



Traditional oases in Northern Africa as multifunctional agroforestry systems: a systematic literature review of the provided Ecosystem Services and of the main vulnerabilities

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Abstract Traditional oases represent unique forms of adaptation to extreme environmental conditions, developed through the centuries by local farmers to support their livelihood, combining different crops (date palms, fruit trees, vegetables and fodder) with livestock breeding. Despite their social, economic and cultural importance, these agroforestry systems are currently facing multiple socio-environmental threats. The aim of the paper is to investigate the variety of Ecosystem Services (ES) and the main threats related to traditional oases in Northern Africa through a systematic literature review. The search returned 257 relevant papers published from 2005 to March 2022, mostly focusing on Tunisian oases (37%), followed by Algerian (23%), Moroccan (19%), Egyptian (17%), and Libyan (4%). Provisioning Services, in particular Genetic diversity, agrobiodiversity and biodiversity, are the most cited ES (36% of the papers) followed by Cultural Services, mainly represented by Traditional knowledge systems, cultural heritage and sense of place (17%), while Regulating Services are less considered. Results highlighted that water related issues

(desertification, drought, salinization or overexploitation) represent the main threat, followed by decrease of agrobiodiversity, primarily due to the spread of monocultures of commercial date varieties, and by social transformations (depopulation, traditional knowledge and cultural heritage loss). The literature review proved that traditional oases are still crucial for the livelihood of local communities since they still provide many ES. Local experiences related to sustainable development and tourism, or innovative solutions to valorize local products and byproducts, could be important for replication in other traditional oases to contribute to the wellbeing of local communities and to the preservation of these agroecosystems.

Keywords Oases · Northern Africa · Agroforestry · Ecosystem services · Date palms · Agricultural heritage

Introduction

Ecosystem Services (ES) are commonly defined as the benefits people obtain from ecosystems and agroecosystems (Reid 2005). In the last few decades it has been recognized, both at the scientific and political level, that traditional agroforestry systems can provide a wide range of ES to rural communities around the world, acting as traditional land-use adaptation systems that can potentially support livelihood improvement through simultaneous supplying of

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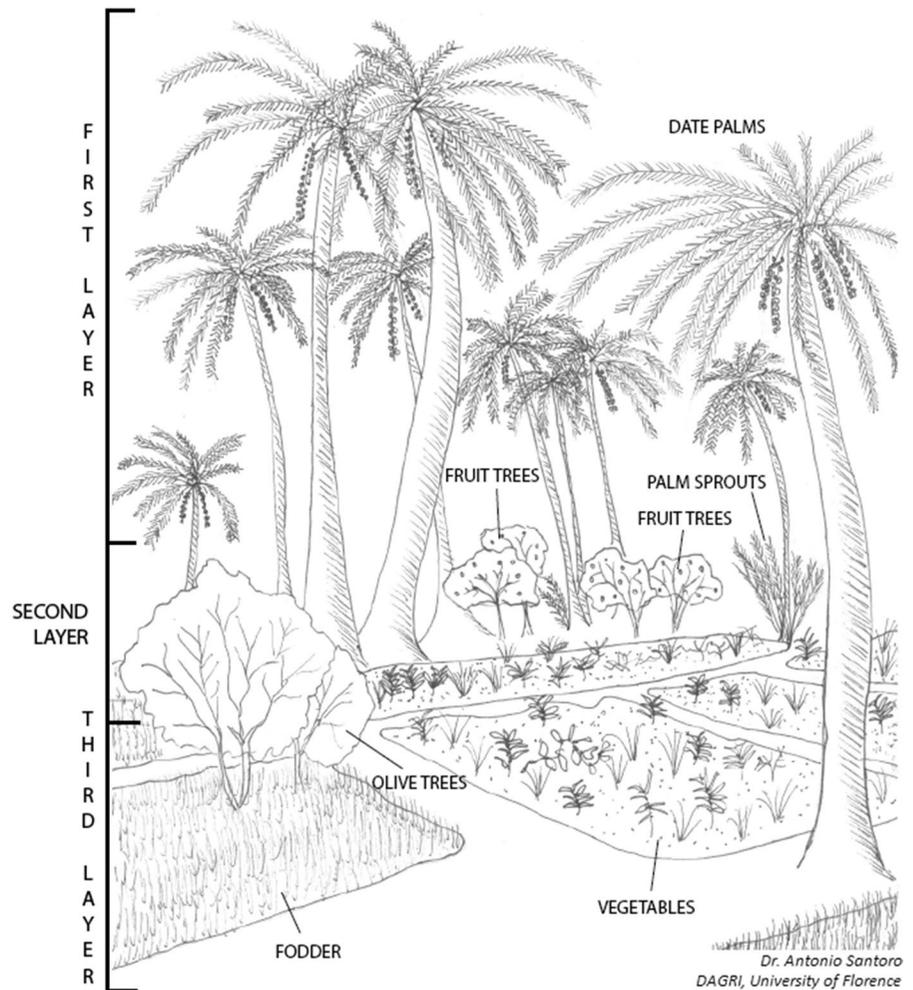
different products, services and materials, as well as representing examples of mitigation and adaptation to climate change (Pandey 2007; Mukhlis et al. 2022). Agroforestry systems are defined as “land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence” (Nair 1993). While the same definition is commonly used by FAO, some authors proposed different definitions in order to highlight the fact that it is not a simple land use system, but a complex of resources management based on traditional knowledge. According to Leakey (2017) agroforestry is a “dynamic, ecologically based, natural resource management system that, through the integration of trees in farm and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits”. These systems are mainly found in tropical or subtropical regions, but their importance is growing also in other parts of the world, i.e. in Europe, as examples of sustainable agroecosystems (McAdam et al. 2009). Despite their recognized importance, agroforestry systems are currently facing various challenges, therefore it is crucial to identify the main vulnerabilities that can be defined as the possibility that future conditions will become worse (Bradley and Smith 2004); other definitions of vulnerability focus on the susceptibility to damage, due to the exposure of a system to pressures, stresses, or perturbations, or on the set of factors that can modify structure, species composition or functionality of a given agroecosystem; but despite the definition, the assessment of vulnerabilities is a crucial component in the analysis of the interrelation of ecosystems and society (Toro et al. 2012).

One of the most common and vulnerable agroforestry systems, capable of providing various ES to local communities in arid and semi-arid environments, is represented by oases. Humans succeeded in developing agricultural and pastoral activities in very harsh environmental conditions, making the most of the limited water supply in order to provide food, materials and services to local communities, in desert or semi-desert environments and to establish small settlements. These areas, characterized by the combination of human settlements and cultivated areas are called oases (Battesti 2005), and their location was historically of fundamental importance for trade

and transportation routes in desert areas, as caravans must travel via oases to stock up on water and food (De Haas 2001). Oases are nowadays spread in different countries, from Northern Africa to Middle East, up to China. Oases in Northern Africa and Middle East can present different characteristics regarding the cultivated species and varieties, vertical and horizontal structure, size or property fragmentation, but all of them are characterized by the presence of the date palm (*Phoenix dactylifera* L.), often representing the only cash crop, that is considered part of the “first wave” of domesticated fruit trees together with olive, grapevine, fig and pomegranate (Jaradat 2011; Barrow 1998).

Despite the differences that can be found at local level, it is important to clarify the differentiation between traditional and modern oases. Traditional oases are complex agroecosystems based on a three-layer vertical structure, with the upper one made by date palms, the intermediate one made by olive trees and other fruit trees, and the lower one used to cultivate vegetables and fodder (Fig. 1). Traditional oases are also well integrated with animal husbandry (Bourzat and Goe 1990), providing fodder to the raised animals, that, in exchange, provide manure for the maintenance of soil fertility and workforce for transport, water extraction and ploughing (Tisserand 1990). A mixture of different varieties of date palms and high levels of agrobiodiversity characterize traditional oases (Santoro et al. 2020); even if a complete database of date palm varieties does not exist, thousands of different date varieties are reported for Northern Africa and Middle East traditional oases, varying in fruit shape, color, texture, taste, and ripening period (Chao and Krueger 2007). In addition, traditional oases are characterized by the absence of a regular palm planting scheme, manually conducted agricultural operations, scarcity of water resources and low annual dates yields, often around 20 kg/palm (Ministère de l’environnement et du développement durable 2015; Lasram 1990). From the social point of view, traditional oases have high degrees of property fragmentation, presence of collectivized land commonly used as pasture at the border of the oases, and collectivized water management. Modern oases, instead, cannot be considered as agroforestry systems, as they correspond to date palm plantations based on regular planting schemes, with no intercropping and no interlinkages with animal husbandry, high annual

Fig. 1 Scheme of the structure of a traditional oasis



dates yield, and often constituted by only one or two commercial varieties of dates.

The aim of this paper is to investigate the variety of ES that traditional oases in Northern Africa provides to local communities, as well as identifying the main threats affecting these agroforestry systems, through a systematic and complete literature review. Literature reviews are commonly used to assess the state of art of a certain topic and to identify perspectives and knowledge gaps (Conrad et al. 2011; Huang et al. 2022). The decision to focus on Northern Africa oases is due to the fact that there is the need to identify an area sharing common social and environmental features. Therefore, the literature review focuses on the following countries: Morocco, Algeria, Tunisia, Libya, and Egypt. Traditional oases can also be found in other parts of the world (i.e. Middle

East, Central Asia, China), but in these cases they are located in different environmental situations or they may differ for vertical structure, cultivated plants and management techniques. Results will allow to deepen the knowledge and to set a baseline about traditional oases in Northern Africa, as well as to identify knowledge gaps and main vulnerabilities. Results could also help in understanding the implications for the future development of research, as well as in highlighting the importance of traditional agroforestry systems for dealing with current socio-environmental challenges.

Methodology

The review process is partly based on the methodological approach described in the guidelines by Pullin

and Stewart for producing systematic reviews (Pullin and Stewart 2006). The main aim of this approach is to formalize systematic reviews providing a more efficient and less biased platform for decision making. Therefore, an internal protocol has been developed to carry out a systematic literature review minimizing biases and increasing repeatability. The internal protocol was based on six different steps:

1. Establishing the “Specific research question”.
2. Establishing what database should be used.
3. Define the time interval.
4. Establishing what keywords should be used.
5. Selection of relevant publications.
6. Extracting and analyzing the data.

Data collection

The research question is related to investigate the ES and the vulnerabilities related to traditional oases in Northern Africa through a systematic literature review, based on the Scopus database. The choice of Scopus is due to the fact that Scopus is easy to navigate, and the multidisciplinary aspect allows researchers to easily search outside their discipline. Despite the fact that Web of Science (WOS) database goes back to 1945, while Scopus database goes back only to 1966, the latter has a deeper coverage for the recent years (Burnham 2006). In addition, a test has been done comparing the results of a search string inside Scopus and WOS databases resulting in a higher number of papers found in the Scopus database.

The time interval has been limited to the last 17 years. This choice is based on the evaluation of *when* the concepts of multifunctionality and of ES has been introduced in scientific debate and studies. In particular, the term “ecosystem services” started to be commonly used in scientific studies after the publication in 2005 of the Millennium Ecosystem Assessment (Reid 2005), while the concept of multifunctionality in agriculture has been introduced some years before (Maier and Shobayashi 2001). Since the main aim of the paper is to provide an extensive literature review about ES in traditional oases of Northern Africa, it has been decided to start the search of relevant papers from 2005.

The sample is limited to English language papers. This could represent a limitation, as many scientific

studies in Northern Africa are locally published in French. However, given that the most relevant studies are published in international journals, and therefore in English, and not in journals with a national dissemination, it has been argued that this choice provides a complete list of the most relevant publications on the addressed issue.

The search inside the database has been done using the following keywords: “oasis” OR “oases” AND the name of each country taken as the reference area. The indication of the name of the country helped in excluding all the papers that refers to oases located in other parts of the world. The use of generic terms as “oasis” OR “oases” allows to include in our literature review the higher possible number of published papers. The search string has been applied to title, keywords and abstracts. Editorials, commentaries, conference proceedings, and book chapters were excluded from the search, while review papers have been included. The search was conducted at the beginning of March 2022.

Selection of relevant publications

The selection of the relevant papers has been done through two different filtering steps. The first filtering has been performed looking both to the title and the abstract, to exclude the papers that were not related to the aim of this literature review (i.e. the ones focusing on geology, paleontology, archeology, chemistry, history, medicine, veterinary) or that refers to oases that are not located in Northern Africa countries despite that their names have been used as keywords. Papers dealing with wild biodiversity were considered only if the focus was specifically related to oases habitats, while papers focused on wild species surrounding the oases (rivers, springs, desert) but not directly related to oases were excluded. A second filtering has been done by reading the whole text, again for checking that they fall into the aim of this review.

Extracting and analyzing the data

After the selection of the relevant publications, the resulting papers have been carefully analyzed through full-text review, reporting on a spreadsheet the main data, including authors, title of the paper, keywords, country where the oasis is located, number of citations, journal name, addressed ES and vulnerabilities.

In the same spreadsheet, a column for each ES has been added, marking the one (or the ones) that each article primary took into consideration. The choice of the ES is based on the ones identified by the Millennium Ecosystem Assessment (Reid 2005), with some integrations due to the intrinsic characteristics of traditional oases: Provisioning services, Regulating services, Cultural services. Since one of the aims is the identification of the vulnerabilities affecting traditional oases, additional columns have been added to the same spreadsheet (Table 1). Finally, papers dealing with territorial planning and policies have been marked, as they can provide useful experiences and suggestions for the future of these traditional agroforestry systems.

Results and discussion

The results of the search phase

The first search in Scopus database returned 909 potentially relevant papers. During the first filtering phase, based on the analysis of titles and abstracts, 461 papers have been excluded for the following reasons: 443 out of scope, 11 focused on different countries, 4 duplicates, 2 proceedings, 1 no abstract of full

text available. Therefore, the first filtering returned 446 potentially relevant papers. The second filtering, based on analysing the whole text, excluded an additional 189 papers: 151 out of scope, 24 focused on modern oases, 9 no full text available online, 5 full text not in English. After the whole filtering process, the number of relevant publications according to the aims of the study has been narrowed down to 257 papers (Fig. 2).

Considering that the systematic review took into considerations papers published from 2005 to the first three months of 2022, it is possible to identify three phases (Fig. 3). In the first one (2005–2006) the number of published papers referring to ES in traditional oases was particularly low. After that, the number increased and remained almost stable until 2017, with an average of 12.7 papers/year. In the last five years the number of published papers progressively increased up to 34 papers in 2021. The value of 2022 is in line with this trend considering that the research has been done at the beginning of March 2022. This trend can be explained according to two different causes. On one side there is an increasing interest in traditional agroforestry systems as examples of sustainability and for ES provision. On the other side, scientific studies from North African universities and research institutions, over the last 5 years, increased

Table 1 List of addressed ecosystem services and of main vulnerabilities

Ecosystem services	1. Provisioning services	1.1 Food and livelihood 1.2 Timber and byproducts 1.3 Genetic diversity, agrobiodiversity and biodiversity
	2. Regulating services	2.1 Water regulation and soil conservation 2.2 Climate change adaptation and mitigation, carbon sequestration 2.3 Plant disease and pest regulation
	3. Cultural services	3.1 Traditional landscape and aesthetic value 3.2 Traditional knowledge systems, cultural heritage and sense of place 3.3 Recreation and ecotourism 3.4 Territorial planning and policies
Vulnerabilities	Depopulation, loss of traditional knowledge and cultural heritage Desertification, drought, salinization or water sources overexploitation Loss of agrobiodiversity, spread of monocultures Plant pests and diseases Pollution Urban sprawl or building of new structures with modern architectural style Others	

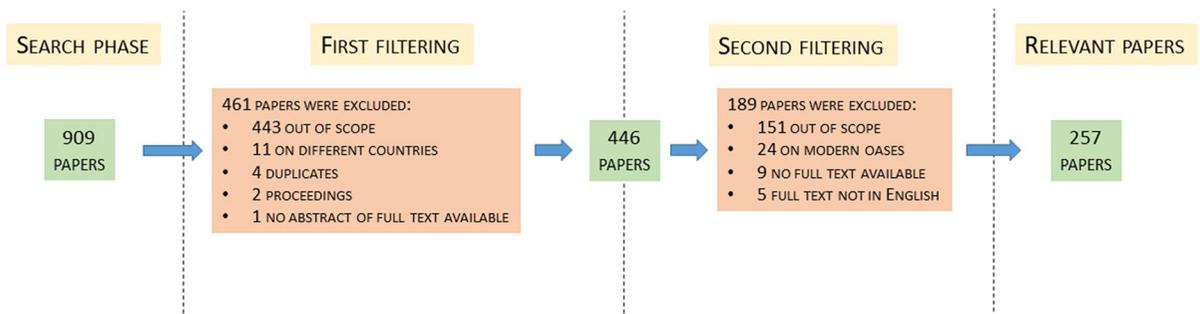


Fig. 2 Results of the papers collection and of the filtering phase

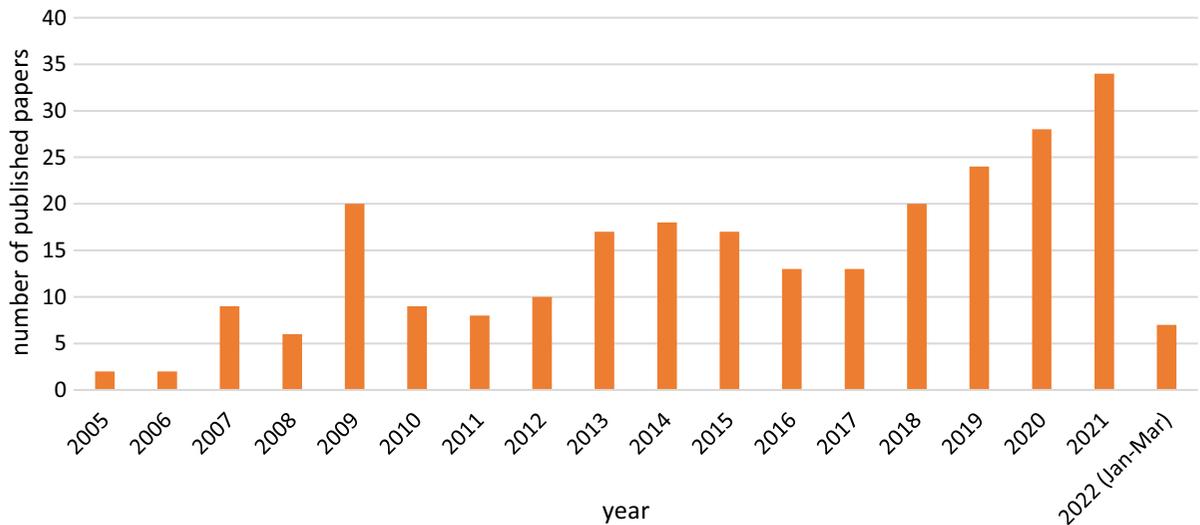


Fig. 3 Number of relevant papers according to the year of publication

their quality and also the opportunity of publishing in international indexed journals.

It is also possible to analyze the results according to the different countries where the oases taken as study cases are located (Fig. 4), considering that in some cases a single paper focused on comparing oases located in different countries or on traditional practices common to more than one country. Most of the papers focused on Tunisian oases (37%), followed by Algerian (23%), Moroccan (19%), Egyptian (17%), and Libyan (4%).

The 257 relevant papers have been published in 151 different journals indexed in Scopus. According to Scopus database, 218 relevant papers on a total of 257 have been cited by other studies, with a total number of citations equal to 2,588 and an average

value of 11.9 citations/paper. Only two papers have been cited more than 100 times, one focusing on date palm wood as a renewable building material (Agoudjil et al. 2011) and the other one on migration and remittances consequences in Todgha oasis in Morocco (De Haas 2006).

Ecosystem services and traditional oases

Two hundred and twenty-five of the 257 relevant papers took into consideration one (69% of the papers) or more (31% of the papers) ES. The other 52 papers did not take into consideration any ES but focused only on threats and vulnerabilities. Despite the fact that most of the relevant papers took into consideration one or more ES, not even one has the

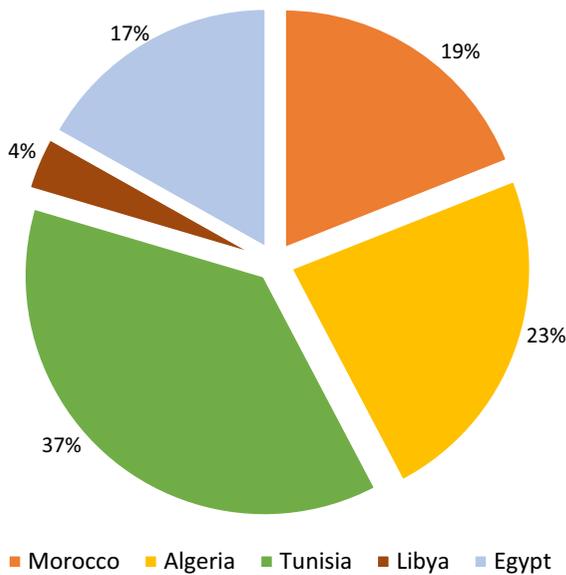


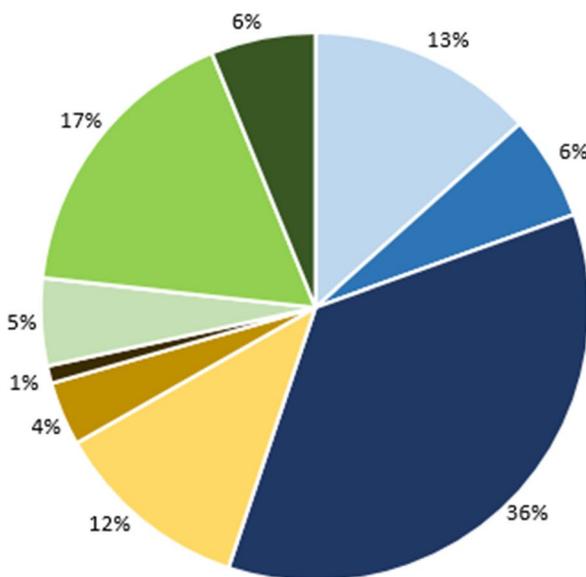
Fig. 4 Percentages of relevant papers according to the location of the oases

specific aim of assessing the different ES provided by traditional oases, testifying the need of an accurate study focusing on this crucial issue. Generally, most of the papers are very sectoral, being focused on a very specific topic. Provisioning Services, and in

particular Genetic diversity, agrobiodiversity and biodiversity, are the most cited ES (36% of the papers) (Fig. 5); Cultural Services correspond to the second typology according to the number of papers dealing with these ES, mainly represented by Traditional knowledge systems, cultural heritage and sense of place (17% of the papers), while Regulating Services are less taken into consideration.

Provisioning services

The most cited ES is related to *Genetic diversity, agrobiodiversity and biodiversity* (104 papers). A large part of the surveyed agrobiodiversity and genetic diversity concerns date palm varieties cultivated in traditional oases (Hamza et al. 2011). It is interesting to notice that in the oases further and less connected to international markets there is a greater number of traditional varieties, as in Libyan oases where according to Racchi et al. (2018) more than 400 different cultivars of date palms still exist, while in other countries, as in Tunisia, commercial date varieties as Deglet Nour are progressively replacing local ones (Santoro et al. 2020). But traditional oases are reported to be crucial also for preserving genetic diversity and agrobiodiversity related to fruit trees (Allam and Cheloufi 2013), such as apricots (Bourguiba et al. 2021, 2012),



PROVISIONING SERVICES

- 1.1 Food and livelihood
- 1.2 Timber and byproducts
- 1.3 Genetic diversity, agrobiodiversity and biodiversity

REGULATING SERVICES

- 2.1 Water regulation and soil conservation
- 2.2 Climate change adaptation and mitigation, carbon sequestration
- 2.3 Plant disease and pest regulation

CULTURAL SERVICES

- 3.1 Traditional landscape and aesthetic value
- 3.2 Traditional knowledge systems, cultural heritage and sense of place
- 3.3 Recreation and ecotourism

Fig. 5 Percentages of citation of different Ecosystem Services for traditional oases in North Africa

olives (Saddoud Deddabi et al. 2020) and pistachio (Ghrab et al. 2012). Other studies highlighted that some varieties of annual crops, i.e. maize, adapted to extreme conditions and could have developed resistance to different environmental stresses, representing an important resource in the context of climate change (Djemel et al. 2012). Wild biodiversity is also taken into consideration, as the vertical structure of traditional oases can provide different key habitats for various animals, including birds (Tabib et al. 2016; Hamza and Hanane 2021), bats (Loumassine et al. 2020), small mammals (Derouiche et al. 2016) and butterflies (Habel et al. 2013). According to El-Saied et al. (2015) Siwa oasis (Egypt) can be considered a floristic diversity hotspot, but also a system in evolution, with species that have disappeared over the decades and others recently introduced, mostly due to changes in agricultural activities then to altered environmental conditions. In fact, some socio-economic dynamics can have surprising effects on agrobiodiversity; Rignal (2016) reported that migration of young people from traditional oases become a factor that indirectly supports local traditional agriculture: some households used migration remittances to experiment with new crops that on one side guarantee a better access to markets, but on the other side cause the loss of some cultivated species and varieties less commercially appreciated.

Food and livelihood, despite being the main reason for traditional oases development in North Africa, has been cited only by 39 papers. Dates represent the main commercial crops, but also a healthy food for local communities, being a source of nutrients and natural antioxidants (Alahyane et al. 2019; Ali Haimoud et al. 2016) strongly connected to the benefits of the Mediterranean Diet (Azekour et al. 2020). The importance of palms is not only related to dates and byproducts, but also because their canopy creates a good microclimate (agroforestry effect) allowing the cultivation of other crops in the lower layers; this microclimate has positive direct effects on the fruit quality, also thanks to the periodic supply of water and nitrogen due to intercropping, as demonstrated for almonds (Ossama et al. 2021), but also for pomegranates that under the palm cover produce larger sized-fruits with higher juice content compared to full sun conditions (Boussaa et al. 2019). Livestock breeding is still a crucial and well-integrated activity in traditional oases, even if it is diminishing in the last

decade (Alary et al. 2022), while beekeeping, in some cases recently introduced, can represent an additional source of income (Zerrouk et al. 2014). New activities or innovations can be useful to increase the incomes of local farmers without affecting the fragile oases agroecosystems, but effectively contributing to their preservation. It is the case of the use of geographical indications for product labelling, that according to Lambarraa-Lehnhardt et al. (2021) can positively address the purchasing decisions of consumers and support rural livelihoods in arid areas.

The provision of *timber and byproducts* is cited only 18 times, but it is interesting that many of these papers focus on the innovative use of byproducts to support new markets and increase farmers' incomes. The oil made by date seeds, in fact, can be considered a high-quality oil from a biochemical and biological point of view, and an excellent source of antioxidants in food and medicine preparation (Harkat et al. 2022; Metoui et al. 2019). Dates can also be used to produce low-cost fructose syrup that can be used as additive in the food industry (Chaira et al. 2011). Palms also provide timber and construction materials for traditional buildings, but palm fibers can also act as good, innovative, and sustainable insulation material (Oushabi et al. 2015; Agoudjil et al. 2011), while palm wastes could be used as biomass for energy production (Bousdir et al. 2014). Also other crops can provide byproducts: according to Abbdellaoui et al. (2019) the essential oil produced with cumin seeds cultivated in traditional oases is an excellent source of natural antioxidants, that could be used for food preservation and health benefits.

Regulating services

Among the Regulating Services, the most cited (in 34 papers) is Water regulation and soil conservation, that is not surprising as water and soil are the most important and limiting resources in oases agroecosystems. This ES resulted to be strictly connected to traditional knowledge and cultural heritage, as many papers focused on the importance of traditional irrigation and water harvesting techniques. In arid environments humans developed ingenious water harvesting systems to intercept the water of the aquifer based on underground channels. These systems, probably originated in Iran (where are called *qanat*) are spread in many other countries with different names,

as *foggara* in Algeria or *khattara* in Morocco. Different papers highlighted the need of preserving these traditional irrigation techniques as they are crucial for water regulation and for the overall sustainability of the system, but also for preserving the local identity (Benqililou and Bensaid 2013; Remini et al. 2011), while the introduction of modern irrigation can contribute to the disruption of the oasis system due to groundwater overexploitation (Rezzoug 2019). Also other traditional practices as circular agriculture including crop rotation, organic fertilization, integration with livestock and crop residue management, are considered important for preserving soil fertility, as demonstrated by El Janati et al. (2021) for traditional oases in southeastern Morocco.

Climate change adaptation and mitigation and carbon sequestration are little considered (only cited by 11 papers), but it is interesting to notice that according to Jeder et al. (2021) local farmers in Tunisia in the last years developed different adaptive strategies, partly combined with local experience and know-how, to deal with climate change and drought and to improve the resilience of agriculture. In addition, the same paper stresses the importance of applying governmental policies and programs to facilitate farmers' access to specialized training. Other papers focused on the response of specific crops to climate change, as the one by Abid et al. (Abid et al. 2016) that highlights how some populations of *Medicago sativa* cultivated in Tunisian oases succeed to maintain good nutritive values under drought conditions representing an important resource for local livestock in a context of climate change. Moreover, arid soils are able to sequester large amounts of organic carbon under oases conditions (Omar et al. 2017).

Scientific literature analyzing the importance of traditional oases management in relation to Plant disease and pest regulation can disseminate potential interesting results for the future of traditional oases; i.e. according to El Arbi et al. (2016) some *Bacillus* strains isolated from the rhizosphere of date palms can act as a biocontrol agent for combatting plant diseases in extreme environments.

Cultural services

Traditional knowledge systems, cultural heritage and sense of place seems to be a crucial ES related to

traditional oases in Northern Africa, as it is cited in 50 different papers, and it is related to different topics.

Traditional agricultural practices are crucial to preserve the three-layer structure and are handed down from generation to generation, especially the ones related to date palm management, including propagation, manual pollination, fruit bunch thinning, dates harvesting, dates processing, and trunk cleaning. Unfortunately, no papers have been found describing in detail these techniques, probably because there are significative differences at local and national level. Date palm-related traditional knowledge is not only linked to agricultural practices, i.e. palm pollen preparations or palm leaves have been used for centuries in traditional medicine (Selmani et al. 2017).

Traditional knowledge is also related to the capacity of adapting to different, and sometimes changing, environmental conditions. The paper by Remini and Miloudi (2021) provides an accurate description of a unique oases system, called *ghout*, in Algeria; here, Sufi farmers decided to plant palms in big craters dug among the dunes of the Grand Erg Oriental, taking advantage of the superficial aquifer, instead of bringing the water to palms through a classic irrigation system. The introduction of motor pumps and boreholes promoted at governmental level in the '80 s to expand agricultural areas, caused an imbalance of the aquifer level between the north and south of the region, so that in the north part water overexploitation caused the lowering of the water table, that is not reached anymore by palm roots. To adapt to this new situation and to save palm trees, local farmers developed an "innovative practice" called "the descent of the palm tree" consisting in lowering the palm of 1–2 m into the ground so that roots can remain in contact with the water table. This "knowledge" represents an adaptation to changing environmental conditions and was crucial to save several palms and the whole *ghout* system, that since 2011 is also recognized as a Globally Important Agricultural Heritage System (GIAHS) by the Food and Agriculture Organization of the United Nations.

Traditional knowledge and cultural heritage are also strictly connected to water harvesting techniques and therefore to the overall sustainability of traditional oases; in fact, the cessation of a regular management of traditional irrigation networks increase the amount of water wastage (Benzouche and Chehat 2019), but these traditional water management

systems are also crucial for the social cohesion as they are collectively managed by local farmers, while the introduction of modern irrigation also means passing from a collective management of water sources to individual management, negatively affecting social dimension and water availability in the long term (Hadidi et al. 2018).

Different papers focused on traditional knowledge related to oases architecture, as local traditional architecture is strictly connected to the oases agroecosystems, as palms provide construction materials, while the characteristics of traditional buildings, usually made of earth, responded to the need of building comfortable houses in a harsh climate (Gado et al. 2010). Traditional oases architecture nowadays represents a crucial cultural heritage, even if it is often disappearing due to political and social changes (Rodríguez-Navarro and Gil Piqueras 2018). In particular, the presence of a well-preserved traditional architecture is related to other ES, such as Recreation and ecotourism and Traditional landscape and aesthetic value. Despite these two ES are not much cited in the relevant papers (Recreation and ecotourism is cited in 18 papers, Traditional landscape and aesthetic value in 15 papers), it is undoubtedly that these ES can be crucial for providing additional incomes to the farmers (Boujrouf 2014; Amara 2010), even if tourism can also cause contrasts in the use of limited natural resources, especially water (Tawfik and Tolba 2014). Few papers specifically focused on landscape and land use analysis through the use of GIS software, even if monitoring oases changes could be crucial,

especially if land uses are put in relation to other ES such as agrobiodiversity (Santoro et al. 2020).

Main vulnerabilities in traditional oases

Overall, 121 papers provided information about vulnerabilities, identifying the main threat (31.7% of the cases) to be water related issues, including desertification, drought, salinization or water sources overexploitation (Table 2). These problems can have different causes. The abandonment of traditional irrigation systems, as *foggaras* in Algeria, and the uncontrolled use of motor pumps can lead to an overexploitation and to an irrational use of water sources, with the consequent increase in groundwater salt concentration that can cause damages to the crops (Belhadj Elmehdi et al. 2020; Rezzoug 2019). The spread of modern oases and of other cultivated land bordering traditional oases thanks to modern irrigation techniques (often without any planning) and consequent overexploitation and salinization of the aquifer is reported both for Southern Tunisia and for Figuig oasis in Morocco (Kamel 2013; Salgot et al. 2014). In other cases, sand encroachment can also represent a threat for traditional oases (Puy et al. 2018).

The second identified threat (17.4%) is related to the loss of agrobiodiversity, mainly in relation to the spread of modern oases and of monocultures of the most important commercial date varieties, i.e. Deglet Nour in Tunisia (Hamamouche et al. 2018; Benaoun et al. 2014; Liu 2003), but is also associated to local fruit tree species and varieties (Allam and Cheloufi

Table 2 Main vulnerabilities affecting traditional oases in the different countries according to the literature review results

Country	Vulnerabilities							Total
	Plant pests and diseases	Desertification, drought, salinization or water sources overexploitation	Loss of agrobiodiversity (spread of monocultures)	Depopulation, loss of traditional knowledge and cultural heritage	Urban sprawl, new buildings with modern architectural style	Pollution	Other	
Morocco	2	16	5	9	–	2	4	38
Algeria	8	7	7	10	6	–	1	39
Tunisia	9	14	12	3	6	9	1	54
Libya	–	2	2	2	–	–	–	6
Egypt	3	12	2	2	2	2	1	24
Total (n)	22	51	28	26	14	13	7	161
Total (%)	13,7	31,7	17,4	16,1	8,7	8,1	4,3	100,0

2013) or to wheat landraces cultivated in the Saharan oases (Zaharieva et al. 2014). Loss of agrobiodiversity can affect the livelihood of local farmers, since the loss of genetic diversity also means a reduced resilience and resistance to pests, diseases, drought, and climate change (Jaradat 2015); in addition, having different date varieties means that not all the dates ripen in the same period, so small farmers can better organize the agricultural operations and can have a better distributed income over time and less depending on the market price fluctuations.

Social-related issues (depopulation, loss of traditional knowledge and of cultural heritage) also represent major threats (16.1%) especially in marginal areas, with negative consequences not only for the cultivated part of the oases but also for the related architectural heritage (Gado et al. 2010). On the other hand, in oases surrounding big cities, where population increased in the last decades, urban sprawl and new buildings made with modern architectural style and materials (reported for 8.7% of the cases) are decreasing the surface of traditional oases, affecting the traditional landscape and its aesthetic and touristic values, and also the quality of life of local communities (Hadagha et al. 2021; Berkouk et al. 2020).

Pests and diseases are reported for 13.7% of the cases and seem to represent a common and serious problem in all the five North African countries. This threat does not affect only palm trees (Idder et al. 2015; Saidi et al. 2013), but also other crops within traditional oases, such as wheat (Oumata et al. 2020) or fruit trees (Sadraoui-Ajmi et al. 2022; Zougari et al. 2021).

Pollution seems to be another important threat (8.1%), but it is localized only in specific situations, such as in the coastal oases of Gabes (Tunisia) that is considered a pollution hotspot in the Mediterranean area due to the emissions of the phosphate treatment complex of Gabès-Ghannouche (Alaya-Ltifi and Selmi 2014), or in the Bahariya Oasis (Egypt) due to near iron ore mines (Baghdady et al. 2018).

Other less reported threats include climate change (Jeder et al. 2021) and the spread of recently introduced water-consuming crops such as watermelon (Lamqadem et al. 2019), that can affect the sustainability of the oases in the long term. According to Peano et al. (2021) also the increasing property fragmentation due to traditional inheritance system can represent a vulnerability, as the new generation of

farmers inherit very small plots not adequate for a sufficient agricultural production and for sufficient incomes; in this regard, the application of a participatory approach, the institution of custodian farmers and of a “*maison de semences*”, can encourage the involvement of young farmers and contribute to the effective preservation of local agrobiodiversity. The uncontrolled use of chemical fertilizers and pesticides can represent an additional threat (Sadraoui-Ajmi et al. 2022), both for the local environment and also for the local population, especially if chemicals reach the aquifer. It is also interesting to notice that in some cases even tourism can become a threat rather than an economic opportunity, as in Siwa (Egypt) where local facilities are not adequate for receiving high tourist flows (Tawfik 2016), or due to the high water consumption by tourists (Ait Lamqadem et al. 2018). Finally, according to Ayadi et al. (2017) and to Hammouda et al. (2015) traditional oases can offer more suitable habitat conditions for birds acting as main hosts for viruses, such as West Nile Virus, and therefore can favor virus circulation among local communities.

Territorial planning in traditional oases

Analysing studies and experiences about territorial planning could be crucial to better understand how to deal with problems and opportunities inherent these fragile agroforestry systems, especially for their possible replicability. Various papers expressed the need to promote sustainable tourism in traditional oases, analysing tourist preferences and sense of place (Abou-Shouk et al. 2018) or investigating experts' opinions, as Amara (2010) did for Siwa oasis (Egypt) reporting the need of discouraging overdevelopment and overexploitation of natural resources, and suggesting the application of sustainability criteria in tourism planning and development. In this regard, accurate plans for traditional architecture conservation and restoration are required, also for preserving aesthetic and cultural values related to traditional oases (Rodríguez-Navarro and Gil Piqueras 2018).

Martínez et al. (2017) reported the results of an experience carried out in M'hamid Oasis in Southern Morocco, where since 2012 the Terrachidia Association focussed on the study, promotion, preservation, and restoration of the local cultural heritage. Here different workshops have been organized with

the involvement of the local population, attended by university students and professionals from different countries, to allow the participants to know places and people in a way hardly achievable through conventional tourism. At the same time, this experience also contributed to strengthen the cultural identity and the awareness of the local population. The involvement of the local farmers and the application of participatory approaches are desirable for developing effective strategies or innovative solutions to deal with socio-economic or environmental changes at local level (Boselli et al. 2020; Peano et al. 2021). Other studies suggested the use of GIS-based monitoring systems or to use new indicators, as the ratio palm number/inhabitant, to evaluate the urban sprawl affecting traditional oases around big cities (Hadagha et al. 2021), or the need to reorganize local water management for a more efficient water use and for improving farmers wellbeing (Mahdhi et al. 2021). GIS can also be used to plan mitigation measures for new infrastructures near oases to minimize the impacts on local wild biodiversity (Dhiab and Selmi 2021).

Conclusions and further development

The applied methodology for paper searching and analysis proved to be effective to reach the goal of this study and in particular to obtain a complete framework about ES and vulnerabilities, but also about possible solutions towards socio-economic changes. The use of “generic” keywords during the search phase allowed to identify a high number of potentially interesting papers, without the risk of excluding some of them, but also required a very time-consuming filtering phase, as it was necessary to evaluate the relevance of more than 900 papers, probably representing the main limitation.

The results of the literature review demonstrated that traditional oases are still capable of providing multiple ES in North African countries, and therefore actively contributing to the wellbeing and livelihood of local communities. This is particularly important considering that these systems are located in arid or semi-arid environments, where agricultural activities have to be based on intercropping, traditional knowledge and traditional irrigation. Different attempts to modernize agricultural activities and to increase the yields have been made,

but almost everywhere this has caused problems of water salinization and overexploitation in the long terms. On the other side, it is evident that traditional oases are facing multiple threats, most of them consequences of socio-economic transformations more than of environmental changes. Socio-economic transformations can have different impacts on ES and vulnerabilities, ranging from the abandonment of traditional irrigation techniques to the spread of monocultures of commercial date varieties with loss of agrobiodiversity and reduced resilience to pests and diseases, or to the aging of the farmers and the abandonment of cultivated plots; in addition, changes at the national level, especially in relation to the perceived level of internal security by tourists, have direct impacts on the touristic flows at local level and, therefore, on possible alternative incomes for local farmers and for their families.

For these reasons, it is necessary to develop and promote innovative and sustainable strategies to deal with socio-economic transformations, diversifying the source of income of local farmers or increasing the market value of local agricultural products. Virtuous examples, including rural tourism in Moroccan oases thanks to the attractiveness of the local landscape and of the well-preserved traditional architecture, innovative solutions to valorize local products and byproducts, as quality or geographical indication label for dates, or the active involvement of local farmers in touristic activities, should be emphasized and reported by scientific studies, especially highlighting and promoting their replicability. The monitoring of land uses, water management, socio-economic, and agrobiodiversity changes at local level is also of primary importance to set baselines and to identify threats, but without the preservation of traditional knowledge developed through the centuries combined with sustainable innovations, it won't be possible to preserve traditional oases in North Africa and therefore to actively contribute to the wellbeing of local communities.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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