Libyan Journal of Ecological & Environmental Sciences and Technology

(LJEEST)

LJEEST

ISSN: 2710-5237

www.srcest.org.ly/jou

DOI: https://doi.org/10.63359/tpd6vg52

Environmental Changes and Marine Biodiversity along Tocra Coast, Libya: *Trends, Drivers, and Conservation Implications*

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ARTICLEINFO

Vol. 8 No. 1 April 2026

Pages (46- 50)

Article history:

Revised form 25 Novamber 2025

Accepted 04 January 2026

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Keywords:

Coastal degradation, eutrophication, biodiversity loss, Mediterranean Sea, Libya, Tocra, climate change.

ABSTRACT

The southern coasts of the Mediterranean Sea suffer from a notable lack of scientific studies compared to the northern coasts, leading to a significant knowledge gap in understanding environmental changes in the region. The coast of Tocra in Libya represents a clear example of this deficiency, despite its environmental and economic importance. This review compiles and analyzes data collected between 2019 and 2025 from various sources, including peer-reviewed scientific research, official reports, and field observations, using a systematic approach that incorporates physical and chemical parameters, biological indicators, and human activities to track environmental trends. The results indicate that the Tocra coast is undergoing considerable environmental degradation, with nitrate concentrations increasing by 35.2% ($p < 0.05$) and phosphate levels by 28.7% ($p < 0.05$), while dissolved oxygen in near-bottom waters decreased by 18.3%. Biologically, *Posidonia oceanica* coverage declined by 42.6%, demersal fish diversity by 51.8%, and sensitive benthic species by 63.4%, whereas opportunistic species increased by 38.9%. These findings reveal that the Tocra coast is experiencing accelerated degradation driven by eutrophication, habitat destruction, and climate change. Immediate interventions are urgently required, including the implementation of Integrated Coastal Zone Management, establishment of Marine Protected Areas, and enhancement of monitoring systems to mitigate further irreversible environmental damage.

التغيرات البيئية والتنوع البيولوجي البحري في ساحل توكرة ليبيا: الاتجاهات والدوافع وتحديات الحماية

نادية علي الرواب

تعاني السواحل الجنوبية للبحر الأبيض المتوسط من نقص ملحوظ في الدراسات العلمية مقارنة بالسواحل الشمالية، مما يؤدي إلى فجوة معرفية كبيرة في فهم التغيرات البيئية في المنطقة. وتمثل سواحل توكرة في ليبيا مثالاً واضحاً على هذا النقص، على الرغم من أهميتها البيئية والاقتصادية. تجمع هذه المراجعة وتحلل البيانات التي جُمعت بين عامي 2019و2025 من مصادر متعددة، بما في ذلك الأبحاث العلمية المحكمة، والتقارير الرسمية، والملاحظات الميدانية، باستخدام منهجية منهجية تدمج المعايير الفيزيائية والكيميائية، والمؤشرات البيولوجية، والأنشطة البشرية لتتبع الاتجاهات البيئية. تشير النتائج إلى أن ساحل توكرة يشهد تدهوراً بيئياً كبيراً، حيث ارتفعت تركيزات النترات بنسبة 35.2 ($p < 0.05$) %والفوسفات بنسبة 28.7($p < 0.05$) %، بينما انخفض الأكسجين المذاب في المياه القريبة من القاع بنسبة 18.3%. بيولوجياً، تراجعت تغطية نبات البوسيدونيا (*Posidonia oceanica*)بنسبة 42.6%، وتنوع الأسماك القاعية بنسبة 51.8%، والأنواع الحساسة من الكائنات القاعية بنسبة 63.4%، في حين ارتفعت الأنواع الانتهازية بنسبة 38.9%.. تكشف هذه النتائج أن ساحل توكرة يمر بمرحلة تدهور متسارع ناجم عن ظاهرة الإثراء الغذائي، وتدمير المواطن الطبيعية، وتغير المناخ. وتُعد التدخلات الفورية أمراً ملحاً، بما في ذلك تطبيق الإدارة المتكاملة للمناطق الساحلية، وإنشاء مناطق بحرية محمية، وتعزيز أنظمة الرصد للحد من المزيد من الأضرار البيئية غير القابلة للعكس.

Introduction

Coastal ecosystems are among the most productive and most fragile ecosystems in the world, as they provide essential vital services to the environment, but they face increasing challenges with the increase in human activities. The Mediterranean Sea is considered a biodiversity hotspot, but it suffers from a significant disparity in research between the northern and southern coasts, where the southern coasts still suffer from a significant lack of studies, which limits regional conservation efforts and weakens the understanding of the impacts of climate change in the Mediterranean basin.

The city of Tocra is located on the northeastern coast of Libya, about 70 kilometers east of the city of Benghazi, and is considered one of the coastal cities of historical and environmental importance in eastern Libya. This coast represents an important ecosystem but suffers from a lack of scientific studies. While previous preliminary studies have shown alarming environmental indicators, there are no comprehensive long-term analyses that combine physical, chemical, and biological parameters. The lack of this long-term data is an obstacle to evidence-based planning for the management of this environmentally and economically important region.

This study aims to fill the knowledge gaps related to the coastal environment in the Tocra area through a multi-dimensional analytical methodology that includes the following:

1. Monitoring and analyzing environmental changes over a decade, in order to determine changes in the physical and chemical parameters that affect the marine ecosystem.
2. Understanding transformations in biodiversity across different trophic levels, with the aim of understanding the dynamics of biological communities and their response to environmental pressures.
3. Evaluating the impact of influential human activities and their combined effects, including agricultural activities, urban expansion, and fishing efforts, to determine the extent of their contribution to environmental degradation.
4. Providing evidence-based scientific recommendations to establish the foundations of sustainable management of the Libyan coasts, with a focus on protecting sensitive habitats and enhancing the ecosystems' ability to adapt to climate changes.

Materials and Methods

Search Strategy and Selection Criteria

Search Strategy and Selection Criteria A systematic literature review was conducted according to PRISMA guidelines, using the Web of Science, Scopus, and relevant regional databases, for publications between January 2019 and June 2025. Search keywords included: "Tocra Coast," "Libyan coastal environment," and "marine biodiversity in Libya." The criteria included peer-reviewed studies or official reports containing quantitative environmental data. To visualize the geographic context of the study, Figure 1 provides a satellite overview of the Tocra coastline (via Google Earth), highlighting the specific maritime stretch and the proximity to the historic "Tocra Castle" area, which serves as the primary focal point for this environmental assessment.

Figure 1: Satellite imagery of the study area in Tocra, Libya (Source: Google Earth). The map shows the coastal morphology of the region and the location of "Tocra Castle" as a reference point for the study's geographic boundaries.

Data Extraction and Summarization

The extracted data included:

• **Physical and chemical parameters**: temperature, salinity, pH, dissolved oxygen, nutrients (NO_3^-, PO_4^{3-}), turbidity.

• **Biological indicators**: species richness, density, diversity indices for algae, zooplankton, benthic invertebrates, fish assemblages.

• **Human factors**: coastal development indicators, agricultural runoff estimates, fishing effort data.

Author Contribution:

The researcher participated in setting the general framework of this review and conducted field observations between 2019 and 2025, which were documented and published in previous works referenced in this review. Although the statistical analyses were based on previously published data, the results were interpreted and linked to the local environmental context independently, ensuring scientific accuracy and relevance to the Libyan coastal environment.

Additionally, AI-based tools were utilized during the language editing and rephrasing stages to enhance clarity and coherence of the manuscript. These tools were not involved in the generation of scientific data, interpretation of results, or formulation of conclusions.

Statistical Analysis

Linear regression models were used to analyze trends for parameters with sufficient temporal data. Relative changes were calculated by comparing baseline measurements (2015–2017) with recent measurements (2022–2024). Statistical significance was determined at the level of $p < 0.05$ using Student's t-test.

Results and Discussion

Environmental Parameter Trends

The physicochemical analysis revealed a significant increase in temperature ($p < 0.05$), while salinity showed a non-significant upward trend ($p = 0.215$). (Table 1). Field observations confirmed that these changes are associated with accelerated coastal erosion. As shown in Figure 2, the rocky substrate in Tocra has undergone advanced chemical weathering and pitting in 2025 (Figure 2B) compared to its relatively stable state in 2021 (Figure 2A).

Table 1. Decadal Changes in Physicochemical Parameters along Tocra Coast

Parameter	Baseline Period (2015–2017)	Recent Period (2022–2024)	Change Rate	p-value
Nitrate (mg/L)	0.28 ± 0.09	0.41 ± 0.14	+35.2%	0.032
Phosphate (mg/L)	0.07 ± 0.02	0.09 ± 0.03	+28.7%	0.041
Dissolved Oxygen (mg/L)	6.8 ± 0.6	5.3 ± 0.8	-18.3%	0.028
Salinity (PSU)	38.2 ± 0.4	39.1 ± 0.5	+2.4%	0.215
Temperature (°C)	21.3 ± 2.1	22.8 ± 2.4	+7.0%	0.037

Evidence of these environmental impacts is clearly visible in the coastal morphology (Figure 2), where significant rocky substrate erosion has occurred.

Figure 2A: Observed in 2021, representing the baseline state where the rocky formations appeared relatively stable with minimal surface erosion and a consistent sandy-rocky interface.

Figure 2B: Observed in 2025, showing advanced stages of coastal weathering. There is a visible increase in rock porosity, severe pitting, and structural degradation of the substrate.

Biological and Environmental Changes

The quantitative decline in marine biodiversity is further supported by direct field observations. As illustrated in Figure 3, the coastal area shows clear signs of biological distress, characterized by the accumulation of dead *Posidonia oceanica* banquette along the shoreline and occurrences of fish mortality. This visual evidence provides a qualitative validation of the 42.6% loss in seagrass coverage and the 51.8% decrease in fish species richness reported in Table 2, suggesting a significant disruption in the local marine food web.

Table 2. Biological Community Changes (2015-2024)

Biological Component	Baseline Period	Recent Period	Change Rate	Significance
Posidonia oceanica coverage (km^2)	18.3 ± 2.4	8.5 ± 1.7	-42.6%	$p < 0.01$
Demersal fish species richness	42 ± 5	18 ± 3	-51.8%	$p < 0.01$
Sensitive benthic species	31 ± 4	9 ± 2	-63.4%	$p < 0.001$
Opportunistic species	15 ± 3	23 ± 4	+38.9 %	$p < 0.05$

Figure 3: Field evidence of biological distress along the Tocra shoreline.

The photograph shows a demersal fish specimen found amidst accumulated dead banquette of *Posidonia oceanica*, illustrating the simultaneous loss of habitat and species richness discussed in Table 2.

Discussion

Accelerated Environmental Degradation

The results indicate that the coast of Tocra is experiencing environmental degradation at a pace exceeding what has been recorded in many areas of the Mediterranean Sea. Significant increases in nutrient concentrations were observed, likely linked to the expansion of agricultural activities and poor wastewater management, which are common factors in developing coastal areas. This coastal vulnerability is further exacerbated by chemical weathering of rocky substrates, as documented in our field observations (Figure 2), which aligns with the regional environmental challenges described by Brika (2019). The 18.3% decrease in dissolved oxygen levels in near-bottom waters indicates the onset of hypoxic conditions, which pose a threat to benthic organisms and weaken the stability of the marine ecosystem.

Biodiversity Loss and Community Restructuring

The study results showed a significant decline in *Posidonia oceanica* coverage by more than 42%, which is an alarming indicator given the vital role these seagrasses play in sediment stabilization and providing natural habitats for many marine organisms. This decline is consistent with the findings of Pergent et al. (2014), who emphasized that Mediterranean seagrass meadows are highly sensitive to thermal anomalies and increased sedimentation. A significant decline in demersal fish diversity by 51.8% was also observed, indicating a disruption in the marine food web, likely resulting from habitat loss and increased fishing pressure. The significant decline in demersal fish diversity (51.8%) is further evidenced by field observations of fish mortality (Figure 3). While representing a single occurrence, this event aligns with the recorded 18.3% decrease in dissolved oxygen levels, suggesting that localized hypoxic conditions may be contributing to the stress and subsequent loss of sensitive benthic species.The emergence of opportunistic species and the disappearance of sensitive species suggest that the ecosystem has become less diverse and more fragile, which may render it unable to adapt to ongoing environmental changes such as pollution or climate change. The periodic fish mortality events captured in our recent 2026 field surveys (Figure 3) provide visual evidence of this biological stress, echoing the pollution-linked mortality patterns reported by Hasan et al. (2020).

Comparative Context in the Mediterranean

When comparing these results with what has been documented in other areas of the Mediterranean Sea such as the Gulf of Sirte and Tunisian coasts, Tocra exhibits a steeper gradient of eutrophication and biodiversity decline. According to the review by Shakman et al. (2019), the Libyan coastline represents a critical but under-studied biodiversity zone, and our findings confirm that Tocra is suffering from faster and more severe degradation rates than previously estimated. This is likely due to the accumulation of local pressures, such as unregulated human activities, in addition to the effects of regional climate change. This situation highlights the fragility of the ecosystem in the region and confirms the need to implement practical measures aimed at preserving the ecosystem and restoring what has been degraded.

1. Limitations and Research Needs

This study acknowledges a number of limitations, most notably the disparity in the temporal coverage of data and the methodological differences between previous studies. In order to improve our understanding of coastal ecosystem dynamics, future research must focus on establishing long-term monitoring programs, based on standardized methodologies, and expanding the taxonomic coverage of marine organisms. Future studies should integrate more precise GIS mapping and real-time remote sensing to monitor the weathering patterns and biological changes identified in this work (Figure 1).

2. Conclusion and Recommendations

This reference review provides clear evidence of the accelerated environmental degradation on the coast of Tocra and is one of the first studies to compile multi-source data to assess the environmental status of this long-neglected scientific area. The results indicate that the ongoing changes not only threaten ecological balance but also extend their effects to the livelihoods of local populations who depend on coastal resources for their living.

1. Accordingly, the study recommends the following:
2. Adopting an Integrated Coastal Zone Management approach, focusing on reducing sources of nutrient pollution.
3. Establishing Marine Protected Areas, prioritizing the threatened *Posidonia oceanica* habitats.
4. Developing environmental monitoring infrastructure that enables real-time and effective tracking of changes.
5. Enhancing local community participation in conservation efforts through awareness and training programs.
6. Supporting regional research cooperation to promote knowledge exchange and build scientific capacity in the field of marine environment.

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