

## Impact of Water Depth Change due to Urbanization on the Demography of Waterbirds at Juliana Lake, Benghazi, Libya

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تأثير التغير في عمق المياه الناجم عن التوسع العمراني على ديموغرافية الطيور المائية  
في بحيرة جليانا، بنغازي، ليبيا

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### Abstract:

Urbanization adjacent to coastal wetlands is one of the major drivers of habitat degradation worldwide, frequently altering shoreline landscape and water depth. Such changes directly influence the community composition, distribution and abundance of waterbirds, particularly species rely on shallow habitats. Juliana Lake, situated in Benghazi, Libya, has experienced substantial urban development over the past two decades, resulting in modifications of its shoreline and shallow-water parts. Using data collected through the International Waterbird Census (IWC) between 2005 and 2026, this study investigated the influence of shallow-water availability on two functional groups of waterbirds: waders (Charadriiformes) and divers. Mann–Whitney U tests were used to compare bird abundance between areas with and without shallow-water. Wader abundance differed significantly between habitat types ( $U = 0.00$ ,  $Z = -2.928$ ,  $P = 0.003$ ), with substantially higher abundances in shallow-water areas. In contrast, diver abundance showed no significant difference ( $U = 17.00$ ,  $Z = -0.439$ ,  $P = 0.661$ ). Temporal variation in the diver-to-wader ratio suggested significant changes in habitat suitability over the study period, including a noticeable increase in the ratio during 2023. These findings indicate that shoreline urbanization and associated reductions in shallow-water environments have disproportionately affected wader birds while exerting comparatively low influence on diving birds. Conservation efforts should prioritize the preservation and restoration of shallow shoreline zones to sustain waterbird diversity in Juliana Lake.

**Keywords:** Urbanization; Waterbirds; Juliana Lake; Libya; Waders; Divers; Habitat degradation.

### المخلص

يعتبر التوسع العمراني في المناطق المتاخمة للأراضي الرطبة الساحلية أحد العوامل الرئيسية المسببة لتدهور الموائل على مستوى العالم، إذ يؤدي في كثير من الأحيان إلى تغيير طبيعة خط الساحل وعمق المياه. وتؤثر هذه التغيرات بصورة مباشرة في تركيب مجتمعات الطيور المائية وتوزيعها ووفرتها، ولا سيما الأنواع التي تعتمد على الموائل الضحلة. تقع بحيرة جليانا في مدينة بنغازي، ليبيا، وقد شهدت خلال العقدين الماضيين تطوراً عمرانياً ملحوظاً، نتج عنه حدوث تغيرات في خط الساحل والمناطق ذات المياه الضحلة. باستخدام البيانات التي جمعت من خلال التعداد الدولي للطيور المائية (IWC) خلال الفترة من 2005 إلى 2026، تناولت هذه الدراسة تأثير توافر المياه الضحلة على مجموعتين وظيفيتين من

الطيور المائية، هما: الطيور الخواضة (Charadriiformes) والطيور الغاطسة. واستخدم اختبار مان-ويتني (U Mann-Whitney) لمقارنة وفرة الطيور بين المناطق التي تتوافر فيها المياه الضحلة والمناطق التي تقتصر إليها. وأظهرت وفرة الطيور الخواضة اختلافًا معنويًا بين نوعي الموائل ( $U = 0.00$ ,  $Z = -2.928$ ,  $P = 0.003$ )، مع تسجيل وفرة أعلى بصورة ملحوظة في مناطق المياه الضحلة. في المقابل، لم تُظهر وفرة الطيور الغاطسة فرقًا معنويًا ( $U = 17.00$ ,  $Z = -0.439$ ,  $P = 0.661$ ) وأشارت التغيرات الزمنية في نسبة الطيور الغاطسة إلى الطيور الخواضة إلى حدوث تغيرات ملحوظة في ملائمة الموائل خلال فترة الدراسة، بما في ذلك ارتفاع واضح في هذه النسبة خلال عام 2023. وتشير هذه النتائج إلى أن التوسع العمراني على طول خط الساحل وما يصاحبه من نقص البيئات ذات المياه الضحلة قد أثر بصورة غير متناسبة في الطيور الخواضة، بينما كان تأثيره محدودًا نسبيًا على الطيور الغاطسة. وينبغي أن تركز جهود المحافظة على التنوع الحيوي على حماية واستعادة المناطق الساحلية الضحلة للحفاظ على تنوع الطيور المائية في بحيرة جليانا.

**الكلمات المفتاحية:** التوسع العمراني، الطيور المائية، بحيرة جليانا؛ ليبيا، الطيور الخواضة، الطيور الغاطسة، تدهور الموائل.

## Introduction

Wetlands considered as the most productive ecosystems globally, supporting exceptional biodiversity while providing crucial ecological services, including nutrient cycling, carbon sequestration, flood regulation and habitat for migratory and resident birds (Mitsch & Gosselink, 2015). Despite their ecological importance, wetlands are disappearing at an unprecedented rate due to urbanization, pollution, land reclamation, hydrological alteration, and climate change (Davidson, 2014).

Coastal lagoons and shallow lakes constitute particularly valuable habitats for migratory waterbirds because they provide diverse feeding and resting sites along major flyways (Kirby *et al.*, 2008). Water depth is one of the main environmental variables determining habitat selection among waterbirds. Several studies have demonstrated that waders preferentially forage in shallow water or exposed mudflats where benthic invertebrates are readily accessible, whereas diving birds generally occupy deeper water where fish and submerged prey are existing (Colwell & Taft, 2000; Elphick & Oring, 1998). Urbanization alters these habitat features by modifying shoreline shapes, increasing artificial banks, reducing littoral vegetation, and changing water depth. Consequently, urban wetlands often show declines in specialist species while favoring more generalist birds (McKinney, 2006). Habitat simplification reduces ecological heterogeneity, thereby limiting foraging opportunities for shorebirds that depend on gradual depth gradients (Ma *et al.*, 2010).

In Benghazi, Juliana Lake has been described as “a fragile ecosystem that is steadily shrinking and exposed to dredging, infilling,” underscoring how urban growth can directly degrade the habitat base that waterbirds depend on (Abulsamad & Elbabour, 2022). It represents one of the few remaining urban wetlands in Benghazi and serves as an significant wintering and stopover site for migratory waterbirds within the Mediterranean Flyway (Smart *et al.*, 2006). During recent decades, considerable urban development surrounding the lake has altered its shoreline through construction, infrastructure expansion and land filling. Such changes have likely modified water depth and reduced shallow habitats available for foraging of many bird species.

Although, there are several studies have documented waterbird diversity in North African wetlands (Green *et al.*, 2002; Smart *et al.*, 2006), relatively little information exists concerning long-term ecological changes in Libyan wetlands. The International Waterbird Census (IWC), coordinated globally by Wetlands International, provides one of the longest continuous monitoring programs for migratory waterbirds and offers an opportunity to evaluate long-term ecological responses to habitat change.

The objectives of this study were therefore to:

1. evaluate whether shallow-water habitats influence waterbird abundance.
2. compare responses between waders and diving birds.
3. examine long-term temporal changes in the diver-to-wader ratio from 2005–2026.
4. Assess the likely ecological consequences of shoreline urbanization at Juliana Lake.

## Material and methods

### Study Area

Juliana Lake is located along the Mediterranean coast of Benghazi, northeastern Libya (32° 05,567 N 20°03,777 E). The lake forms part of a coastal wetland complex characterized by shallow margins, open-water zones, and seasonal mudflats. Increasing urbanization has transformed large sections of the shoreline, replacing natural littoral habitats with roads, buildings, and artificial ridges (fig. 1).

Historically, the lake supported numerous migratory and resident waterbird species using both shallow and deep habitats during winter migration. However, shoreline modification has reduced habitat heterogeneity.

## Waterbird Surveys

Waterbird monitoring followed the standardized protocols of the International Waterbird Census (IWC) between 2005 and 2026. Counts were conducted annually during the winter census period using direct visual observations from established observation points around the lake (Azafzaf *et al.*, 2005, 2006; Etayeb *et al.*, 2007; Hamza *et al.*, 2008; EGA-RAC/SPA, 2012; Bourass *et al.*, 2013; Etayeb *et al.*, 2015, 2023).

Birds were classified into two ecological groups (table 1):

- Waders (shorebirds dependent on shallow habitats).
- Divers (species feeding in deeper water).

## Habitat Classification

Study sites were classified depending on the presence or absence of shallow-water habitats along the lake shoreline. The presence of shallow habitats indicates natural coastal areas with a slope from zero to a depth of 4 meters, while their absence indicates modified or relatively deep coastal areas ranging from 60 cm to a maximum lake depth of 4 meters (table 1).

## Statistical Analysis

Because the abundance data were non-normally distributed and sample sizes were relatively small ( $n = 13$ ), Mann–Whitney U tests compared bird abundance between shallow and non-shallow habitats. Statistical significance was accepted at  $P < 0.05$ .



**Fig 1.** Juliana Lake in Benghazi.

**Table 1.** Diversity and abundance of Divers and Waders in Juliana through the IWC years.

| Year | No. of Divers | Abundance | No. Waders | Abundance | Min. depth (m) | Max. depth (m) |
|------|---------------|-----------|------------|-----------|----------------|----------------|
| 2005 | 22            | 2616      | 18         | 648       | 0              | 4              |
| 2006 | 22            | 2652      | 16         | 308       | 0              | 4              |
| 2007 | 20            | 3293      | 17         | 670       | 0              | 4              |
| 2008 | 11            | 1746      | 11         | 539       | 0              | 4              |
| 2009 | 14            | 1476      | 8          | 86        | 0              | 4              |
| 2010 | 20            | 2520      | 15         | 1068      | 0              | 4              |
| 2011 | 11            | 260       | 10         | 141       | 0              | 4              |
| 2012 | 8             | 196       | 8          | 102       | 0              | 4              |
| 2022 | 11            | 2788      | 4          | 91        | 0.6            | 4              |
| 2023 | 10            | 1826      | 6          | 20        | 0.6            | 4              |
| 2024 | 7             | 363       | 5          | 24        | 0.6            | 4              |
| 2025 | 8             | 356       | 12         | 84        | 0.6            | 4              |
| 2026 | 12            | 640       | 6          | 57        | 0.6            | 4              |

## Results

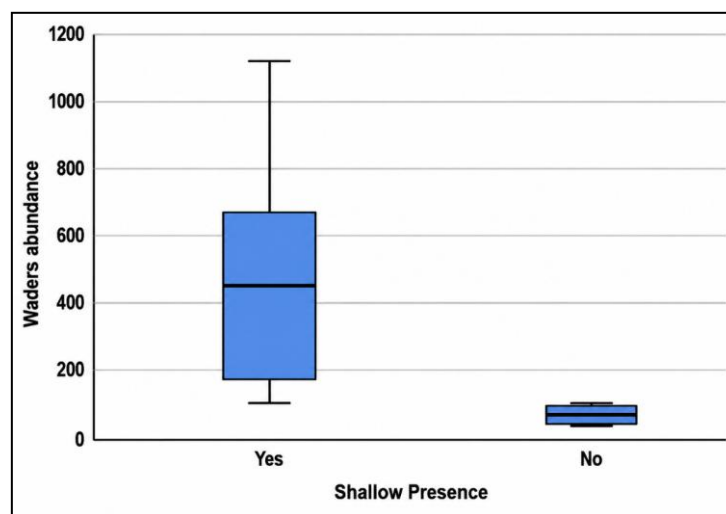
### Influence of Shallow Water on Wader Abundance

The Mann–Whitney analysis revealed a highly significant relationship between shallow habitat availability and wader abundance ( $U = 0.000$ ,  $Z = -2.928$ ,  $P = 0.003$ ). Sites containing shallow habitat showed a mean rank of 9.50 compared with only 3.00 in areas lacking shallow water, indicating consistently greater numbers of waders in shallow environments. The accompanying boxplot further illustrates this difference, showing considerably greater median abundance and wider variability where shallow habitat was present (fig. 2). The absence of overlap between the two groups reflects strong habitat selection by waders. These findings indicate that shallow-water habitat constitutes a critical ecological resource for shorebirds using Juliana Lake.

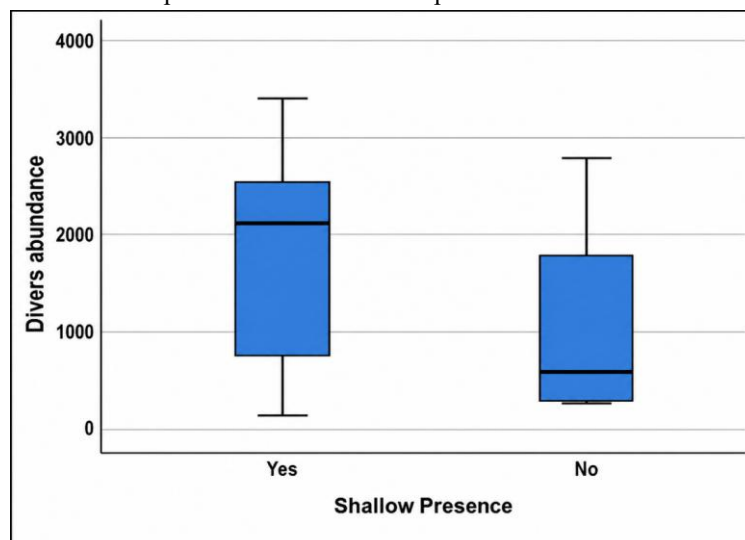
### Influence of Shallow Water on Diver Abundance

Unlike waders, diver abundance showed no significant response to shallow-water presence ( $U = 17.00$ ,  $Z = -0.439$ ,  $P = 0.661$ ). Mean ranks were similar between habitats (7.38 versus 6.40), indicating relatively even distribution regardless of shoreline depth. The boxplot demonstrates overlapping abundance distributions, consistent with the non-significant statistical outcome (Fig. 3).

This result reflects the ecological characteristics of diving birds, which forage primarily beneath the water surface and therefore depend less on shallow zones.



**Fig. 2.** The relationship between shallow water presence and wader birds' abundance.



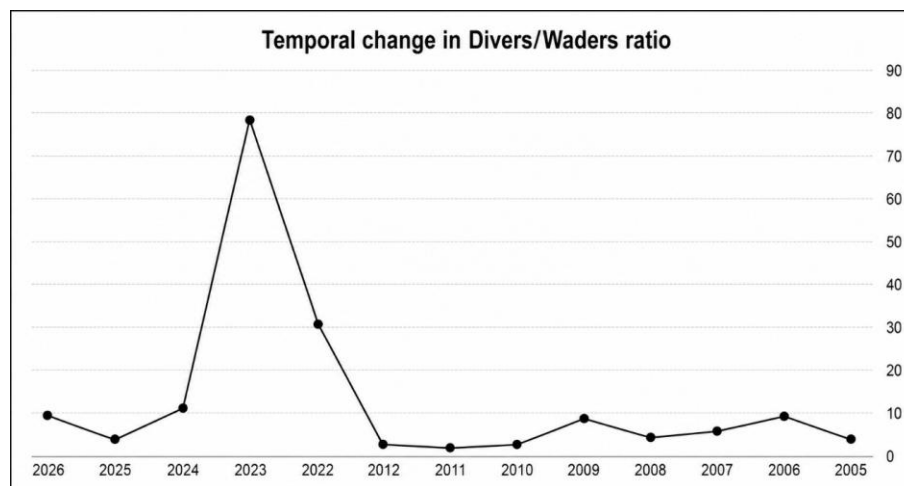
**Fig. 3.** The relationship between shallow water presence and diver birds' abundance.

### Long-Term Changes in the Diver-to-Wader Ratio

The temporal analysis of the diver-to-wader ratio revealed noticeable inter-annual variation throughout the monitoring period. Most years exhibited relatively low ratios, indicating either dominance of waders or balanced community composition. However, an exceptional increase occurred in 2023, after which the ratio declined toward previous levels (Fig. 4).

This temporary increase may reflect short-term habitat alteration, unusually low wader abundance, or increased utilization of deeper habitats by diving birds. The subsequent decline suggests that waterbird communities remain dynamic and respond rapidly to environmental changes.

Although causal relationships cannot be confirmed without concurrent environmental measurements, these temporal fluctuations coincide with ongoing urban development around the lake and likely reflect changing habitat conditions.



**Fig. 4.** Temporal analysis of the diver-to-wader ratio.

### Discussion

The results certainly demonstrate that shallow-water habitats are fundamental determinants of wader abundance at Juliana Lake. Shorebirds showed significantly greater abundance where shallow habitats remained available, supporting previous studies emphasizing the importance of water depth for foraging efficiency (Colwell & Taft, 2000; Elphick & Oring, 1998).

Shallow water permits access to benthic invertebrates while minimizing energetic costs associated with prey capture. Urban shoreline modification frequently eliminates these habitats through dredging, land reclamation, and construction of steep artificial banks (McKinney, 2006). Consequently, habitat loss is expected to reduce the carrying capacity of urban wetlands for migratory shorebirds.

Conversely, diving birds showed little response to shoreline depth. Their prey consists primarily of fish and aquatic organisms captured underwater, allowing them to exploit deeper habitats unaffected by shallow-water loss. Similar ecological partitioning has been documented across numerous European and Mediterranean wetlands (Bibby, 2003).

The pronounced temporal fluctuation in the diver-to-wader ratio suggests changing ecological conditions during the monitoring period. The exceptionally high ratio observed in 2023 probably reflects either temporary reductions in shallow-water availability or localized disturbances affecting shorebird distribution. Similar shifts have been associated with fluctuating water levels, human disturbance, and habitat change in Mediterranean wetlands (Ma et al., 2010).

Urbanization around Juliana Lake probably represents the principal long-term driver of these changes. Shoreline development reduces habitat complexity, fragments feeding areas, and increases anthropogenic disturbance. Many studies have shown that urban wetlands increasingly favor generalist species while reducing specialist shorebirds dependent upon shallow-water habitats (McKinney, 2008).

Despite these pressures, the persistence of substantial wader numbers in remaining shallow habitats demonstrates the conservation importance of protecting the lake's littoral zone. Maintaining shallow-water gradients, minimizing shoreline hardening, and preventing further reclamation should therefore constitute management priorities.

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One limitation of the present study is the absence of direct annual measurements of water depth, habitat extent, and urban expansion. Consequently, observed ecological patterns cannot be attributed exclusively to urbanization. Future studies should integrate remote sensing, GIS analyses, and hydrological monitoring to quantify shoreline change and establish stronger causal relationships between habitat alteration and waterbird responses.

## Conclusion

Analysis of more than two decades of IWC monitoring indicates that shallow-water habitats strongly effect the abundance of wading birds at Juliana Lake. Wader abundance was significantly greater where shallow habitat remained, while diving birds showed no comparable response. These findings support the hypothesis that urbanization-induced modification of shoreline depth disproportionately affects species dependent on shallow environments. Conserving and restoring these habitats are essential for maintaining the ecological integrity of Juliana Lake and its role as an important refuge for migratory waterbirds along the Mediterranean Flyway.

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## Compliance with ethical standards

### *Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

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