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ECOSYSTEM RESTORATION AS A NATURE-BASED SOLUTION: A CASE STUDY OF WADI RUM

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Abstract: This research examines the significance of ecosystems and their restoration in local or landscape-level management, using a case study of the Wadi Rum eco-region in southern Jordan. It emphasizes the need for nature-based solutions in light of considerable worldwide ecological deterioration. Aims: As global environmental degradation accelerates, ecosystem restoration has emerged as a critical strategy to combat land degradation, biodiversity loss, and climate change. This research investigates the role of ecosystem restoration as a nature-based solution (NbS) through a case study of the Wadi Rum Protected Area (WRPA) in southern Jordan. The aim is to assess restoration efforts in Wadi Rum, evaluate their effectiveness, and derive lessons to inform sustainable restoration practices globally. Method: The study employs a case study methodology, combining multiple site visits over five years with extensive literature review and stakeholder interviews. Both qualitative and quantitative approaches were integrated, including ecological and socio-economic data collection, GIS-based geographical analysis, and participatory methods involving local communities. Key ecological indicators and restoration practices were monitored and evaluated to determine the effectiveness and sustainability of interventions. Results: Findings reveal that Wadi Rum's ecosystems face critical threats from tourism, aquifer depletion, overgrazing, and climate change. Despite these challenges, several passive and active restoration techniques, such as habitat protection and community engagement initiatives, have shown promising results. Ecological indicators such as biodiversity distribution, soil stability, and community participation rates have improved in areas under active restoration. Geographical mapping highlighted zones of significant environmental change and areas where restoration efforts yielded the greatest impact. Interpretation: The research demonstrates that integrating ecological restoration within a broader NbS framework can significantly enhance ecosystem resilience and community well-being. Success in Wadi Rum underscores the importance of community participation, adaptive management, and the integration of socio-economic benefits into restoration projects. These insights offer scalable models for ecological restoration in other arid and semi-arid regions globally, emphasizing that sustainable outcomes depend on interdisciplinary approaches and localized, inclusive practices.

Keywords: Ecosystem Restoration, Nature-based solutions (NbS), Wadi Rum Protected Area (WRPA)

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INTRODUCTION

Ecosystem restoration - from the regeneration of degraded soils through rainwater harvesting to the rehabilitation of mountains that trap and channel precipitation - has been of great significance in many ancient cultures. A number of spiritual traditions center on stories that transfer lessons of ecological balance and harmony into social and spiritual thought or practice. Thus, for centuries, millions of individuals have worked to combat desertification, eroded slopes, and land abandonment through the implementation of various environmental technologies. As we face climate catastrophe and global industrial expansion, ecosystem and land restoration are growing as key strategies and methods for nature-based solutions, capable of supporting the scalability and sustainability of global environmental management efforts (Quintero-Angel et al., 2023). This paper explores the importance of ecosystems and their restoration in local or landscape-level management through a case study of the Wadi Rum ecoregion in southern Jordan. It outlines the necessity of nature-based solutions based on a background of significant global ecological degradation. The Wadi Rum case study is described here as a living laboratory within which nature-centered methods of environment and ecosystem repair have proven effective

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and resilient in restoring soil and ecosystems on degraded lands. The message promoted in this paper is that ecosystem restoration, capable of amplifying natural design patterns or processes, holds solutions to fields such as eroded land capping and restoration, indigenous land management, environmental engineering, landscape management and restoration, rainfall harvesting, soil moisture collection, landform engineering, sediment retention, as well as strategies supporting carbon sequestration and regional resilience building (Zhensikbayeva et al., 2024; Kurar & Kavacik, 2023). The central aim of the research presented is to better understand how to restore ecosystems that are showing signs of degradation. For that purpose, we have identified mitigation and adaptation to climate change as segments of vital importance to the overall health and welfare of residents and visitors to the protected area. In pursuing these objectives, the guiding questions of this research are: What restoration efforts are currently taking place, or have been implemented, in Wadi Rum? Are there any measurable changes that can be made to evaluate the success or failure of the restoration efforts in Wadi Rum? To develop an answer to these questions, we have decided to use Wadi Rum as a case study. Our choice was made after several personal visits to the area during the last five years and through a brief review of the existing literature on Wadi Rum. The importance of this research is threefold. Firstly, it provides an opportunity to record some original primary data from Wadi Rum. Secondly, the processes of degradation and the other pressures enumerated in this chapter replicate a global pattern of increased stress and degradation of protected areas in response to the increasing impacts of human activity. Thus, the research not only makes a valuable contribution to the existing body of literature on Wadi Rum but also to the practice of protected area management and ecosystem restoration more broadly. Thirdly, while ecological restoration efforts in Wadi Rum have been carried out in the past, systematic data on such efforts, their outcomes, and their efficiency have never been collated or evaluated in an academic article. Such an undertaking can help to improve future ecological restoration practices in Wadi Rum and globally.

2. BACKGROUND OF WADI RUM PROTECTED AREA

Ecosystem restoration is undergoing renewed interest, particularly in the form of forest restoration and associated work as a key nature-based solution in the context of changing Nature's Contributions to People. While degraded lands, deforested and eroded, have been a focus across continents and decades, including the Thar Desert, the Newe Hishu Desert in Israel, and the Bajio in Mexico – emulated by advocates for soil and conservation districts engaged in controlling erosion in the US Dust Bowl of the 1930s – no comprehensive efforts in restoration have addressed the lifestyle and culture of the people living there. Societies and cultures of all regions have watched degradation unfold over long periods. Three trends have been particularly alarming in recent decades, less so due to revelation and more due to synthesized and circulated data (Al Dein, 2022; Sen et al., 2024; Al Fahmawee & Jawabreh, 2022a).

Degradation and erosion continue perpetuating desiccation and accelerated soil loss while aquifers – and therefore, the hydrologic link to fertility and bodies of water – continue to be overdrawn. These historical and current patterns highlight the necessity for restoration. Additionally, efforts that restore ecological functioning can be as much as 25 times lower than appropriations for high-tech interventions to secure water elsewhere, such as desalination or dam construction. An integrated land, water, and soil husbandry approach encompassing stewardship is applicable for all ecosystems with pre-industrial human populations or impacted analogs worthy of emulating for contemporary socioeconomic reasons. Ecosystem health and associated ecosystem functioning are the significant criteria for sustaining quality of life.

Ecosystem restoration has become the talk of the town in conservation science. The interrelationships between various forms of environmental degradation and human security need an interdisciplinary and multiform approach to ecological restoration. As a result, ecosystem restoration has evolved as a transversal ecosystem management approach intersecting with many other related fields such as rewilding, ecological gardening, ecological social work, reconciliation ecology, and many others (Le et al., 2024; Lin et al., 2022; Al Fahmawee & Jawabreh, 2023 ; Al-Shawabkeh, 2023). Diverse as these approaches are in their goals and philosophical foundations, they all assume the possibility of humans as ecosystem healers, no matter the reasons for or the scale of ecosystem degradation. The theories and practices of ecosystem restoration have deeply grounded theoretical and ideological roots dating back to at least the early 1940s for restoration ecology, the 1920s for nature conservation philosophy, and the 1910s for forestry science. The intellectual and ideological roots of ecosystem restoration shape the practice of restoration ecology and help explain the emergence and multifaceted identity of the different approaches to ecosystem restoration and management today.

The field of ecosystem restoration has not consensually defined limits yet, but there seems to be a consensus about certain concepts and basic principles of using human interventions to improve and restore ecological functions and ecosystem services. For some, ecosystem restoration is a social-ecological process of renewing and re-renewing the environmental and cultural bases of human relations with the environment, seeking possible futures based on better understandings of their past (Sutiksno et al., 2024 ; Al Dein, 2021 ; Al Fahmawee & Jawabreh, 2022b). Others define it as a process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, resulting in a forest ecosystem. Consider ecosystem restoration as a multi-faceted social and ecological intervention whose ambition is to create the conditions for a self-sustaining dynamic recovery of the ecosystem, specific species, and the ecosystem services they supply. Reconstruction is yet another area within ecosystem restoration, defined as the re-creation of a pre-existing community where management aspirations are to widely be part of influencing the recovery of the ecosystem. A common theme for the abovementioned definitions is that while broad in scope, they are also strongly and exclusively oriented towards deliberate and targeted human interventions, paying little attention to what happens in cases in which human intervention is minimized. The theoretical framework developed can be applied in broader and shallower terms to support such a view. Building on the early theoretical work, this approach considers that the more fundamental concept of restoration ecology begins from the premise of recovery or repair, most often in terms of human values (Jawabreh & Al

Fahmawee, 2023a). This theoretical approach is, therefore reflective of the restoration practice and strategy applied in various contexts. Similar to the many definitions provided for ecosystem restoration, its importance has diverse meanings: from the willingness of scientists, practitioners, and land managers to restore ecosystem functions and sustain or encourage particular ecosystem services and the biodiversity levels based on the restoration management historical or cultural values at multiple spatial and temporal scales; to conservational considerations that push to the optimum conditions for insufficiently explored ecologies to reveal the discovery of new species and facilitate the global exchange of genes. But the challenges have also been vividly laid out: ecosystem resilience is determined by the social-ecological state of the system, and because financial and human resources are spread very thin across the planet, priorities are necessary.

Although the latest trends in literature demonstrate a growing divergence of views on the aspects of restoration, the most widely accepted definition of ecosystem restoration is still that of the Society for Ecological Restoration. According to this understanding, 'ecosystem restoration' means "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." The definition provided by SER is instrumental in highlighting the multi-dimensional aspects of ecological restoration, from physical rehabilitation works to the structural processes defining the compositions of restorative interventions, holistic projects, restoration of new ecologies, and participative decision-making as innovative management practices, to name a few. Professional restorationists share the view that similarities and differences occur among and within all ecosystem types. Four different levels of restoration success are suggested for possible objectives as ultimate targets, which fall within three categories: repairing the components; achieving ecological criteria that are not directly linked to any specific species and might therefore be considered "structural" or "functional"; rehabilitation or full restoration of the ecological functioning or integrity; and re-creation of the original ecosystem according to reference conditions (Jawabreh & Al Fahmawee, 2023b; Jawabreh, 2020).

There are countless different classifications of the types of restoration. Some are based on species, sites, modality, handicap, and social factors. The scope of ecological restoration practices encompasses a wide range of restoration actions and measures. Many typologies of desired results concerning ecological restoration actions are adopted, including the complete amelioration or reduction of negative impacts caused by human activities, the recovery of a previous situation, or the restoration of the "ecological functionality" of an area in the context of a new land resource. Subtitling all these intended goals as "ecological restoration" likely accommodates some propaganda to provoke support and funding (Jawarneh, 2021; Morino et al., 2022). These insights are crucial for addressing the situation in Wadi Rum, where supported actions aim to redefine the North-Western range of the protected area system.

Importance of Ecosystem Restoration

Ecosystem restoration is a critical means of maintaining the integrity of ecosystems and ensuring their continuous ability to provide services to human beings and diverse life. One of the major environmental benefits of restoration is the mitigation of climate change by enhancing carbon storage and sequestration in vegetation and soils. The restoration of degraded areas is also a means for conserving biodiversity by creating more habitats and corridors for species. It can also reduce loss and damage to lives, livelihoods, and properties (Jawabreh et al., 2021; Shatnawi & Obaidat, 2022; Seidualin et al., 2024). There are many forms of nature-based solutions that rely on ecosystem restoration to help in disaster risk reduction, such as restoring mangroves to buffer tidal waves or protecting watersheds to reduce the risk of flash floods. Restoration work can also enhance ecosystem services like water purification and the provision of products such as clean water, timber, and non-timber forest products, staples, indigenous knowledge, and cultural values. It can thus improve human well-being and provide an asset base for adaptation to climate change and other stresses. Restoration can potentially deliver greater efficiency, convenience, and cost-effectiveness of ecosystem services compared to build-engineered solutions.

Restoration provides worth to other restoration projects through its means of securing the legal right to land, creating more ownership ties, promoting investments, and building social capital. It also brings indirect benefits in restoring social and cultural values of an area, empowering local people, reducing their vulnerability, and promoting social accountability, social learning, and security. Moreover, at the macroeconomic level, restoration contributes to poverty reduction, rural-urban economic growth, engendering development, and improving employment opportunities while preventing increasing migration. In this way, an economic approach could serve as a strong tool in launching a business-as-unusual style restoration (Voronkova et al., 2021; Wang et al., 2023). Any nature-based solution must present an outstanding and compelling case in each country for why it is important, linking it to national biodiversity conservation, climate change, land degradation, and national environmental policies and goals. Such a case can be made powerfully by demonstrating restoration.

Nature-Based Solutions

Nature-based solutions (NbS) are approaches to societal challenges based on ecosystem-based responses (Clement, 2021). They aim to address global challenges such as climate change, food and water security, and loss of biodiversity, all of which are unlikely to be achieved through technological, infrastructure-based, or other anthropocentric pathways alone (Konijnendijk, 2021). Ecosystem restoration makes use of nature-based solutions and is often ascribed as one of the most effective actions to increase our resilience against climate change while also mitigating some of its impacts. NbS must be based on the protection, management, or restoration of natural and/or modified ecosystems. They should concurrently provide environmental, social, cultural, and/or economic benefits for human well-being. NbS should also be proven to balance the distribution of their benefits and costs to all stakeholder groups. Finally, their methods of application are generally sustainable and do no harm to the natural or built environment. These characteristics place NbS as inherently interdisciplinary, focusing on the benefits that natural systems provide through their services.

NbS is guided by the aspiration to create societies in which people enjoy a better quality of life, within the carrying capacity of ecosystems, care for and conserve nature, and thus will leave a rich legacy to future generations (La Notte & Zulian, 2021). The implementation of NbS is based on several principles. Given that they are focused on connectivity between diverse systems, they should remain sustainable and adaptive for the long term. NbS tend to be most effective when they are integrated into local contexts and are best when they make use of broad interdisciplinary frameworks. Human health and social welfare frameworks can also form intersections with these strategies. As such, ecosystem restoration for exactly that focus can be seen in this broader context. Restoration can be undertaken as a response to long-term systems collapse or as an intersection of natural and human systems. When focused on human systems, in this broader context, ecosystem restoration can most conveniently be integrated, understood, and acted on as a form of nature-based solutions. Such a designation inherently places restoration within the purview of interdisciplinary interest and enables stakeholder interaction across various fields, ensuring innovation—and hopefully solutions—in the face of complex and urgent challenges. Using our case study thus provides a comprehensive example of the benefits of utilizing such holistic approaches (Bonham-Corcoran et al., 2022; Andreucci, 2021; Alshamali, 2020).

Nature-based solutions (NbS) are interventions that harness biological and ecological processes to address societal challenges, including water scarcity, climate change impacts, and land degradation, within a framework of socially inclusive, sustainable development. NbS are currently enjoying attention from practitioners, policymakers, and scholars alike, attracting investment from international conservation, development, and financial institutions. NbS tempts an array of stakeholders because these strategies leverage the straightforward concept of assisting nature to "do the work." Importantly, the definition and guiding principles of NbS stress the importance of listening, valuing, and incorporating traditional ecological knowledge of natural resources. Solutions must be co-designed, using input and influence from local communities, other government actors, and community-based organizations active in the landscapes.

They must support locally defined pathways to include increased spatial connectivity for socio-ecological well-being. When "done well," NbS can support opportunities to restore local economies, empower women and younger generations, and generally incentivize pro-environmental behaviors and choices. To this end, principles that characterize NbS include: (i) Localization and customization: Solutions must integrate experience from the natural and social sciences with traditional ecological knowledge to be effective in their unique biophysical, social, and cultural context. In restoration projects in particular, the principle of localization can emphasize enhanced adaptability to site and programmatic sustainability. (ii) Adaptability and responsiveness: Flexibility is a key asset of locally appropriate NbS across operation, structure, and scope, and supports sustainable long-term interventions that co-evolve with the target system. (iii) Multi-functionality and co-benefits: NbS should create multiple benefits for landscapes, ecosystems, and societies, including an increase in the production of food and the assurance of water and energy, biodiversity conservation, climate change mitigation and adaptation, disaster risk reduction, and cultural services. (iv) Restorative approach: NbS typically emphasize the ecological benefits of restoration or rehabilitation and their potential to function in socially valued ways. Science and traditional knowledge can inform and infuse this principle to ensure that socio-ecological dynamics and trade-offs are managed to support ecological health and foster thriving local traditions and livelihoods (Chen et al., 2021).

The histogram below shows the number of articles on "Ecosystem Restoration as a Nature-Based Solution" from 2014 to 2024. The fundamental understanding is as follows: Initial Period (2014–2020): During this era, there were a limited number of publications, totaling less than 25 per year. The subject was likely gaining momentum and generating initial interest. A significant escalation started in 2021, culminating in 61 publications and thereafter expanding to 86 in 2022. There is an increasing recognition of the importance of ecosystem restoration in addressing environmental problems. Research production reaches its zenith in 2024 with 137 articles, after 110 in 2023. There is a growing global focus on restoring ecosystems to meet sustainability goals and combat climate change as it clear in Figure 1. The trend highlights the increasing significance of ecosystem restoration as a nature-based solution, accompanied by heightened interest and study in recent years.

Figure 1. The quantity of articles on "Ecosystem Restoration as a Nature-Based Solution" from 2014 to 2024

Methodology

This research employs a case study methodology, concentrating on the Wadi Rum Protected Area (WRPA) in southern Jordan. The researchers conducted multiple site visits over five years to gather firsthand observations and document ecological restoration efforts. This fieldwork was complemented by a thorough review of existing literature on Wadi Rum, ecosystem restoration practices, and nature-based solutions. The study combined qualitative and quantitative methods, including interviews with local stakeholders, community members, and environmental experts, to capture diverse perspectives. Additionally, geographical and ecological data were collected and analyzed to assess land degradation,

biodiversity distribution, and restoration progress. The researchers also incorporated participatory approaches, engaging local communities in restoration discussions and decision-making processes. This method gave a complete picture of restoration practices and their effects by combining ecological, socio-economic, and cultural factors. It focused on long-lasting and community-driven solutions. A vast, arid valley called Wadi Rum is located on the southern border of Jordan. About half the size of Amman, Wadi Rum is situated 100 kilometers south of the ancient Nabatean ruins at Petra and 60 kilometers east of the Jordanian seaside city of Aqaba. The valley is surrounded by peaks of granite and sandstone that have been eroded over thousands of years by an unforgiving desert wind. These mountains' highest point is 1,754 meters above sea level. Along a north-south axis, the old valley floor is dotted with large sand dunes and a number of granite and basalt hills as shown in Figure 2. Approximately 720 square kilometers of nothingness, a level and featureless desert plain that extends all the way to the Saudi Arabian border, replace Wadi Rum in the east (Jawabreh et al., 2025).

Figure 2. Wadi Rum Protected Area Map: Prepared by the researchers, using Global Mapper software, April 2024

Case Study: Wadi Rum

Wadi Rum is a remote desert wilderness in southern Jordan, one of the driest areas in the country. The face of Wadi Rum is dramatically sculpted by sandstone and granite outcrops that rise up from the southern desert plains (Jawabreh, 2017; Giersch, 1993). With limited military activities in the past, Wadi Rum has remained relatively untouched over the years, and it is here that the Wadi Rum Protected Area (WRPA) was established. WRPA is home to a surprising amount of biological diversity, mainly due to its varied landscapes. Few places in the world contain such a complete range of landscapes within a small an area. The erosion of granite has created long, narrow ravines and valleys. In contrast, the massive, chiseled sandstone ridges dominate the northern half of the WRPA, some of them rising from low desert valley floors to nearly 1800 m above sea level. Other high cliffs form an impenetrable barrier against the east-west oriented sandstone valleys. On entering the protected area, the visitor is struck by the deep silence and immense beauty.

The Wadi has attracted humans for thousands of years, with tribes settling in caves to escape persecution (Kottangal & Purohit, 2024; Eid & Mallon, 2021). Over time, these tribes became the Nabateans. Wadi Rum is world-renowned for its rock art, consisting of petroglyphs, inscriptions, and archaeological remains. It is a vast collection of sites, covering an area of about 400 sq km and containing tens of thousands of individual inscriptions and representations in various locations. Wadi Rum is, however, increasingly under pressure, mainly due to tourism, although climatic changes and public perceptions of nature are rapidly altering the landscapes of the wider area. Both of these issues contribute significantly to the physical land degradation problem. Among these pressures, the most significant one is the mining of the delicate aquifer waters.

Location and Description Situated in the heart of the Arabian Desert, Wadi Rum is a unique and spectacular desert landscape in Jordan, known colloquially as the Valley of the Moon. Wadi Rum is characterized by a series of parallel sandy wadis that run in a north-northwest-south-southeast orientation and form the drainage system of the western Rum sandstone massif. The area can be divided into five main habitats: sand valleys, sandstone and granite jebels, sabkhas, semi-fixed and fixed dunes, and irrigated or cultivated areas (Strachan, 2012; Jawabreh et al., 2025). Wadi Rum is situated in a hyper-arid zone with a desert climate, characterized by a mean annual temperature of 20–24°C and summer temperatures often exceeding 40°C. Annual average rainfall is currently approximately 35.5 mm, occurring in two periods—winter from November to March and late spring to early summer in April to May (Shawash et al., 2023). Wadi Rum is a window into the past and reflects a landscape formed during a more humid, cooler, and different climatic era several thousand years ago. The area is especially famous for some of its features which are of universal significance. Wadi Rum is often used as a model for desert-type landscapes and is renowned for its rock formations, flora and fauna, and bird species, with high rates of endemism and threatened species. The area is an outstanding example of the interaction between human communities, an

original indigenous community with a cultural and Stone Age lifestyle, and the desert landscape, and has maintained a rich oral history, etched into the landscape as petroglyphs, built structures, cairns, and other traces since prehistoric times to date.

Ecosystem Degradation and Pressures

Wadi Rum suffers from several pressures that affect its ecosystem and lead to its degradation. Over the decades, several human activities have put pressure on the Wadi Rum environment and its natural systems. The increasing interest in the natural and cultural heritage of the place and the emerging tourism has been considered a double-edged phenomenon. Although tourism has always been a primary source of income for the local community, if not well managed, it has also been known to cause irreversible damage to the designated area. In Wadi Rum, the increase in tourist visits has led to the exploitation of resources, such as stone theft, over-pastoralization by livestock, and desert drivers enlarging tourist sites and routes, negatively influencing valuable habitats and turning them into degraded lands (Bedarkar et al., 2024).

The loss of biodiversity in Wadi Rum stems from habitat destruction. Pressures on the land are removing its capacity to support and maintain this variety of species. Any degradation of the protected area, due to overuse or any other unsustainable practices, may have spillover impacts on the local communities that are partially dependent on the ecological services that an intact environment provides. Climate change is expected to have a range of negative impacts on Wadi Rum's ecosystems, including more frequent and severe droughts, heat waves, and changes in species distribution. This degradation bars natural systems from being able to perform the services that they have provided for centuries, including maintaining freshwater sources and allowing species and plants to adapt their movements and dispersion strategies. Given such multiple and repeated threats pressing on local ecological resources, the pursuit of restoring these ecosystems comes as a priority. Wadi Rum's desert ecosystems are linked to the local population and are affected by social and economic factors, such as population growth and extensive grazing. Any initiative to restore Wadi Rum should, therefore, take these challenges into account.

Geographical and Ecological Analysis of Wadi Rum

Wadi Rum, also known as the "Valley of the Moon," is one of Jordan's most iconic desert landscapes, characterized by its towering sandstone mountains, vast sandy plains, and rich cultural heritage (McKee, 2009; Chatelard, 2003). This region, with its unique geological formations and ecological significance, faces various environmental challenges that require sustainable management and conservation efforts. The following sections provide an in-depth analysis of four key aspects related to Wadi Rum: topography, environmental changes, biodiversity distribution, and land use.

Topographic Features of Wadi Rum (Topographic Map of Wadi Rum)

Wadi Rum's topography is defined by a combination of towering sandstone mountains, deep canyons, and expansive desert plains. The region features several prominent rock formations that rise up to 1,800 meters above sea level, creating a dramatic landscape that has been shaped over millions of years by erosion and geological processes. The elevation gradients in Wadi Rum play a crucial role in shaping the local climate and ecosystems. Higher elevations, such as Jebel Rum and Jebel Umm ad Dami (the highest peak in Jordan), experience slightly cooler temperatures and occasional precipitation, which contribute to the development of microhabitats for various plant and animal species (Zhang et al., 2021).

Conversely, the lower desert plains are characterized by extreme aridity and high temperatures, making them more susceptible to desertification. The rock formations in Wadi Rum consist primarily of red sandstone and granite, which have been sculpted by wind and water erosion into unique shapes, including natural arches, bridges, and deep canyons. The region's rugged topography also influences human settlement and land use patterns, as certain areas provide natural protection and shade, historically attracting nomadic communities and wildlife. Understanding Wadi Rum's topography is essential for conservation and tourism management, as its unique geological features not only attract visitors but also serve as natural refuges for various species as shown in Figure 3. Proper mapping and analysis of elevation patterns help in designing sustainable trails, minimizing human impact on fragile ecosystems.

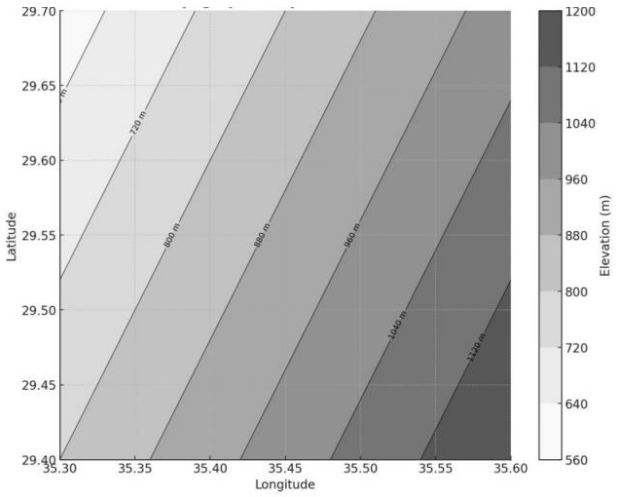

Figure 3. Topographic Map of Wadi Rum: Shows the terrain and geographical features of the region. Illustrates elevations and terrain using grayscale and contour lines to accurately define high and low areas. (Source: Author, prepared by the researchers using Global Mapper software, April 2024)

Environmental Changes in Wadi Rum (Environmental Change Map of Wadi Rum)

Wadi Rum is experiencing significant environmental changes due to a combination of natural and human-induced factors (Fernandes & Marshall, 2023). The region's ecosystem is under pressure from desertification, biodiversity loss, and water resource depletion, each of which poses serious threats to its ecological stability.

Desertification and Land Degradation

Desertification is one of the most pressing environmental issues in Wadi Rum. The increasing aridity, coupled with climate change, has led to soil degradation and loss of vegetation cover. Overgrazing by livestock, off-road vehicle tourism, and deforestation of native shrubs have accelerated the spread of barren land, reducing the ability of the soil to retain moisture and support plant growth.

Biodiversity Loss

The fragile balance of biodiversity in Wadi Rum is at risk due to habitat destruction and human activities. Several species, including the Arabian oryx (*Oryx leucoryx*) and the sand gazelle (*Gazella subgutturosa*), have experienced significant population declines as a result of overhunting and habitat fragmentation. Additionally, the loss of key plant species has disrupted the ecological food chain, leading to a decrease in herbivore populations and their natural predators, such as the desert fox (*Vulpes rueppellii*).

Water Resource Depletion

Water scarcity is a major challenge in Wadi Rum, as the region relies on limited groundwater sources (Brand, 2001). The extraction of water for agricultural and tourism purposes has placed stress on underground aquifers, leading to lower water tables. Additionally, climate change has disrupted rainfall patterns, further exacerbating water shortages. Conservation efforts are needed to implement sustainable water management practices, such as rainwater harvesting and the restoration of natural water catchment areas. Addressing these environmental challenges requires a comprehensive restoration strategy that includes reforestation of native plants, controlled grazing, and eco-friendly tourism regulations to minimize land degradation as shown in Figure 4.

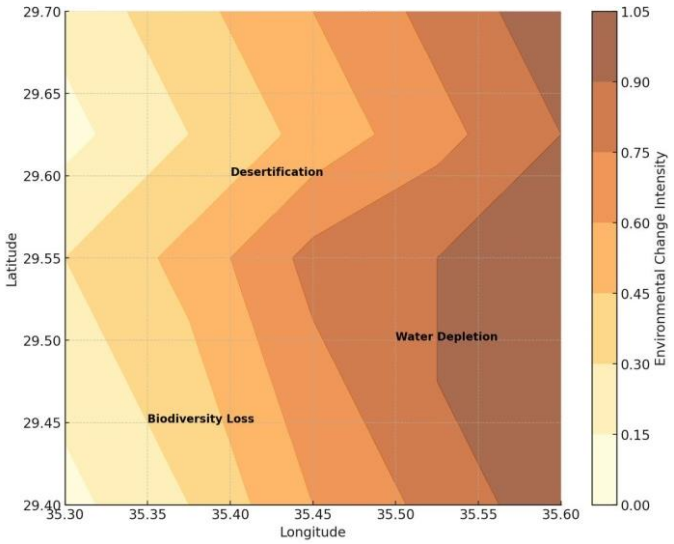

Figure 4. Environmental Change Map of Wadi Rum: Displays the effects of desertification, biodiversity loss, and water resource depletion. (Source: Author, prepared by the researchers using Global Mapper software, April 2024)

Biodiversity Distribution in Wadi Rum (Biodiversity Distribution Map of Wadi Rum)

Despite its harsh desert environment, Wadi Rum is home to a diverse range of flora and fauna, many of which have adapted to survive in extreme conditions. The biodiversity of Wadi Rum is distributed across various microhabitats, depending on factors such as elevation, soil type, and water availability.

Key Species and Their Distribution

- Arabian Oryx (*Oryx leucoryx*): once extinct in the wild, the Arabian oryx has been successfully reintroduced in select areas of Wadi Rum. These antelopes prefer open desert plains where they can detect predators from a distance and find sparse vegetation for grazing.
- Sand Gazelle (*Gazella subgutturosa*): This species is well adapted to arid environments and is found in semi-fixed dunes and rocky desert areas. Sand gazelles rely on their ability to obtain moisture from the plants they consume, making them highly resilient to water scarcity.
- Desert Fox (*Vulpes rueppellii*): The desert fox is a nocturnal predator found in rocky outcrops and sand valleys. Its keen sense of hearing and exceptional night vision help it hunt small mammals and insects while avoiding daytime heat.
- Native Plants: Wadi Rum hosts several drought-resistant plant species, including Acacia trees, Retama shrubs, and Artemisia plants. These plants play a crucial role in stabilizing the soil and providing food and shelter for herbivores and pollinators.

Threats to Biodiversity

The main threats to biodiversity in Wadi Rum include habitat destruction, poaching, and climate change. Conservation

efforts, such as the establishment of protected reserves and anti-poaching initiatives, are essential for safeguarding the region's unique wildlife as shown in Figure 5. By mapping biodiversity distribution, conservationists can better allocate resources to protect critical habitats and promote sustainable coexistence between humans and wildlife.

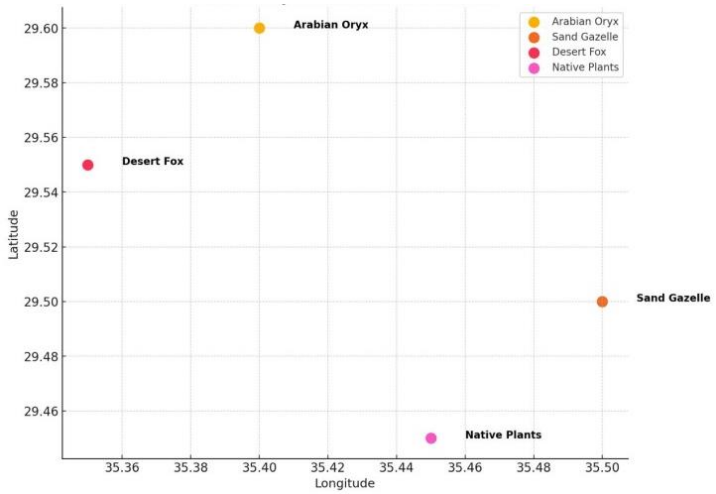

Figure 5. Biodiversity Distribution in Wadi Rum: Indicates the locations of Arabian oryx, sand gazelles, desert foxes, and native plants. (Source: Author, prepared by the researchers using Global Mapper software, April 2024)

Land Use Patterns in Wadi Rum (Land Use Map of Wadi Rum)

The land used in Wadi Rum is shaped by a combination of natural landscapes, cultural heritage, and economic activities. The main categories of land use in the region include protected areas, tourism zones, agricultural lands, residential areas, and human settlements.

Protected Areas: The Wadi Rum Protected Area (WRPA) covers a vast expanse of the desert and is designated as a UNESCO World Heritage Site. This area is managed to preserve its ecological and cultural significance, restricting activities such as hunting, excessive tourism, and unregulated development.

Tourism Zones: Tourism is a major economic driver in Wadi Rum, with designated zones for eco-tourism, hiking, and camel trekking. Several luxury desert camps and adventure tourism activities are concentrated in specific areas to minimize their impact on the environment.

Agricultural Lands: Although agriculture is limited due to water scarcity, some small-scale farming initiatives exist in Wadi Rum, mainly relying on greenhouse technology and drip irrigation to cultivate crops like tomatoes and date palms.

Residential Areas and Human Settlements: The local Bedouin communities have traditionally lived in Wadi Rum, maintaining a nomadic or semi-nomadic lifestyle. However, with the rise of tourism, many have settled in designated residential areas, where they operate eco-lodges, craft markets, and tour services.

Challenges in Land Management:

The growing tourism industry and increasing human activities pose challenges to sustainable land management in Wadi Rum. Without proper regulations, unplanned development could lead to overcrowding, environmental degradation, and depletion of natural resources (Bott, 2013). To balance conservation with economic growth, land use planning strategies should focus on sustainable tourism, controlled development, and the protection of fragile ecosystems.

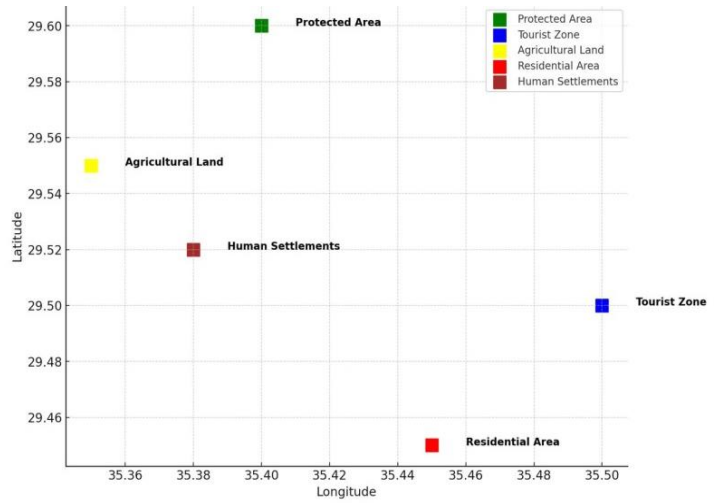

Figure 6. Land Use Map of Wadi Rum: Illustrates protected areas, tourist zones, agricultural lands, residential areas, and human settlements (Source: Author, prepared by the researchers using Global Mapper software, April 2024).

The study of Wadi Rum's topography, environmental changes, biodiversity, and land use reveals the need for a holistic conservation approach that integrates scientific research, policymaking, and community engagement as shown in Figure 6. Mapping these key aspects provides valuable insights into sustainable management strategies that can preserve Wadi Rum's natural beauty and ecological integrity for future generations (Pongratz et al., 2017).

Ecosystem Restoration Techniques

Restoration techniques are generally categorized into passive and active approaches. Passive restoration refers to no or minimal intervention by humans, with the underlying idea of ecosystems recovering themselves. Restoration in such ecosystems can be characterized by allowing the natural ecological processes to have their way and focusing on the removal of barriers rather than the promotion of recovery (Pan et al., 2016). This approach is generally applied in areas where ecosystems show resilience and are able to naturally shift back to their original state over time (Kimball et al., 2015: Berger, 1993). Wadi Rum would also be sampled eventually to revert to its predominantly vegetated state if not for the constraining harsh climatic and geological factors. Conversely, active restoration can signal a range of treatments which involve significant manipulation to act towards the restoration aims. This can include human interventions within the site by planting or habitat manipulation, or the ecosystem is managed and assisted in improving its condition. A plethora of tools may be suggested for active restoration depending on the goals, including mainly physical restoration, ecosystem reconstruction, chemical repair, biological reparation, and simplification approaches.

Passive Restoration

Ecosystems have an intrinsic ability to regenerate and self-organize, and nature-based solutions - and by extension ecological rehabilitation - have been demonstrated to be effective in promoting ecosystem recovery. Furthermore, given the breadth and scope of benefits derived from such an approach, the resultant ecosystem can become self-sustaining and naturally evolve towards a self-organized climax state, with species composition and community dynamics reflecting those of the unimpacted or minimally impacted state. There is a veritable dearth of research examining the potential of passive restoration in arid ecosystems (Da Silva et al., 2017). This is especially relevant considering the working framework of AGE, the ecosystem type within which Wadi Rum occurs, and ecosystems within this broad ecological type in arid regions have been identified as being relatively intact - this ranges from varying degrees of slight degradation to being deemed intact. Age is semiarid rather than the fully arid contexts described in these studies. Ecosystems with intact seed banks and a relatively resilient viable ecological framework have the potential to respond readily to appropriate interventions in the effort to manage and rehabilitate land. It is promising that many of these past studies have demonstrated positive outcomes in terms of intensified seed deposition, seed germination, and seedling and plant establishment, pointing to the potential for passive approaches to ecosystem restoration in arid regions (Lin et al., 2017).

Active Restoration

The intervention stage is known as active restoration, which utilizes applied techniques in the process of ecosystem restoration. These practices become efficient in increasing the recovery rate by decreasing total time. Limitations in the performance of these techniques are noted due to missing treatment windows, but the global overview on active restoration is positive. Habitat improvement has become beneficial for many species such as scavengers, large herbivores, and ungulates, acting as species reintroduction-friendly methods. There are also reintroductions of species that involve extinct or extirpated species that occurred due to overhunting, coral bombing, and others. The active restoration section will critically overview all other interventions presented and see its applicability in practice and the possibility to further develop the needed techniques. The appropriate techniques to be applied for each system highly depend on the local conditions and context. Creating and fostering the participation of relevant stakeholders and local inhabitants are crucial to designing a proper active restoration plan. Yet, active restoration has also encountered various challenges, among which are resource allocation and limiting factors, such as source population and breeding facility special considerations, as well as the ecological impact. Thus, active restoration activities should be viewed within the framework of adaptive sustainable management. This grants the development of restoration attempts to current and genuine situations while still considering the future arguments for which the strategy is also oriented. Many examples show the successful results of active restoration.

Monitoring and Evaluation

Monitoring and evaluation are crucial to the success of an ecosystem restoration project. The role of monitoring is to verify whether the objectives set out in the planned activities are achieved over time and to make corrections where progress is not as fast or successful as expected. Management actions have to take into account existing information and gradually build a robust system based on logical and achievable indicators and metrics. The process of evaluating the success of restoration based on ecological criteria is a specific research field, and methodologies exist to assess whether restored ecosystems are functioning appropriately in terms of diversity, structure, and ecological processes (Zhang et al., 2025). To define the criteria for success, a general reference to ecological theory is needed, as restoration's ultimate goal is to reconstruct processes and functions that were disrupted by the degradation of an ecosystem.

In addition, two methodologies exist: Habitat Quality Assessment for characterizing the existing state of the target habitat and learning from the Past to define the trajectory and aims of a restoration plan. A key tool for a restoration initiative is adaptive management to progressively learn from the results of monitoring, accurately assess the success of a chosen strategy, and then evolve the strategy according to the results of the continuous monitoring. The combination of

both scientific data and local knowledge is critical to assessing and effectively managing a restoration project. Long-term success in an arid mountain environment is only possible if adequate planning, feasibility studies, local knowledge, participative approaches, and monitoring systems are integrated into the restoration process.

Key Indicators and Metrics

Continued success of the general vision outlined above depends on the continuous unit-specific monitoring of the main restoration targets and activities. To guide the monitoring of ecosystem restoration projects, we propose the following metrics and indicators to be considered: - Ecological indicators for restoration such as species richness, functional composition, ecosystem functions, and processes. - Socioeconomic indicators encompassing indicators of capability, livelihood, and vulnerability, and indicators of the distribution of benefits and costs, such as specific indicators for monitoring marginalized and vulnerable groups. - Indicators reflecting changes in ecosystem services, including the enhancement of the cultural and well-being services and the regulation and support services necessary for long-term, sustainable ecosystem functioning (Pouso & Gómez-Baggethun, 2021).

Monitoring of project implementation and of ecological and sociocultural goals and objectives should be based on monitoring of selected key indicators. Qualitative metrics, such as focus group discussions and key informant interviews in ecological and sociocultural networks, should also be used to complement quantitative monitoring and to allow stakeholders whose priorities differ to be included. Monitoring of key indicators will be important to determine whether the project has met the project's goals and purposes. However, it is important to remember that this is a linear trade and that each level of monitoring provides progressively more detailed information and understanding.

Any one level of trade is not considered an appropriate substitute for another.

Community Engagement and Participation

Community involvement is considered to improve the effectiveness and sustainability of restoration projects by enabling more effective planning that is based on a wider knowledge base and is more likely to succeed, supporting and strengthening local social networks and relationships, creating a sense of local ownership and helping maintain the results of the project, and contributing to wider learning and transfer of technology (Elliot et al., 2019).

There are many ways that local communities, by virtue of being local, can be involved in a restoration project. In particular, they can participate in the planning of restoration activities, review proposed activities (and scale down or reject them as necessary), help implement proposed activities, monitor their impact and effectiveness, and help maintain and manage the resources that are restored. Approaches that are concerned with fostering greater participation include participatory planning, consultative meetings, and review at each stage of the proposal process, information dissemination, sharing of technical knowledge, and so on. In particular, the use of indigenous or local knowledge and the practice of reintegrating indigenous or local regenerative practices, including agroforestry, alley cropping, or fallow land regeneration, must be fully considered and possibly integrated into any activities (Clement, 2021).

Partnerships and stakeholders: In considering the beneficiaries of restoration, it is important to work to develop collaborative arrangements and partnerships with other stakeholders that have some interest in the area being restored. One of the key tasks in setting up community-based processes for conservation and restoration is to establish multi-stakeholder partnerships and promote collaboration and linkages across a wide range of interests. Experience and case studies: Community involvement in restoration activities is not an extensively researched field, and as yet there are not many hard benefits of the process in terms of ecological or economic change. There are several areas that have been more rigorously studied, including the development of agroforestry as part of community resource management projects and socio-forestry projects and ecological management. Other areas where the role of community involvement has been researched include catchment management, small-scale fisheries management, and pest management.

This must be taken as preliminary evidence of the merit of community involvement in restoration activities because it is possible for short-term improvements as a result of short-term action or investment plans, and it is the longer-term objective of sustainability in all spheres that is of interest to us. Barriers to involvement: In community-based processes for problem-solving or nature conservation, a range of different people and social groups with different objectives for the area come together in what is generally called a multi-stakeholder workshop. This process can throw up a number of problems and barriers to communication, not all of which can be solved. A common problem is the unequal representation, power, and knowledge of the various stakeholders involved in the planning for restoration or for the process of restoration. Because of this, it is necessary to establish clear rules in the use of indigenous and local community knowledge in terms of intellectual property rights and political and regulatory frameworks.

Economic and Social Benefits of Ecosystem Restoration

Many restoration projects have shown that ecosystem restoration can increase the provision of essential goods such as soil fertility and clean water, and biodiversity conservation while enhancing other ecosystem services that are important to local communities. Economic arguments for restoration are powerful. Investing in nature can lead us to the triple win of increased human well-being, improved environmental conditions, and reduced air pollution while building resilience to the impacts of climate change. In addition, setting restoration targets based on the provision of benefits or ensuring that benefits trickle down to all stakeholders can reduce environmental injustice. This is important considering that degraded lands, when unrestored, not only have lower biodiversity but also emit significant amounts of CO_2 every year. Investing in restoration is therefore a key part of the toolkit for meeting sustainable development goals (Wang et al., 2024). Nature-

based solutions refer to sustainable management and use of nature for tackling socio-ecological challenges that combine the human, social, and ecological aspects of sustainability. Ecosystem restoration and afforestation in Jaisalmer, Rajasthan, India, have led to the increased availability of ingredients such as honey and significantly contributed to the household income of local communities while providing additional economic incentives for ecotourism in the area.

CONCLUSION AND FUTURE DIRECTIONS

The presented findings have reinforced the conviction that ecosystem restoration should be the heartbeat of nature-based solutions, both in practice and research. This has been illustrated through the Nexus of Wadi Rum, where restoring ecological health has multiple implications for the well-being of a community. We have highlighted the necessity of novels, effective practices that are attuned to local socio-ecological contexts and have drawn out key lessons for designing restoration initiatives from communities and practitioners in Wadi Rum. These include fostering collective ownership and community participation processes, broadening our understanding of success, and integrating ecological and socio-economic outcomes in restoration activities. Several success stories illustrate this approach. Included are cases examining integrated ecological and social results, building community inclusivity, designing adaptive restoration plans, and developing partnerships that play on a community's aligned objectives. These sections also provide details on the lessons these cases offer, with a view to informing future workshops and research.

Future research in the area of sustainable natural resources management is rich with opportunities to continue this work. For instance, in the establishment of peri-urban settlements, questions of tensions between livelihood strategies linked to towns and agricultural lands and conservation will only grow in importance and could be the focus of further research. Additionally, there is a need to continue to develop and document effective participatory means for natural resources management, and to compare these experiences with participatory resource management strategies in other countries, which may well hold important lessons of relevance for communities in Wadi Rum. A further area of interest for the research would be the barriers and approaches to developing viable industries linked to restoration activities generally.

Although there are promising examples related to the harvesting of restoration-related products in these case studies, their knitting together in a series of complementary activities to create a viable small business is rare. Such examples are rich in the further questions they might raise about necessary marketing strategies, appropriate local processing and associated training and skills transfer, and approaches to value adding. Furthermore, the ways in which various organizations have worked with such communities will continue to offer valuable lessons. One approach, in a region like Wadi Rum that may be increasingly affected by climate change impacts on changing rainfall and increased temperatures, could be methods and technologies that contribute to water harvesting, minimizing water losses in restoration, and increasing water retention in soil and vegetation in order to increase resilience.

Moreover, Wadi Rum rapidly growing tourist industry provides terrific opportunities for linking restoration with nature-based tourism, and indeed, any sector is growing in resource-constrained and water-stressed areas across the globe. Open spaces and outstanding nature are becoming scarcer, and available water reserves are more than ever a strong economic development asset. A related study could also investigate the establishment of planned parks and reserves in Wadi Rum with the various stakeholder groups currently involved.

Limitations

It is widely acknowledged that ecosystem restoration is not easy; indeed, it is fraught with many complex biological, social, and economic challenges. Specifying causes of degradation and well-defined communities or natural assemblages as targets makes the work on whole or semi-natural processes 'ecological hard restoration.' Such projects, therefore, typically require a profound understanding of ecosystem assembly rules, successful propagation, and reintroduction of all natural community components. For example, in many biogeographical regions, habitat patches have been lost not only from exploitation and degradation but also due to habitat fragmentation.

Redesign of such areas to create ecologically functional or refuge eco-restoration islands and corridors can facilitate re-expansion of all major compartments of natural assemblies. However, a great many exist in situ, with flow-on implications for the phenotypic value of propagules and anticipated dynamics.

Restoration is also complicated by our lack of knowledge and understanding of effective techniques, often under climate scenarios that favor new competitors over key native biota. Long-term restoration planning is constrained by unpredictable climate variability and change. There are also diverse social barriers, including lack of government, community, and philanthropic funding; landholders choosing not to participate; and conflict with community-based activities. Projects require adaptive management so that unanticipated difficulties and negative effects from interventions can be accommodated. It is also clear that interdisciplinary research is required to address issues of greatest complexity, e.g., tourism and ecological restoration. Interdisciplinary restoration research capable of such valuation also needs to be developed since the 'environmentally friendly restoration market' is currently significantly undervalued.

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