

Environmental Change and Ecosystem Services in the Albanian Sector of Small Prespa Lake: Challenges and Opportunities for Sustainable Development

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Abstract The Small Prespa Lake basin, located in southeastern Albania, is a distinctive transboundary landscape of significant ecological, geological, and cultural value. This study aims to deliver a comprehensive assessment of ecosystem services in the Albanian portion of the lake, utilizing the Millennium Ecosystem Assessment framework to analyze regulating, supporting, provisioning, and cultural services. The research combines karst hydrogeology, biodiversity surveys, land-use analysis, and archaeological heritage studies to understand the dynamic interactions between natural processes and human activities over time. The findings reveal that, despite ongoing environmental challenges such as sedimentation, eutrophication, and unsustainable water management, the basin still possesses strong potential for sustainable development. Key results highlight the importance of nature-based tourism, including geotourism, ecotourism, and cultural tourism, as a practical strategy to promote conservation, bolster local economies, and revitalize rural communities. Nonetheless, challenges like population decline, inadequate infrastructure, and limited community engagement remain significant hurdles. The study concludes that interdisciplinary scientific monitoring, adaptive land and water management, and the incorporation of ecosystem services into local development

plans are essential steps toward fostering resilience and long-term sustainability. An important contribution of this research is the proposal to designate the Small Prespa wetland as a "living laboratory" for environmental education, scientific innovation, and cross-border collaboration, thereby increasing its regional and international importance. Limitations include a lack of long-term ecological data and the need for more robust institutional frameworks to support implementation. Nonetheless, the practical implications are substantial, offering policymakers, local stakeholders, and international partners pathways to balance ecological integrity with socio-economic progress. Socially, the study underscores the importance of community participation and cultural heritage preservation as key pillars of sustainable management. Ultimately, this research advocates for a holistic approach that positions the Small Prespa Lake basin as a model landscape where ecological conservation and human development coexist harmoniously.

Keywords Small Prespa Lake, Albania, Ecosystem Services, Sustainable Development, Environmental Change

Figure 3. Hydrogeological map of the Prespa-Ohrid region. Source: after Hydrogeological map of Albania, scale 1:200,000 [14]

4. Human Interventions in the Albanian Sector

Over the past century, the Albanian and Greek parts of Small Prespa Lake have undergone significant human modifications. In Greece, the Agios Germanos stream was diverted to Big Prespa Lake between 1935 and 1945 to reduce flooding and support agriculture [38]. In Albania, a canal was built in 1953 to connect Small Prespa Lake with the Devoll River for seasonal irrigation [14,39].

The entire hydraulic system, designed with a maximum capacity of $10 \times 10^6 \text{ m}^3$ per year, was constructed in 1976 (Figure 4). However, because of malfunctioning sedimentation basins, approximately $40,000 \text{ m}^3$ of fine sediment accumulate in the lake each year, reaching nearly 1.2 million m^3 [39]. Satellite images from 1977, 2006, and 2022 (Figures 5 and 6) reveal a reduction in the lake's surface area, connected to reedbed expansion (*Phragmites australis*, *Typha angustifolia*) and eutrophication caused by agricultural runoff and domestic waste [40,41].

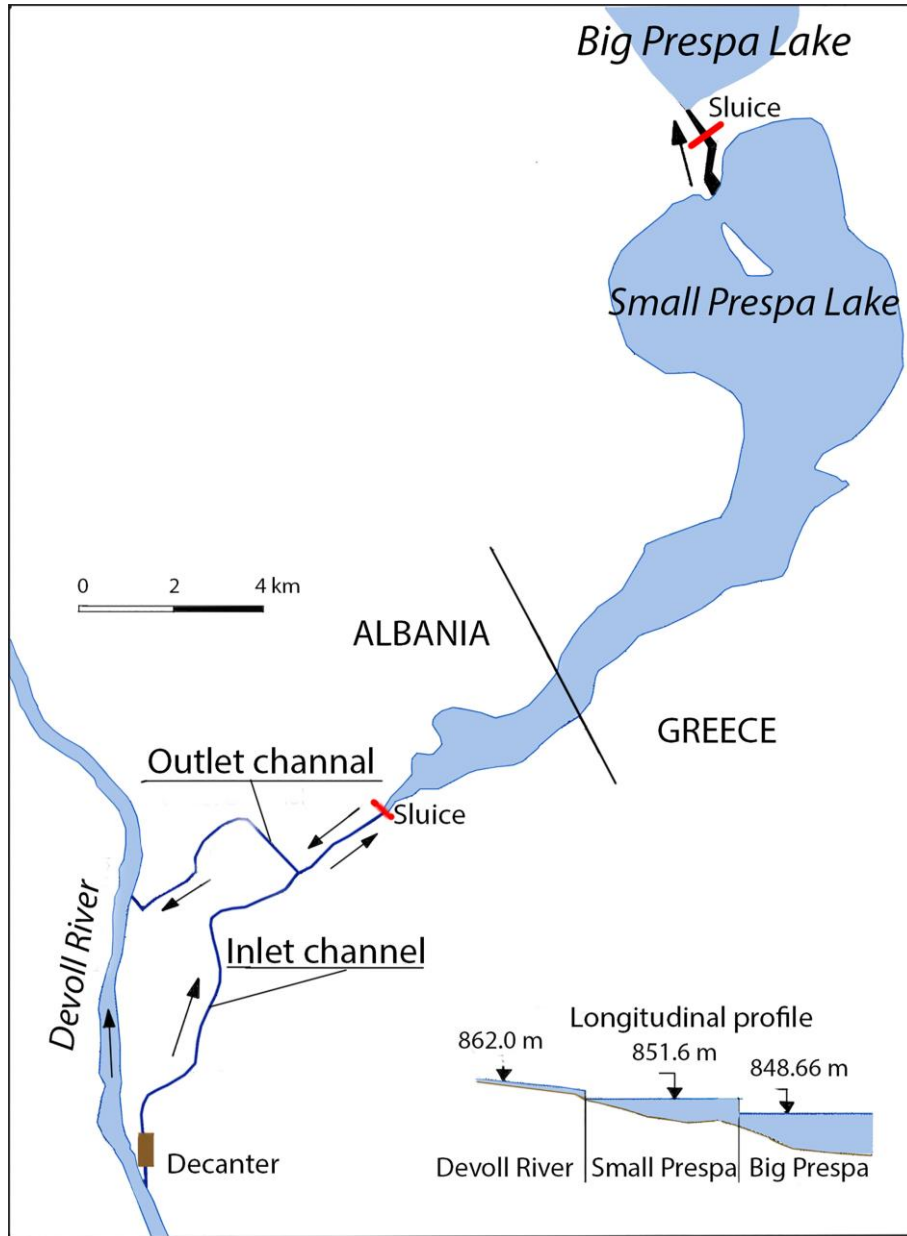


Figure 4. The irrigation scheme with diversion of the Devoll River to the Small Prespa Lake, after Pano [40]

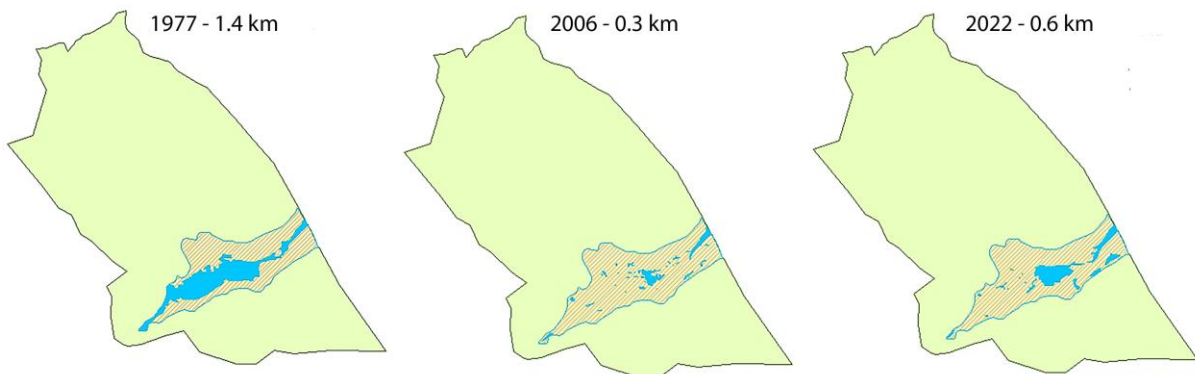


Figure 5. Albanian share of the Small Prespa Lake sub-basin and the chronology of surface reduction of the Small Prespa Lake by Devoll River sediments. (authors' mapping created with ArcGIS 10.1; based on satellite images from 1977, 2006, and 2022)



Figure 6. Sediments from the Devoll River caused the transformation of Small Prespa Lake; A - The westernmost part of Small Prespa Lake in 1957; B - The same area in 2015; C - A general view of Small Prespa Lake (photo from west to east); D - Reeds growing in most areas of Small Prespa Lake

5. Ecosystem Services in the Small Prespa Basin

Despite pressures from human activity, the Small Prespa Lake basin still offers a wide range of ecosystem services. According to the Millennium Ecosystem Assessment (2005), these services are classified into four main categories: regulating, supporting, provisioning, and cultural.

5.1. Regulating Services

The Small Prespa sub-basin includes various natural features and processes that help control air quality, moderate the climate, manage floods, and prevent erosion. Large limestone formations (Upper Triassic–Lower Jurassic, T3–J1) support karst development, where water enriched with CO_2 dissolves carbonate rock, forming extensive underground drainage systems. The high porosity of these karst rocks reduces surface erosion and reduces flood risks. Two main karst plateaus are located near the villages of Cerje and Rakicka, along with the karst fields of Shuec and Rakicka and the Treni Cave system (Figure 2). Key karst springs such as Ventroku, Proгри, and Manqarishti (Figure 3) are essential to the local water system. The basin also features dry valleys that only become active during heavy rainfall. Isotopic analyses of

δD and $\delta^{18}\text{O}$ in precipitation [42] show that seasonal climate variations affect the Prespa Lake system. Additionally, the lake's thermal inertia helps regulate the microclimate by warming the air in winter and cooling it during summer.

5.2. Supporting Services

Supporting services include ecological functions that sustain biodiversity and human well-being. The lake and nearby wetlands host various bird species, including the Dalmatian Pelican (*Pelecanus crispus*), Great White Pelican (*Pelecanus onocrotalus*), and Pygmy Cormorant (*Phalacrocorax pygmaeus*) [18]. Karst groundwater from Rakicka Mountain flows into the Devoll River valleys, recharging the Proгри and Manqarishti with average discharges of 120 l/s and 70 l/s, respectively [43]. Ventroku Spring, which was discharging 200 l/s, has been blocked by sediment. Carbonate soils (Rexinat), which are highly calcium-saturated and neutral in pH, support agricultural productivity [44]. Treni Cave, situated at 856 meters above sea level and approximately 300 meters long, holds significant archaeological value [45]. Excavations reveal continuous human occupation from the Neolithic period through the Middle Ages [46-48]. The cave also serves as a habitat for bat species such as *Miniopterus schreibersii* [49]. Treni Cave, at 856 meters above sea level and roughly

300 meters long, has notable archaeological importance [45]. Excavations show ongoing human presence from the Neolithic to the Middle Ages [46-48].

5.3. Provisioning Services

Provisioning services refer to tangible, physical goods that humans extract directly from ecosystems. In the Small Prespa basin, these services have historically played a key role in supporting local livelihoods and cultural development. Geological materials like limestone, mud, and gravel have been regularly used since the Bronze Age, as shown by the construction techniques seen in the fortifications at Trajani Castle and the Moku Castle complex [48]. The Ventroku Castle also highlights the region's traditional architectural heritage, where locally sourced stone and earth materials shaped the foundation of settlement infrastructure over thousands of years.

Carbonate rocks from the area have remained essential cultural resources, still used in mosaics, rock engravings, and traditional art. A notable example is the Spileja rock art from the Iron Age, which depicts hunting scenes and reflects long-standing interactions among local communities, natural materials, and symbolic expression [50]. In addition to geological resources, freshwater springs such as Shuec and Rakicka in the Buz ëiqenas area provide vital drinking water for surrounding villages, demonstrating the ongoing importance of provisioning services to contemporary community well-being.

Historically, water from the lake itself also served as an irrigation source. Between 1976 and 1995, Small Prespa played a significant role in supporting agricultural production in the broader Korça region, contributing to food security and local economies. The lake remains an important source of nutritional value due to its endemic fish species. Species such as *Barbus prespensis*, *Alburnus albidus*, and *Chondrostoma nasus* are part of a unique

evolutionary lineage and are key elements of traditional diets and artisanal fisheries.

The basin's wetlands also offer a variety of plant-based resources. Dominant species, such as *Phragmition australis*, *Scirpo-Phragmitetum*, and *Scirpetum lacustris*, have long been harvested for construction materials, traditional crafts, and livestock feed [51]. These macrophytes are ecologically critical but also economically valuable, providing renewable raw materials that support household subsistence practices.

Additionally, the region hosts a rich diversity of medicinal and aromatic plants, including *Primula veris*, *Orchis spp.*, and *Juniperus communis*, which are collected for culinary uses, herbal medicine, small-scale trade, and heating. Their continued use reflects a deep cultural tradition of ethnobotanical knowledge, contributing both to local livelihoods and to the preservation of intangible heritage.

5.4. Cultural Services

Cultural services encompass intangible benefits like recreation, education, and aesthetic appreciation. The basin's geodiversity supports geotourism, which improves public understanding of Earth's history and encourages conservation awareness [52-54]. Key geosites include Treni Cave, Stone Columns, Mumje Rocks, and Spileja Rocks, all suitable for guided tours, geoeducation, and speleological exploration (Figure 7).

The scenic landscape including mountains, slopes, water bodies, and diverse ecosystems, supports outdoor activities like hiking, cycling, camping, fishing, birdwatching, and art inspired by nature. Archaeological sites such as Treni Cave and prehistoric paintings (Figure 8), along with fortification remains near Ventrok and Gradishta, demonstrate the region's long history of human presence and cultural heritage.

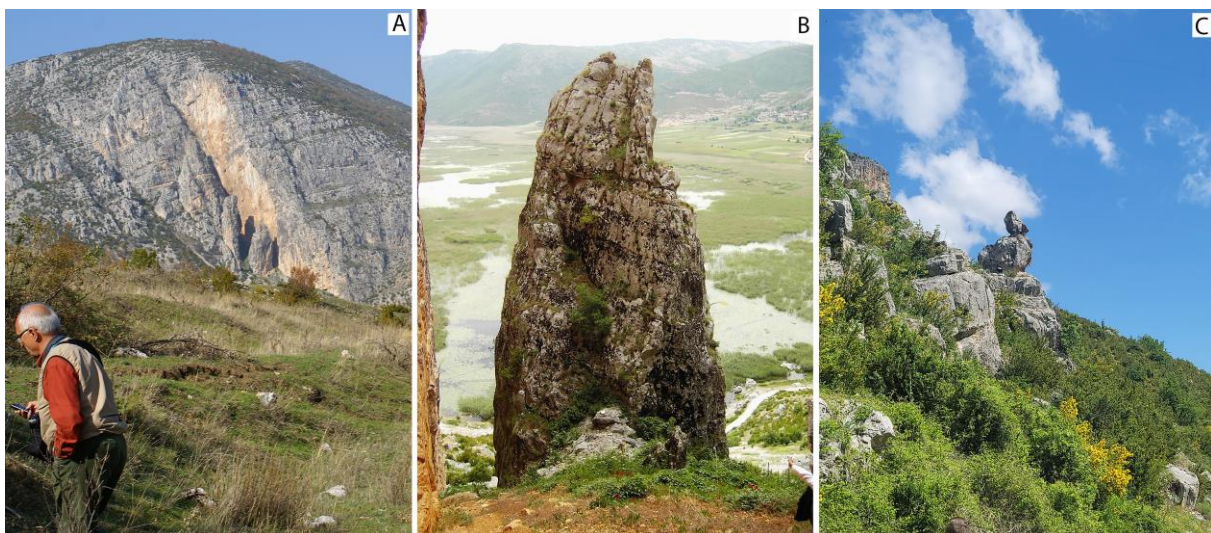


Figure 7. Karstic-erosional rock forms; A-Stone columns located near the Woolf Throat; B-Stone column; C- The Mummy's Rock monument.

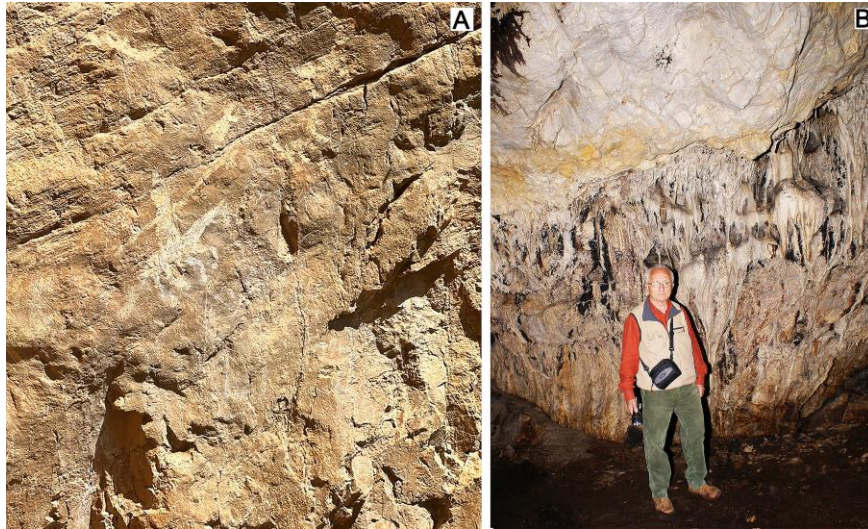


Figure 8. A- Prehistoric paintings of Spile B-Karst Cave of Teni, Neolithic settlement

The combination of natural and historical assets makes the Small Prespa basin an ideal location for sustainable tourism and conservation efforts. These cultural landmarks highlight the area's strategic and social significance throughout various historical periods. In addition to its artistic heritage, the Small Prespa Lake basin features a visually stunning, ecologically diverse landscape.

The catchment area features wet meadows, unique karst formations in the surrounding mountains, and gently sloping terrain, all of which boost the region's visual and recreational appeal.

This blend of natural beauty and historical importance increases the basin's potential for integrated conservation and sustainable tourism development.

6. Discussion

This study shows that the Small Prespa Lake basin has experienced significant ecological and hydrological changes due to long standing human interventions, especially the Devoll diversion/hyrotechnical scheme and the poor performance of the sediment decanter. Together, these factors led to the deposition of about 1.2 million m³ of fine sediments on the Albanian side. These processes caused reedbed expansion, a reduction in open water areas, and clogging of the karst network, directly impacting provisioning services (such as freshwater, fisheries, and plant biomass), regulating services (like nutrient retention and thermal buffering), and cultural services (including landscape quality and nature-based tourism). Similar findings are well documented for Mediterranean shallow lakes, where eutrophication and macrophyte overgrowth result in biodiversity loss, water quality deterioration, and weakened hydrological functions [20,51,52]. In comparable karst systems, conduit clogging and loss of subsurface permeability decrease spring discharges, fragment habitats, and disrupt lake aquifer exchanges,

confirming the mechanisms identified here [1,13,14].

Regarding provisioning services, evidence shows that artisanal fisheries and freshwater resources for agriculture and households are very sensitive to changes in water quantity, quality, and habitat structure. The reduction of open-water areas and chemo thermally induced changes negatively impact locally important fish populations and the food web. This matches international observations from Mediterranean shallow lakes, where eutrophication and the mixing of nutrient-rich inflows increase ecological instability and decrease sustainable fishery yields [55]. For plant-based services, reed biomass serves as a "double-edged sword": it is a traditional material and potential energy source, but its uncontrolled growth disrupts the habitat mosaic needed by waterbirds and fish. The literature suggests spatially rotated reed cutting and/or water-buffalo grazing to create shallow-water pockets and channels that improve habitat diversity, an approach tested in Prespa with positive ecological and socio-economic results.

In this context, the ecosystem services economic perspective provides a practical framework to clarify trade-offs and benefits of restoration. Methods like replacement cost (freshwater), net revenue (fisheries), resource rent (geological materials), and market price/cost savings (reeds and non-timber products) can convert ecological changes into decision-relevant monetary values. Incorporating these valuations into cost benefit analyses of "with/without intervention" scenarios (such as periodic decanter maintenance, seasonal control of Devoll–Prespa inflows, reed/buffalo programs, riparian buffer zones) would allow prioritization of measures with the highest benefit-to-cost ratios and most tangible co-benefits (for example, improved water quality, enhanced birdwatching, and increased local income).

From an integrated management perspective, our findings support a collaborative transboundary plan that aligns conservation goals with local development efforts. Implementing extensive agriculture with reduced

agrochemical inputs, especially during the high-rainfall October–February period, should reduce nutrient runoff. The installation and maintenance of green buffer strips along micro-streams and the lakeshore can trap sediments and phosphorus before they reach the lake; meanwhile, water-quality monitoring (TP, TN, chlorophyll-a, transparency, dissolved oxygen) should be institutionalized with seasonal schedules and standardized stations. A key element is regulating water exchanges between the Devoll and Small Prespa: inflows should only be allowed when quality thresholds are met, and hydrotechnical interventions (such as sediment traps and targeted dredging) should be planned based on environmental impact assessments [20,51].

Cultural and nature-based tourism can offer a way to diversify local livelihoods, but it requires light footprint infrastructure such as trails, viewpoints, and interpretive signage and service capacity including guiding, hospitality, and safety designed to respect protection regimes and environmental carrying capacity. International examples demonstrate that combining geotourism with birdwatching and cultural heritage interpretation results in steady revenues, fosters community engagement, and strengthens landscape identity [18]. For Small Prespa, integrating into Korçë itineraries will likely boost visitor flows, which must be managed through carrying-capacity thresholds and experience-quality standards to prevent new pressures.

Key limitations of this study include the absence of long-term data on spring discharges, species-specific annual fish catches, and detailed local market data for non-timber products. Additionally, parts of the historical hydrotechnical record depend on secondary sources such as technical reports and institutional memory. Future research should focus on: (i) modeling sediment budgets and nutrient pathways at the sub-basin level; (ii) conducting controlled management experiments (e.g., buffalo grazing versus mechanical reed cutting) with pre- and post-measurements of water quality and biodiversity; (iii) performing comprehensive monetary valuations following TEEB/MEA methods across different restoration scenarios; and (iv) assessing socio-economic elasticity how quickly and strongly ecological improvements translate into local income and employment. Integrating these elements would support an adaptive management framework where decisions are periodically updated based on ecological and economic indicators.

In sum, Small Prespa constitutes a natural laboratory where balancing conservation with sustainable use is attainable through cost-effective, nature-based interventions, while the economic valuation of ecosystem services provides a common language for scientists, policymakers, and communities. Implementing a package of measures, such as selective sediment control, inflow regulation, reed management with buffalo grazing, extensive agriculture, and low-impact nature tourism, can generate ecological and socio-economic co-benefits, in line with international best practice for analogous karstic lake

systems.

7. Conclusions

Although geographically small, the Albanian sector of the Small Prespa Lake basin concentrates exceptional natural and cultural assets that can underpin sustainable development at local, regional, and international scales. The area combines high geodiversity and biodiversity with a dense archaeological and historical record, making it an important arena for integrative conservation, development planning, environmental education, and nature-based tourism. Notably, Trajan's Castle, recognized as the largest fortification by surface area in Albania, constitutes a cultural monument of outstanding value, and its systematic archaeological investigation, conservation, and conversion into a fully visitable site are strategic priorities. In parallel, Tren Cave, among the oldest caves in Albania and the Balkans, retains significant stratigraphic, palaeontological, and cultural-historical deposits; any controlled opening to visitors should be accompanied by strict protocols to protect resident bat colonies and in situ archaeological layers.

Despite these exceptional assets, persistent environmental and socio-economic pressures, sedimentation and eutrophication of littoral habitats, together with demographic decline, underscore the need for integrated, cross-border management that aligns ecological integrity with cultural-heritage preservation and livelihood diversification. Lessons learned from effective conservation actions on the Greek side of the basin should be contextualized and adapted to the Albanian setting, emphasizing (i) agricultural practices that minimize agrochemical runoff, (ii) seasonal fishing restrictions and enforcement, and (iii) the incorporation of conservation objectives into tourism planning.

From a tourism development perspective, promotion must be balanced with heritage preservation. Improving access and interpretive infrastructure to Trajan's Castle, Tren Cave, the prehistoric Spile rock paintings, Shuec Fortress, and key geomonuments (e.g., the "Mummy Stones"), along with surveying and documenting additional archaeological sites, would significantly increase the destination's cultural value. However, the current lack of tourist signage and basic amenities (such as accommodations and food services) continues to restrict sustainable growth; therefore, targeted investment in wayfinding, low-impact access, visitor safety, and bilingual interpretive media is crucial.

Finally, engaging the community through training and participatory stewardship is essential for embedding environmentally responsible tourism and enhancing local guardianship of natural and cultural resources. Additional investments in low-impact infrastructure, destination marketing, and professional guiding and interpretive services are necessary to unlock the basin's full potential.

Including the Albanian side of Small Prespa in regional thematic routes, especially those focused on Korçë, can increase visibility, create diverse income sources, and support the long-term protection of this uniquely rich natural and cultural landscape.

Conflicts of Interest

The authors declare no conflicts of interest.

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