https://doi.org/10.1038/s40494-025-02118-7

Oases of the world: Urgent call to save key archives for cultural and biological diversity

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Oases are key to humanity's settlement in drylands in the past, today, and in the future. They form complex geo-bio-cultural systems of pivotal importance. Present climatic, economic, and social changes may lead to the demise of tangible and intangible values in and of oases, potentially affecting 500 million people. We aim at raising awareness of the accelerating threat to oases and argue for immediate action to protect this unique system.

Oases occur globally and at varying elevation in arid to semi-arid environments. Their habitats range in size from just a few square metres to thousands of square kilometres. Oases can be classified into three groups distinguished based on the intensity of human intervention: natural oasis, traditional oasis, modern oasis (Fig. 1). Oases shaped by agriculture represent unique forms of humanity's adaptation to constraining environmental conditions[1]. Long-term successful practices often combine different crops, including date palms, fruit trees, vegetables, cereals, and fodder, with livestock breeding. Over millennia, oasis farmers have guaranteed a variety of ecosystem and cultural services, such as food, shelter, recreation and the maintenance of traditional knowledge systems, securing biological, cultural, and linguistic diversity linked to traditional practices of managing soils, animal and plant species, as well as water.

Oases are located in some of the driest regions in the world and are therefore among the most vulnerable systems to the impacts of climate change and related land-use changes. Increasing industrialisation of agricultural production, including expansion of intensively irrigated monoculture plantations, overexploitation of groundwater, and declining water tables exacerbate risks for systems of pivotal biological and cultural importance. The effects of these drivers and changes reach far beyond local boundaries of oases and include regional declines in biodiversity, loss of tangible and intangible heritage, and vanishing farming traditions that have ensured humanity's survival and prosperity in arid regions for millennia.

Researchers and the public frequently imagine oases as stable islands of fertility in arid lands. However, oases, their local communities, and societies that rely on the multiple ecosystem and cultural services provided by oases are under accelerating threat. A hidden global crisis is gaining momentum under ongoing climatic, economic, and social changes that may lead to the demise of biological and cultural values in and of oases, potentially affecting 500 million people. Due to the appalling condition of many oases, we are calling for urgent actions to initiate comprehensive and systematic studies to gain a fundamental understanding of the complex interplay of social, cultural, economic, and environmental factors, locally to globally. We are convinced this will produce the data, knowledge and policy guidance required to mitigate the deterioration of oases, foster their sustainable development, and ensure the preservation of unique records of biological and cultural heritage.

Oases are complex geo-bio-cultural systems that require systemic approaches

The viability of oases as settled spaces, archives of tangible and intangible heritage, as well as hotspots of biodiversity *sensu lato*, relies on the interplay of secure local water sources and a dynamic network of knowledge connecting oases with each other and with external socio-economic centres through trade and exchange[2–4]. The on-going deterioration of oases and a lack of prospects for recovery result in a decline of traditional farming knowledge, which exacerbates loss of biodiversity, culture and heritage[5] (Fig. 2). For example, recent studies demonstrate how date palm agrobiodiversity is critical to the sustainable development of oases in northern Africa[1]. Documenting local knowledge about endogenous varieties and characterizing their genetic integrity and mode of propagation represent the essential leverage needed to ensure sustainable livelihoods[6]. Recent studies recommend rethinking models for development and elaborating new actions that respect local specificities, consider environmental equilibria, and revitalize entire ecosystems[7]. Agriculture in oases has been changing rapidly, albeit with poor documentation. Current research explores how agricultural and food heritage are entangled, revealing reasons for shifting crops and interpretation of both short- and long-term adaptations to changing physical, such as climate, and socio-economic conditions[8]. Faced with multiple threats to oases, the scientific community needs to better document and understand endangered legacies associated with crop selection, food knowledge, and their ecohydrogeological and biological contexts.

Oases represent model systems for examining spatial and temporal patterns in geo-bio-cultural diversity[9]. Despite their ecologic, social, economic, and cultural importance, these agro-ecosystems face multiple threats[10]. For example, recent studies in Siwa Oasis, Egypt, located at the crossroads of ancient Trans-Saharan routes, document threats to traditional crops and linguistic diversity[11]. At the same time, water salinization at Siwa may soon preclude traditional agricultural and cultural practices[12]. A dramatic loss of intangible heritage (i.e., local customs and traditions) was

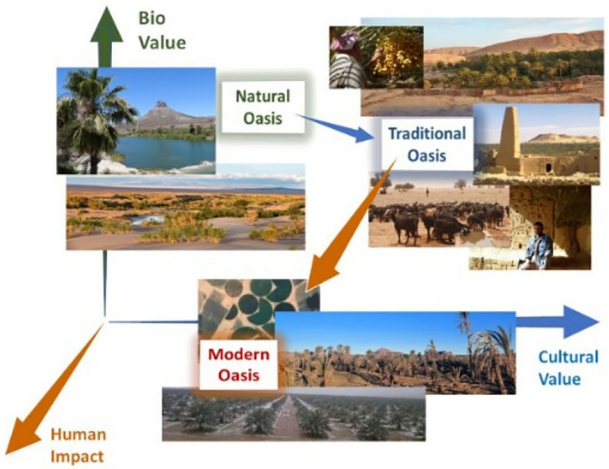

Fig. 1 | Schematic representation of the main types of oases and their relation to biological and cultural values. NATURAL OASES are defined by an unaltered geological origin and are often related to artesian springs. Increased geo- and biodiversity, often with high species endemism in natural oases, signal long-term stability of ecological niches. TRADITIONAL OASES, in contrast, are man-made and linked to the implementation of water management systems. They are characterized by increased bio-cultural diversity. MODERN OASES have developed with increasingly effective water extraction technologies, irrigation techniques, and industrial infrastructure in the last century. They support intensified production through lower crop diversity, unimodal water supply, and dependence on exogenous fertilizers and energy sources. With intensive agriculture and revenue-oriented management, modern oases are often degraded biologically, geochemically, and culturally.

already noted several decades ago[13]; however, that loss is still not being systematically addressed today. Preserving the integrity of oases requires profound knowledge about aquifers, springs, soil and human interactions as well as their interlinked impacts on natural and agricultural biodiversity[14]. Successful conservation further requires systematic study of climate change, infiltration and aquifer mechanics, and surface expression, particularly for karstic and fossil-water aquifers, as well as geothermal systems. Effective conservation must consider strategies of extraction, distribution and use of groundwater[15]. Results of ecohydrogeological[16] research at oases can inform policy makers on how best to respond to the Paris Agreement on Climate Change and to the Kunming-Montreal Biodiversity Framework and develop short-, medium-, and long-term adaptation plans[17].

Oases are key to humanity's settlement in drylands in the past, today and in the future

Oases have played a crucial role in humanity's societal evolution but are becoming increasingly vulnerable. They exemplify the human capacity to inhabit some of the most extreme environments on the planet. Research on these unique settings is essential for developing effective climate adaptation strategies in drylands[18]. The prehistoric settlement of oases started roughly one million years ago, for example in the El Kowm Basin in the Syrian Desert[19]; long before humans started transforming the natural landscape of oases into highly specific agricultural systems about 5000 years ago[20]. Quaternary archaeological and paleo-environmental records provide important data on the pristine state of oases, human impacts, and their diachronic evolution. Available evidence indicates, for example, that hominin occupation of arid regions was not limited to humid climatic episodes but rather determined by local hydrogeological conditions[21]. Other important diachronic data include the effects of increased salinity on the natural habitat and human use[22]. Archaeological and paleo-environmental records from oases preserve a wide range of data and information, likely including key evidence on human adaptation to environmental and social-ecological change through time. Integrated research programmes should include the study of pre-agricultural and agricultural phases of human occupation, new excavations of specific localities, and analyses of the extensive collections housed in museums and research centres.

Projects aimed at preserving contemporary lifeways in oases should demonstrate and scale up successful, sustainable land-use practices and transmission of related knowledge[23]. They should also promote appropriate approaches to soil, water resource and biodiversity management, as well as actions that enhance oasis agro-ecosystem services[24]. Government policies to develop oasis agro-ecosystems should be framed within the context of applied research. Projects focusing on the preservation of bio-cultural life in and of oases may strengthen the institutional, management, and technical capacities of key stakeholders. Further, they will reinforce locally adapted practices to preserve landscapes under sustainable land, soil, and water management and ensure successful combinations of traditional and innovative practices. These approaches will help preserve diversity, safeguard vulnerable species, and increase awareness of the role of small family farmers for sustainable resource management.

Why we need a global effort for resilient oases

Oases reflect complex networks shaped by interlinked geological, hydrological, environmental, and socio-economic processes. Archives preserved in oases document how societal, economic, and climate changes have impacted these ecosystems in the past and how these complex adaptive systems have been modified in response to shifting conditions. Today, the unsustainable use of groundwater and other resources exacerbates the impacts of climate change and reduces the resilience of these ecosystems, in some cases devastating them entirely. This crisis is driving increased emigration from and abandonment of oases, the erosion of traditional knowledge, and a decline in biodiversity. At the same time, population growth, including relocation from other regions, is contributing to the expansion of existing settlements and the rise of new ones, thereby dramatically increasing the aforementioned risks.

To raise awareness about the values and risks associated with oases and to promote initiatives supporting their preservation, researchers from the Senckenberg Society for Nature Research, Germany, in collaboration with the UNESCO Regional Office for Egypt and Sudan, established a global network of 30 researchers from diverse disciplines. We introduced this initiative and its goals at COP 28 in Dubai and elaborated upon its mission at an international workshop on cultural heritage at Jebel Faya, UAE, in 2024. The goals of this Oases Initiative are linked to the COP 28 Joint Statement on Climate, Nature and People and the Emirates Declaration on Cultural-based Climate Action. Our initiative supports the UN Convention of Biological Diversity (CBD) and the implementation of the Post-2020 targets, the UNEP Ecosystem Restoration Decade Flagship Programme, the UN Future Summit, the UNESCO Decade for Science for Sustainable Development, and the FAO Family Farming Decade.

We argue that changing climatic, environmental, and anthropogenic pressures pose challenges that require bold and urgent action to protect oases and save their essential roles for cultural and natural systems in arid lands. We emphasize that any prospective global effort must recognize oases as components of dynamic networks with inter-regional links and interdependencies that offer both challenges and resilience. To guide the process towards resilience and increased organizational flexibility of oases systems, we advocate the Resilient Oasis Concept (ROC), which rests on three

Fig. 2 | Example of oasis types, their values and threats. a Natural oasis in Mongolia. **b** Traditional oasis in southern Morocco. **c** Traditional three-level agricultural system (Palm trees, fruit trees/bushes, cereal and vegetable cultivation) from southern Morocco. **d** Salination of soil in the Dakhla Oasis in Egypt. **e** Collapsing mudbrick architecture indicating loss of traditional knowledge in Mides Oasis in Tunesia. **f** Currently preserved mudbrick architecture in Ziz oasis in southern Marocco.

Fig. 3 | Steps recommended to initiate global action for the protection of oases.

FIRST STEPS TOWARDS OASIS PROTECTION

1. Contribute to the development of a global map of oases and the identification of oases that exhibit urgent conservation needs.
2. Establish a knowledge exchange platform and create a master bibliography of oasis-centered investigations.
3. Determine reference / baseline conditions by studying near-natural oases worldwide.
4. Support comprehensive documentation of traditional and ecological knowledge (TEK) about biocultural diversity in oasis, including agrobiodiversity and aquatic biodiversity.
5. Systematically assess water and soil resources and related management strategies. Document sensitivity to depletion and degradation.
6. Analyze oases based on a social-ecological network approach and identify the drivers determining cultural and biological diversity in and of oases.
7. Develop research agendas specifically considering ecological, cultural and social resilience and their mutual impacts and interactions.
8. Decipher the oasis niche in human settlement systems. Identify the role of oases in larger regions (e.g., the entire Sahara), and globally.
9. Conduct holistic analyses of ecosystem energy and materials subsidy exchange in relation to ecosystemic, cultural and socio-economic values.

foundations: (1) initiating a grass-roots approach to identify imperatives, values, and ideas established by local communities; (2) establishing state-of-the-art, comprehensive international research agendas to document the components and processes in and of complex oasis systems, and to identify strategies to mitigate impacts on biodiversity, cultural systems, heritage and ecosystem services; (3) developing recommendations to support decision-makers in identifying and implementing policies that increase the sustainability and resilience of oases worldwide. ROC is built on a social-ecological network approach[25] to record and map the variety of stakeholder interests and interactions with social, cultural, economic, political, and natural environments across the full range of global oases.

Important first steps (Fig. 3) towards the protection of oases include establishing a knowledge platform that facilitates access to data and information and fosters exchange among local communities, researchers, and decision-makers. In this way, users can record and analyze data and information about past, present, and future developments in oases. A critical component of such a platform will be the establishment of a master bibliography of research on oases. Beyond providing access to information and opportunities for exchange, holistic research remains essential. Research agendas should explicitly address ecological and social resilience and their mutual impact through identification of coping, adaptive, and transformative capacities that enable comparative analyses. Due to the increasing loss of intact oases, we argue that research on the ecohydrogeology of oases, oasis networks, and the oasis' niche in human settlement systems is urgently required to build a comprehensive understanding of oases and to facilitate clear, well-reasoned recommendations for their protection and management. We are convinced that concerted global action, initiated without delay, can safeguard these unique oasis systems.

Data availability

No datasets were generated or analysed during the current study.

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Received: 1 September 2025; Accepted: 14 October 2025;
Published online: 06 November 2025

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Author contributions

Conceptualization: N.S., N.J.C., and K.T.; Writing - Original Draft, Review & Editing: K.B, N.S., M.F., S.S.A., M.C., M.D., L.F., R.F., J.A.H.-A., K.H., J.M.J., C.J., K.K., J.Mc.C., L.P., A.A.S., T.S., L.S., K.W., C.Z., N.J.C., K.T.

Competing interests

The authors declare no competing interests.

Additional information

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