae predominated at Tis Fishing Beach (Figure 8; Table 1).

Darya-Bozorg Beach features vertical walls with supratidal zones that contain pools, which, although not submerged by tides, remain filled by sea waves. These pools provide an environment for fish that are adapted to cling to vertical substrates and to maintain aerobic respiration under

wave-exposed conditions. Additionally, the intertidal ecosystem includes crevices and boreholes that serve as critical shelters for small benthic and demersal fish. Conversely, the supratidal pools at Darya-Bozorg display smoother, more refined substrate textures than the intertidal pools at Tis Fishing Beach. Species such as *Alticus* (e.g., *A. kirki*) are well adapted to these conditions, using their pelvic suction discs to cling to rocky surfaces, resist waves, and maintain their position on vertical substrates. They demonstrate aerial locomotion through jumping and rock-skipping and can survive prolonged emersion via cutaneous respiration and moisture retention [22, 25]. *Antennablennius* also utilizes pelvic discs to anchor in wave-swept habitats, tolerating brief aerial exposure by retreating to moist crevices, although they exhibit limited terrestrial movement [26, 27]. *Istiblennius* employs similar adhesive discs for stability in turbulent zones, but its aerial activity is rare and brief, reflecting underdeveloped physiological adaptations for air exposure [28]. Meanwhile, *Omobranchus* relies on pelvic fin modifications to cling in estuarine and rocky habitats; some species, such as *O. punctatus*, can tolerate short emersion through cutaneous and buccopharyngeal respiration, though terrestrial locomotion is minimal [28, 29]. Thus, the specific microhabitat characteristics of Darya-Bozorg Beach make it particularly suitable for genera such as *Alticus, Antennablennius, Istiblennius*, and *Omobranchus*. Aside from representatives of Blenniidae and Gobiidae, few fish can withstand the harsh environment of Darya-Bozorg Beach (Table 1; Figure 2).

At Tis Fishing Beach, the permanent residents of the rockpools [9, 10, 15, 16] are primarily representatives of Gobiidae, including *Istigobius ornatus, Bathygobius meggitti, Cryptocentroides arabicus*, and *Callogobius* sp. Both blennies and gobies have independently evolved a range of morphological, physiological, and behavioral adaptations to cope with the challenging conditions of the intertidal zone. However, their strategies differ based on their ecology, phylogeny, and habitat preferences [29]. *Istigobius, Bathygobius, Cryptocentroides*, and *Callogobius* typically remain submerged in rockpools or shallow water and rarely venture onto land. The pelvic fins of these gobies have fused into sucker discs for adhering to substrates, similar to blennies, but they are often less robust for aerial clinging. These gobies are less specialized for air breathing than blennies, relying more on aquatic respiration and using burrows or crevices for shelter during low tide [29-31]. This adaptation allows them to thrive in the gravel-and-sand intertidal pools at Tis Fishing Beach, making them less suited to the vertical walls and smooth pools at Darya-Bozorg.

Transient species, which spend only part of their lives in the intertidal zone, include members of the Lutjaniidae, Mugilidae, Pomacentridae, Epinephelidae, and Terapontidae [9]. Most transient species are juveniles that utilize the intertidal zone during high-tide feeding excursions or during part of their life cycle [3]. The large pools at Tis Fishing Beach also provide essential habitat for juveniles and feeding opportunities for adult fish from families such as Apogonidae, Pomacentridae, Terapontidae, Mugilidae, Lutjanidae, and Labridae, according to the results of this study.

Each of these families plays a critical ecological role. Apogonidae (Cardinalfishes) are nocturnal predators that help regulate

invertebrate and plankton populations while serving as prey for larger fish. They also engage in symbiotic relationships that enhance reef complexity[32,33]. Pomacentridae (Damselfishes) are herbivorous and control algae, promoting coral growth, providing nursery habitats, and shaping reef spatial organization through their territorial behavior [34]. Terapontidae (Grunters) are omnivores that balance invertebrate and algal populations in estuarine and freshwater environments, influencing nutrient cycling through their feeding and excretion [35]. Mugilidae (Mullets) maintain water quality by recycling nutrients and preventing algal blooms, linking marine and estuarine food webs [36]. Lutjanidae (Snappers) are top predators that regulate prey populations and drive trophic cascades, with juveniles utilizing mangroves and seagrass beds as nurseries, thus connecting ecosystems [37]. Labridae (Wrasses) are cleaner fish that enhance the health of reef fish and control sea urchin populations to prevent overgrazing, sustaining benthic community structure through their diverse feeding habits [38]. Consequently, transient fishes in intertidal pools also hold significant ecological importance within marine habitats. There may be seasonal changes in biodiversity and in the frequency of intertidal ichthyofauna, which could be the subject of future studies. The three studied beaches exhibit distinct ecological characteristics and values that are crucial for environmental protection programs. In addition to their ecological roles, members of the Gobiidae and Blenniidae are popular in the aquarium trade. Transient fishes also possess aquarium and fisheries value, underscoring their economic importance. Given that not all intertidal areas are ecologically identical, it is essential to identify and protect distinct habitats with unique ichthyofauna to support practical conservation efforts. The findings of the present survey will enhance our understanding of the diverse intertidal habitats of Chabahar, particularly as the region faces challenges posed by early industrialization.

Conclusion

This study reveals significant adaptations in intertidal fish species in the Sea of Oman that enable them to thrive in the variable conditions of their habitat. The diversity and composition of these fish are closely linked to their specialized morphological, physiological, and behavioral traits, reflecting the unique ecological conditions of the intertidal zone. Our findings support previous research highlighting Blenniidae and Gobiidae as key components of the ichthyofauna in the Persian Gulf and the Sea of Oman, with distinct species dominance patterns across sites.

At Darya-Bozorg Beach, the vertical walls and supratidal pools provide a suitable environment for genera like *Alticus*, *Antennablennius*, *Istiblennius*, and *Omobranchus*, which are adapted to cling to substrates in wave-exposed conditions. In contrast, Tis Fishing Beach supports a range of Gobiidae, which are better suited to the gravel and sand pools.

The ecological role of transient fish species is also emphasized, as they utilize the intertidal zone for feeding and nursery habitats. Families such as Apogonidae, Pomacentridae, Terapontidae, Mugilidae, Lutjanidae, and Labridae contribute to community dynamics and nutrient cycling within these ecosystems.

Given the distinct characteristics of the

studied beaches, this research highlights the need for targeted conservation efforts to protect these habitats and their associated fish populations. The economic value of species from the Gobiidae and Blenniidae, popular in the aquarium trade, further underscores the importance of sustainable management practices. The insights from this survey will help develop effective conservation strategies to enhance biodiversity and ecological resilience in Chabahar's intertidal ecosystems.

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