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Regulating ecotourism is the key to protecting intertidal ecology along the Magna coast, Saudi Arabia

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Original Article

Abstract

Tourism and recreational activities pose a significant threat to intertidal ecosystems, which are more vulnerable than other marine ecosystems due to their accessibility. The Red Sea, a unique biodiversity hotspot with numerous endemic marine organisms, is under threat from the rapid development of the tourism industry in the Kingdom of Saudi Arabia (KSA). As part of an effort to protect intertidal biodiversity and enhance ecotourism, a study was conducted to identify the impact of tourism on intertidal biodiversity at a popular tourist destination along the coast of Magna, Saudi Arabia. The study identified a total of 24 species, including macroalgae (5), gastropods (7), chitons (2), sea cucumbers (2), corals (2), brittle stars (2), crab (1), bivalve (1), sea urchin (1), and fish (1). While major recreational activities are currently limited to swimming, rock pooling, fishing, and intertidal walking, they may rise in the near future through developments. The number of casualties of marine life doubled on weekends due to the high visitor count. To address this issue, the Kingdom of Saudi Arabia implemented several Royal decrees. The local government should be strict with these decrees as well as create an awareness program to educate locals and tourists about marine sustainability, particularly in the diverse rocky intertidal regions.

Keywords: *Ecotourism, recreational activities, intertidal ecosystem, Red Sea, endemic*

Introduction

The intertidal zone is the space between the high and low tide, a critical ecosystem constantly facing a series of threats through natural and anthropogenic interventions (Micheli *et al*,

2016). In general, intertidal biodiversity flourishes with various marine organisms but is greatly influenced by physical factors such as waves, tides, and temperature (Gaylord, 1999; Calcagno *et al*, 2012). In recent trends, the intertidal communities are facing serious threats due to the development of the coast for tourism and recreational activities (Crowe *et al*, 2000; Davenport and Davenport, 2006). The tourism industry has grown exponentially in the last few decades, with coastal cities being the main attractions for various recreational resources (Miller, 1993; Dadon, 2002; Davenport and Davenport, 2006). Though tourism and recreational activities provide economic benefits to the countries, they still create disturbances and damage the intertidal ecosystem (Dadon, 2002; Davenport and Davenport, 2006). The impacts on the ecosystem will be in highly protected or reserved areas (Fletcher and Frid, 1997). Further, the prolonged activities will lead to the deterioration of the natural ecosystem (Mendez *et al*, 2017). In recent decades, ecotourism has emerged as a prominent strategy for many countries to balance biodiversity conservation with tourism development (Brett, 2018; Holland *et al*, 2022). However, the impacts of ecotourism on protected and diverse regions are multifaceted and require careful consideration of potential economic, social, and environmental trade-offs (Teshome and Demissie, 2018).

Compared to other intertidal ecosystems, the rocky intertidal ecosystem is more diverse and richer in flora and fauna. The crevices and rock pools among the rocky shoreline protect the marine organisms from predators and heat stress, which in turn leads to the flourishing of marine organisms (Nandhagopal *et al*, 2020). These marine resources are facing serious threats due to human interventions and exploitation

(Brosnan and Crumrine, 1994; Povey and Keough, 1991; Eckrich and Holmquist, 2000; Jenkins *et al.*, 2020).

The Kingdom of Saudi Arabia is rapidly emerging as a prominent destination for tourism, boasting an extensive rocky shoreline along the Red Sea. In recent years, Saudi Arabia has launched numerous projects to attract tourists, particularly focused on the Red Sea development initiatives, such as NEOM (Ibrahim *et al.*, 2021), a flagship project of Saudi Arabia's Vision 2030. However, this fast-paced development poses serious risks to ecosystems, especially intertidal ecosystems, due to developments targeting the coastline. Nevertheless, NEOM is committed to preserving 95% of the land and sea for nature, allowing residents, wildlife, and tourists to benefit from a sustainable model of greening and rewilding (Alam *et al.*, 2021). This initiative is one of the first and most significant globally in support of Biodiversity Sustainability. Numerous studies have shown that ecotourism is one of the effective ways to boost tourism as well as to conserve biodiversity (Abuhay *et al.*, 2023). The Red Sea is a global hotspot rich in various marine endemic organisms (DiBattista *et al.*, 2016). The region's isolation by the Gulf of Aden and the Bab al-Mandab Strait, combined with its shallow depth, high temperature, and salinity, has likely restricted the movement of marine flora and fauna (Kemp, 2000), resulting in a unique endemism. To mitigate the serious impacts of tourism development on marine ecosystems and to establish sustainable management practices, extensive research is required, particularly concerning intertidal communities. Currently, the Royal Commission of Jubail and Yanbu is developing an Environmental Sustainability City (JCPDI) in the Jazan Province along the Red Sea, incorporating the objectives of Vision 2030. This sustainable city has the potential to set a benchmark for sustainable urban development across the Kingdom of Saudi Arabia, especially in greenery and biodiversity. In general, the noninvolvement of the locals was the major reason for the failure of ecotourism policies (Liu *et al.*, 2012; Abdurahman *et al.*, 2016). Hence, the Royal Commission of Jubail and Yanbu incorporated the sustainability practices during the development stage itself by obtaining the LEED (Leadership in Energy and Environmental Design) platinum certificate for the design. As part of its efforts to support the country's ecotourism vision and identify gaps in existing policies, a first-time study was conducted on the intertidal zone along the Magna coast in Tabuk. The Magna coast is rich in flora and fauna with diverse species. This diverse ecosystem will be affected due to the rapid development of tourism industries. Hence, the current study investigated the impact of recreational activities on the diversity of rocky intertidal ecology in the selected location along the Magna Coast, Saudi Arabia.

Material and methods

Study area

Magna is a town in the Tabuk Province of Saudi Arabia. It is situated on the coast of the Gulf of Aqaba, at coordinates 28° 23' 51" N and 34° 44' 59" E, southwest of Al-Bad' (Fig.1). The Red Sea near Magna is home to pristine coral reefs and is well-known as a scuba diving site. As a part of the NEOM project, Saudi Arabia has recently revealed plans to develop the Magna coast as one of the prime luxury lifestyle coastal destinations.

Field study

The field survey was conducted at one of the tourist spots along the Magna coast (28.399169° N, 34.738769° E) during the period of April 2024. The visitors count and activities were tracked continuously for a period of one month (April, 2024) during one weekday (Tuesday, low activity) and one weekend (Friday, peak activity) (Machado *et al.*, 2017). In Saudi Arabia, Friday and Saturday are considered weekends with high activity during Friday, which was the reason to consider Friday for the peak activity. The data was collected between 5 pm and 10 pm on both days due to peak activity time. The time period and survey day were finalised based on the preliminary survey. During the preliminary survey, continuous monitoring was carried out for a week to observe peak activity hours and days. Hence, based on the preliminary survey, the day and time were identified to obtain highly efficient data in a short period of time.

An extensive field survey was conducted along the 5 km coastal stretch of Magna to study the distribution and diversity of intertidal species. The intertidal diversity assessment was conducted in parallel with the visitor count. A series of field surveys, conducted through intertidal walking at low tide (Jebakumar *et al.*, 2015), along the entire stretch without creating any harm to the animals and the study area is presented in Fig. 1. The diversity of the intertidal samples was analysed using 1 X 1 m quadrates (Megina *et al.*, 2013). The samples were collected and coded for identification in the laboratory. They were brought in clean sample containers (one sample per container), and the specimens were photographed immediately after transportation and onsite. The sample size, shape, colour, texture, total length, breadth, and oscule diameter were noted to identify the specimen using morphological characteristics. Further, to determine the specimen's species level, individual samples were preserved in 90% alcohol (Vinod *et al.*, 2014).

The cluster analysis based on the Bray-Curtis similarity matrices of root-transformed visitor counts between the weeks was

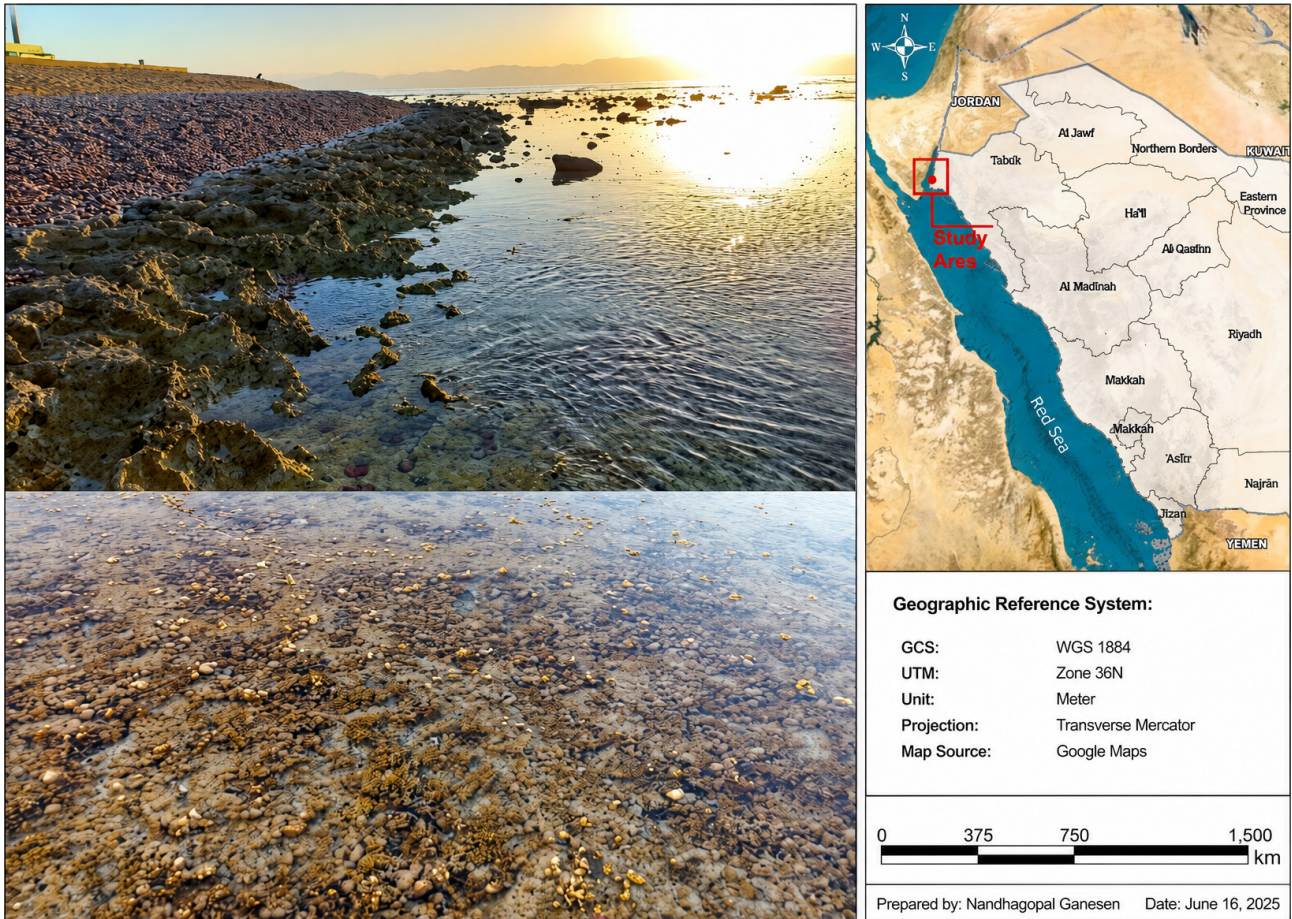


Fig. 1. Figure represents the study area

used to analyse the differences in the visitor counts between the weeks. In addition, the root-transformed visitor activities data were used to create the Non-metric multidimensional scaling ordinations (nMDS) plot based on Bray-Curtis similarity matrices. The Primer v7 was utilised to perform this analysis (Jebakumar *et al.*, 2015; Nandhagopal *et al.*, 2020).

Results

Visitor numbers and activities

Based on the collected data, the weekly average visitor count was significantly higher on weekends (310 visitors/hour) compared to weekdays (125 visitors/hour). The overall monthly average was 87 visitors/hour, though this likely fluctuates with seasonal cycles typical of the Red Sea. As illustrated in Fig. 2, visitor counts varied between weeks, with similarity indices shown in Fig. 3, Fig. 4 further clarifies the hourly variations in visitor counts between weekdays and weekends. Following the complete development of the NEOM coast, visitor counts could potentially increase to approximately 1000/hour, a projection that necessitates robust management interventions,

such as designated walkways, to prevent the 39% increase in mechanical damage typically observed with unregulated foot traffic (Pinn and Rodgers, 2005).

Regarding activities, rock pooling and intertidal walking were the most common. Fig. 5 presents the variations in these activities between the weeks. Visitors were frequently observed walking over algae and harvesting limpets and gastropods. Adult visitors were noted to cause more significant

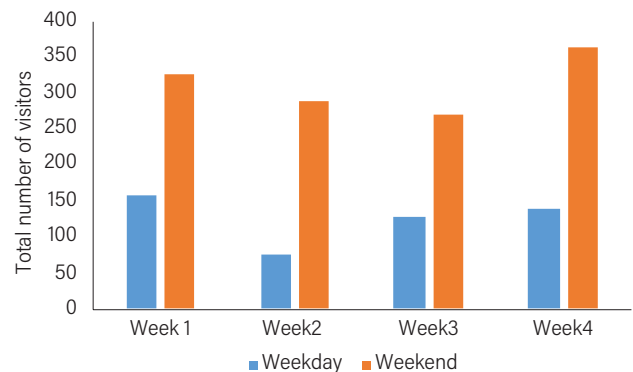


Fig. 2. Variations in the visitor count between weekdays and weekends

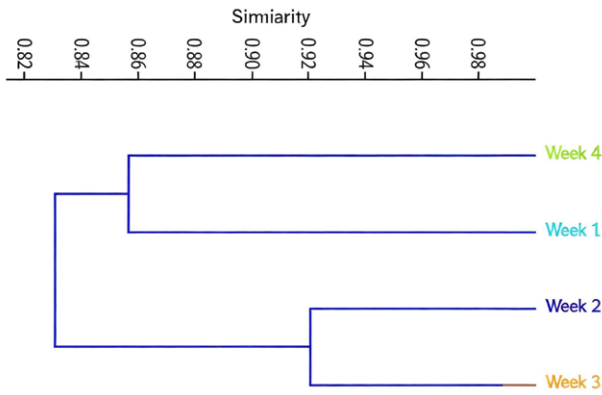


Fig. 3. Cluster Analysis between Weeks using Bray-Curtis Similarities from v-Transformed Visitors density data

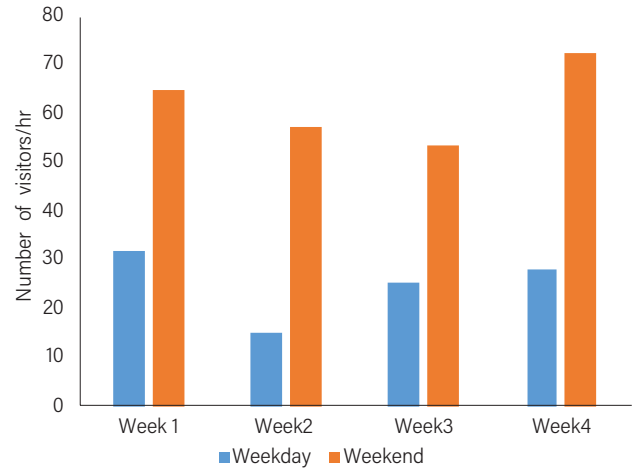


Fig. 4. Variation in the Visitors/hour between weekdays and within the weeks

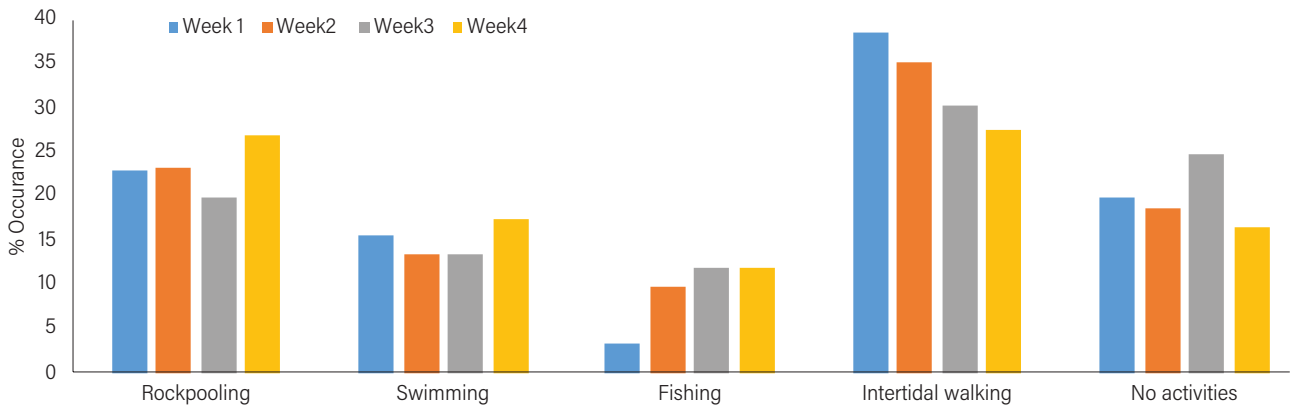


Fig. 5. Illustrations represent the variations in activities

damage than children, likely due to higher static pressure (trampling), which is known to crush barnacles and displace sessile epibiota. Non-Metric MDS (Fig. 6) identifies intertidal walking as the prominent activity. A direct correlation was

observed between activities, visitor numbers, and ecosystem damage; as foot traffic increases, it leads to the loss of foliose algae and the depletion of large, dominant individuals, thereby destabilising the intertidal community structure.

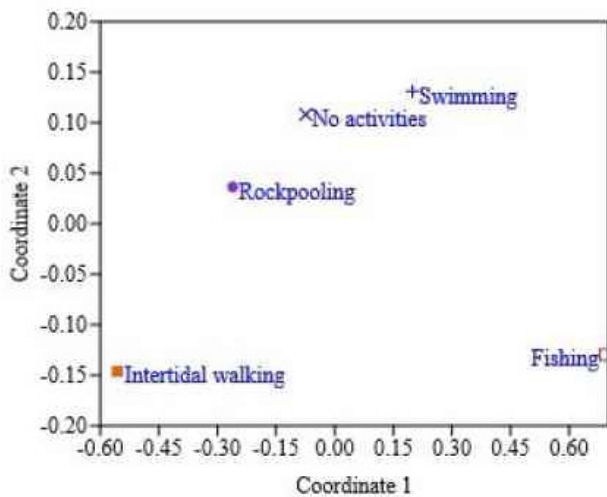


Fig. 6. Non-metric MDS plot establishing the deviations between the activities

Biodiversity

A total of 24 species, belonging to 20 genera, 14 classes, 8 phyla, and 3 kingdoms, were identified (Fig. 7, Table 1). Seventeen species were identified to the species level, while seven were identified to the genus level. Taxa included Chlorophyta, Rhodophyta, Ochrophyta, Mollusca, Arthropoda, Chordata, Echinodermata, and Cnidaria. Fig. 8 illustrates the percentage composition of this biodiversity. The majority of recorded epibiota were sessile, resulting in minimal changes in species density and diversity over short intervals. Mollusca was the dominant taxon in terms of diversity (11 species; 46%), followed by Echinodermata (13%).

Seaweeds dominated the terrain in terms of density, followed by chitons. Macroalgae such as *Jania adhaerens* and *Acanthophora spicifera* occupied the entire habitat (Fig. 9a

Table 1. Intertidal biodiversity along the Magna coast, Saudi Arabia

Kingdom	Phylum	Class	Genus	Species	Density (No./m ²)	IUCN Status
Plantae	Chlorophyta	Ulvoephyceae	<i>Valoniopsis</i>	<i>Valoniopsis pachynema</i>	4	LC
Plantae	Rhodophyta	Florideophyceae	<i>Jania</i>	<i>Jania adhaerens</i>	7	LC
Plantae	Rhodophyta	Florideophyceae	<i>Acanthophora</i>	<i>Acanthophora spicifera</i>	18	LC
Chromista	Ochrophyta	Phaeophyceae	<i>Turbinaria</i>	<i>Turbinaria ornata</i>	4	LC
Chromista	Ochrophyta	Dictyotaceae	<i>Padina</i>	<i>Padina</i> sp.	12	LC
Animalia	Mollusca	Polyplacophora	<i>Acanthopleura</i>	<i>Acanthopleura testudo</i>	14	LC
Animalia	Mollusca	Polyplacophora	<i>Acanthopleura</i>	<i>Acanthopleura vaillanti</i>	6	LC
Animalia	Mollusca	Ophiuroidea	<i>Ophiocoma</i>	<i>Ophiocoma erinaceus</i>	2	LC
Animalia	Mollusca	Ophiuroidea	<i>Ophiocoma</i>	<i>Ophiocoma dentata</i>	4	LC
Animalia	Mollusca	Gastropoda	<i>Clypeomorus</i>	<i>Clypeomorus bifasciata bifasciata</i>	5	LC
Animalia	Mollusca	Gastropoda	<i>Nerita</i>	<i>Nerita undata</i>	2	LC
Animalia	Mollusca	Gastropoda	<i>Nerita</i>	<i>Nerita</i> sp.	3	LC
Animalia	Mollusca	Gastropoda	<i>Turbo</i>	<i>Turbo argyrostomus</i>	1	LC
Animalia	Mollusca	Gastropoda	<i>Planaxis</i>	<i>Planaxis sulcatus</i>	29	LC
Animalia	Mollusca	Gastropoda	<i>Engina</i>	<i>Engina mendicaria</i>	2	LC
Animalia	Mollusca	Bivalvia	<i>Pinna</i>	<i>Pinna</i> sp.	1	LC
Animalia	Arthropoda	Malacostraca	<i>Grapsus</i>	<i>Grapsus grapsus</i>	1	LC
Animalia	Arthropoda	Thecostraca	<i>Balanus</i>	<i>Balanus</i> sp.	5	LC
Animalia	Chordata	Teleostei	<i>Parapercis</i>	<i>Parapercis nebulosa</i>	1	LC
Animalia	Echinodermata	Holothuroidea	<i>Holothuria</i>	<i>Holothuria forskali</i>	1	LC
Animalia	Echinodermata	Holothuroidea	<i>Holothuria</i>	<i>Holothuria</i> sp.	1	LC
Animalia	Echinodermata	Echinoidea	<i>Stomopneustes</i>	<i>Stomopneustes variolaris</i>	1	LC
Animalia	Cnidaria	Scleractinia	<i>Porites</i>	<i>Porites</i> sp.	1	NT
Animalia	Cnidaria	Scleractinia	<i>Acropora</i>	<i>Acropora</i> sp.	5	NT

to 9c). These species function as ecosystem bioengineers, providing critical protection from thermal stress and water loss for associated macroinvertebrates. An IUCN status

analysis indicated most species are of Least Concern, though Cnidarians such as *Porites* sp. and *Acropora* sp. are classified as Near Threatened. No invasive species, such as *Codium*

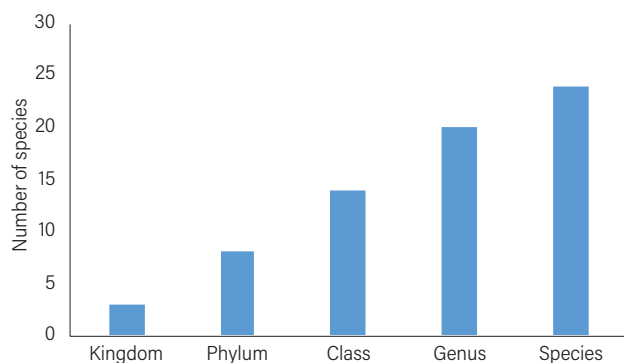


Fig. 7. Differences in the taxon along the Intertidal coast of Magna, Saudi Arabia

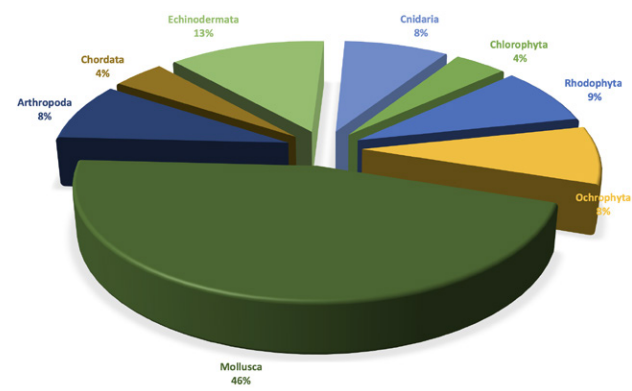


Fig. 8. Percentage composition of the intertidal biodiversity along the coast of Magna, Saudi Arabia

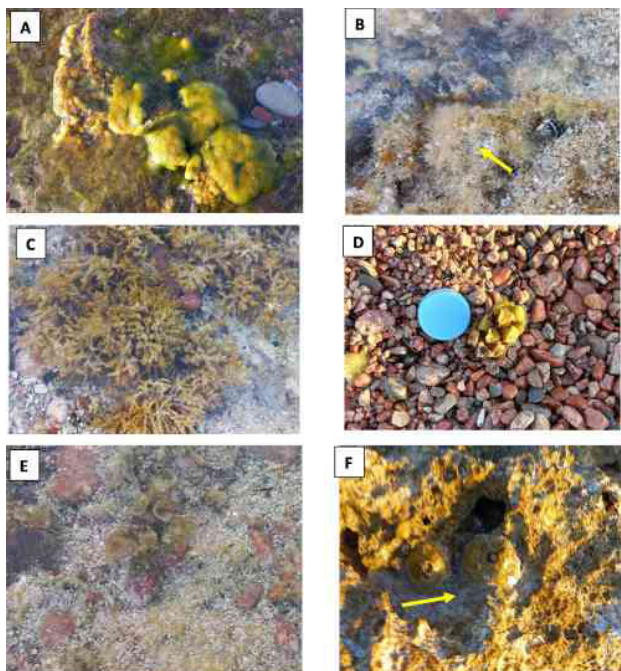


Fig. 9a. List of species identified along the Study area, A- *Valoniopsis pachynema*, B- *Jania adhaerens*, C- *Acanthophora spicifera*, D- *Turbinaria ornata*, E- *Padina* sp., F- *Balanus* sp.

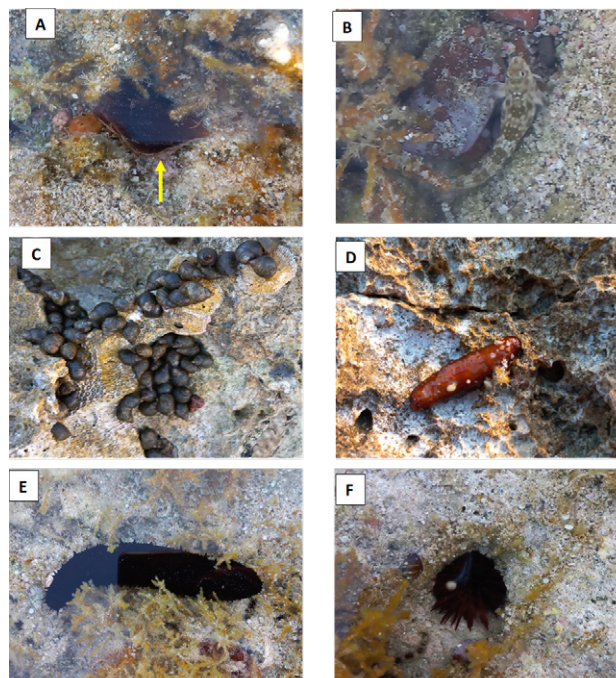


Fig. 9c. List of species identified along the Study area, A- *Pinna* sp, B- *Parapercis nebulosa*, C- *Planaxis sulcatus*, D- *Holothuria* sp., E- *Holothuria forskali*, F- *Stomopneustes variolaris*

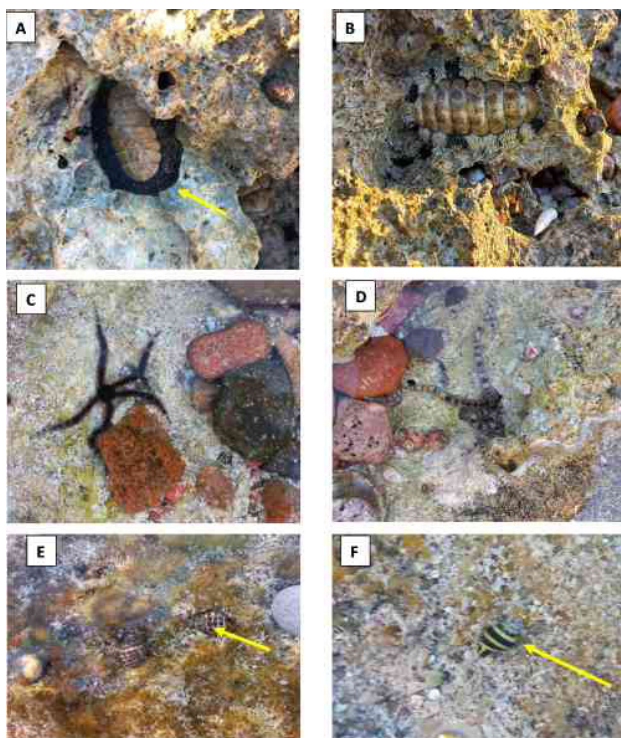


Fig. 9b. List of species identified along the Study area, A- *Acanthopleura testudo*, B- *Acanthopleura vaillanti*, C- *Ophiocoma erinaceus*, D- *Ophiocoma dentate*, E- *Clypeomorus bifasciata bifasciata*, F- *Engina mendicaria*

fragile, were identified, which is vital for maintaining the native resilience of the Red Sea's unique intertidal zones

Discussion

Limited information is available on the taxonomy, distribution, abundance, and non-indigenous species of intertidal fauna along the coast of Magna. With the rapid development of the Kingdom of Saudi Arabia's tourism sector and the recent increase in outdoor activities, the potential impacts of tourism on marine biodiversity remain understudied (Eckrich and Holmquist, 2000; Schlacher *et al.*, 2013). This study represents a pioneering effort to address this knowledge gap by investigating the impacts of tourism on marine biodiversity and tracing the subsequent effects through ecotourism policies. It is important to note that the coastal region of Saudi Arabia is home to a diverse array of endemic and endangered species. The shift in species diversity and reduction in density were among the more common effects observed due to frequent recreational activities. This assessment will serve as a tool to strengthen existing ecotourism policies.

The intertidal fauna of the Magna coast remains taxonomically understudied, particularly regarding the distribution of non-indigenous species (NIS) and the abundance of endemic taxa. This study identifies a distinct pulse disturbance pattern (Mendez *et al.*, 2017), where visitor counts surge during weekends. Such fluctuations mirror the findings of Pinn and Rodgers (2005), suggesting that recreational pressure is not a constant stressor but a series of high-intensity events.

The ecological danger of these “pulses” is that the recovery time for intertidal assemblages often exceeds the interval between disturbances. Bravo *et al.* (2015) demonstrated that macroalgal recovery and invertebrate recolonisation cycles are frequently interrupted by weekly high-traffic events, leading to a state of chronic degradation despite the seemingly “low” average monthly visitor counts (87 visitors/hour).

Despite the Kingdom of Saudi Arabia launching numerous initiatives such as the Saudi Green Initiative, CORDAP, Vision 2030, and Net Zero Emission to safeguard terrestrial and marine biodiversity, the cumulative long-term impacts of visitors could lead to chronic and persistent damage to the ecosystem (Davenport and Davenport, 2006).

Common activities among visitors included rock pooling, intertidal walking, swimming, and fishing. Intertidal walking was identified as the most pervasive activity. While often perceived as benign, the cumulative mechanical stress of trampling triggers significant structural changes in the community. Our observations of the vulnerability of branching macroalgae align with the findings of Povey and Keough (1991) and Jenkins *et al.* (2020), which indicate that upright, branching taxa are more susceptible to breakage than prostrate or turf-forming species.

The replacement of canopy-forming algae (*Jania adhaerens*) with opportunistic ephemeral species often leads to a reduction in habitat complexity. This loss of “biogenic housing” directly impacts the recruitment of juvenile invertebrates, potentially leading to a localised decline in biodiversity. The extraction of gastropods and limpets for bait or food, observed primarily among adult visitors, removes top-down grazers. This removal can trigger trophic cascades, where the absence of herbivores allows algal biofilms to overgrow and outcompete sessile calcifiers for space (Dutton *et al.*, 2005).

Based on the collected data, a One-way Analysis of Variance (ANOVA) revealed that visitor counts were significantly higher on weekends ($p < 0.05$) compared to weekdays. The Non-Metric Multidimensional Scaling (nMDS) ordination (Fig. 6) provided a clear spatial representation of activity deviations, with a low stress value (< 0.1), indicating a highly reliable fit of the data. The nMDS plot clearly separated “intertidal walking” as the most distinct and prominent cluster, showing a high degree of centroid grouping across all sampled weeks. This statistical relationship confirms that as visitor numbers increase, the integrity of the ecosystem decreases in a linear, predictable fashion.

Studies on the impacts of trampling on rocky shores have shown a sharp reduction in the density of larger and branching

macroalgae alongside an increase in turf species (Povey and Keough, 1991; Fletcher and Frid, 1997; Keough and Quinn, 1998; Jenkins *et al.*, 2020). Supporting this research, in the current study, the area was noted to be flourishing with branching macroalgae alongside high rates of intertidal walking. As mentioned earlier, tourism may lead to alterations in the macroalgal communities, which in turn could impact the entire ecosystem. Furthermore, ephemeral algal species tend to be more abundant in areas of heavy activity (Fletcher and Frid, 1997).

The Magna coast serves as a critical refuge for Near Threatened scleractinian corals, including *Porites* sp. and *Acropora* sp. These species exist at their physiological limits during low tide, facing extreme thermal stress and desiccation. When recreational trampling is superimposed on these environmental stressors, the metabolic cost of repair may exceed the energy budget of the coral, leading to localised extinction (Bogorodsky, 2019). The presence of these species underscores the urgent need for ecotourism-specific zoning, as even low levels of trampling can cause irreversible damage to slow-growing coral recruits that are essential for the reef’s long-term accretion.

The “pulse disturbance” identified in this study is statistically characterised by high temporal variance. The similarity indices shown in Fig. 3 (Bray-Curtis Similarity) suggest that while the biological community remains relatively stable during the week, the weekend surge causes a significant dissimilarity shift in the benthic cover. This suggests that the ecosystem is experiencing “Statistical Homogenization,” where sensitive, branching species are being filtered out, leaving. A general lack of knowledge and awareness regarding the importance of intertidal communities contributes significantly to these impacts. Ecotourism is considered a viable option to mitigate these impacts and protect marine biodiversity, aligning with Saudi Vision 2030 ambitious goal of safeguarding 30% of Saudi Arabia’s land and sea (Saudi Green Initiative, 2024). Recent awareness of biodiversity sustainability, along with developments in the Red Sea region such as NEOM and the JCPDI (RCJY), has led to the incorporation of sustainability goals into master plans aimed at protecting ecosystems. One of the main responses to combat threats to biodiversity is the conversion of biodiversity-rich areas into protected reserves (Gossling, 1999).

Saudi Arabia’s transition toward a “blue economy” through Vision 2030 and the Saudi Green Initiative has catalysed a massive expansion of protected areas, now covering approximately 14.9% of the Kingdom’s territory (Vision 2030 Annual Report, 2023). However, as Davenport and Davenport (2006) argue, the mere designation of protected areas is insufficient without active enforcement and monitoring.

Table 2: List of recommendations to implement

Management category	Observed impact	Proposed intervention	Strategic alignment
Zoning & access	Weekend visitor spikes (310/hr) are causing mechanical stress.	Implement Spatiotemporal Zoning; restrict access to sensitive reef flats during low-tide peaks and weekend "pulse" periods.	Saudi Green Initiative: Sustainable Tourism.
Physical infrastructure	Trampling of <i>Porites</i> and <i>Acropora</i> sp.	Installation of elevated eco-walkways or floating pontoons to eliminate direct contact with the substrate.	NEOM Nature: 95% Conservation Commitment.
Resource protection	Extraction of limpets and gastropods for bait/food.	Establish "No-Take" Marine Micro-Reserves to preserve top-down grazers and prevent trophic cascades.	Vision 2030: Biodiversity Protection.
Public engagement	Lack of awareness regarding sessile epibiota.	Deployment of Smart-Signage (QR-coded) and "Intertidal Rangers" to educate visitors on the "Don't Turn the Rock" principle.	Saudi Vision 2030: Quality of Life Program.
Technological monitoring	Inability to track real-time ecosystem shifts.	Use of AI-driven computer vision (NEOM's digital infrastructure) to monitor visitor density and detect unauthorised harvesting.	Cognitive Cities (NEOM): Data-driven conservation.

To meet the goal of protecting 30% of marine domains by 2030, coastal developments like NEOM and JCPDI must move beyond traditional conservation. Our results suggest that a lack of public awareness is a primary driver of ecosystem damage. Implementing "Citizen Science" programs and educational signage could mitigate the impacts observed in this study.

While the Saudi Green Initiative and CORDAP provide a high-level framework, local authorities must implement site-specific regulations (*e.g.*, seasonal closures during spawning periods) to prevent the "pulse" disturbances from becoming permanent ecological shifts. To mitigate the observed impacts of "pulse disturbances" and unregulated intertidal activities, the following management strategies are recommended for the Magna coast (Table 2).

Conclusion

In conclusion, the intertidal ecosystem of Saudi Arabia, while providing essential ecological services, is increasingly subjected to anthropogenic pressures driven by expanding coastal tourism. The study clearly demonstrates that intensified recreational activities—particularly weekend "pulse disturbances"—and projected high visitor densities under developments such as NEOM lead to measurable ecological impacts, including physical damage to sessile epibiota and a decline in branching macroalgae. Despite ongoing sustainability-oriented initiatives, including Jazan City for Primary and Downstream Industries, the findings underscore that current and future tourism pressures pose significant risks to sensitive intertidal habitats, especially those harbouring endemic and threatened species. Therefore, achieving a balance between development and conservation necessitates a holistic management framework integrating ecotourism principles, continuous ecological monitoring, targeted conservation strategies, public awareness, and strict regulation of visitor intensity and activities. Such measures are

critical to safeguarding the long-term health and resilience of intertidal ecosystems.

Author contributions

Conceptualisation: NG, TAJ, KPK; Methodology: NG, RSA; Data collection: NG, RSA; Data analysis: NG, RSA; Writing original draft: NG, TAJ, KPK; Writing review and editing: TAJ, KPK; Supervision: NG

Data availability

The data are available and can be requested from the corresponding author.

Conflicts of interest

The authors declare that they have no conflict of financial or non-financial interests that could have influenced the outcome or interpretation of the results.

Ethical statement

No ethical approval is required as the study does not include activities that require ethical approval or involve protected organisms/ human subjects/ collection of samples/ protected environments.

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