Cuadernos de Investigación Geográfica *Geographical Research Letters*	2026	Nº xx (x)	pp. xxx-xxx	EISSN 1697-9540

http://doi.org/10.18172/cig.7467

DESERTIFICATION: TRAPPED IN TIME AND SPACE. REFLECTIONS ON THE *ATLAS OF DESERTIFICATION IN SPAIN*

ESTELA NADAL-ROMERO*
JOSÉ M. GARCÍA-RUIZ

Instituto Pirenaico de Ecología (IPE-CSIC), Campus de Aula Dei, P.O. Box 13034, 50080 Zaragoza, Spain.

ABSTRACT. This paper presents and discusses the most significant features of the *Atlas de la desertificación de España* (Atlas of Desertification in Spain), a work of outstanding scientific and practical value that comprehensively examines the main drivers of desertification processes. The authors of the *Atlas* demonstrate that desertification is far more complex than a simple consequence of aridity, soil erosion, or the associated degradation of vegetation cover. Nor can it be explained solely by human activities, although these play a decisive role in the deterioration of soil and water resources. Drawing upon the findings presented in the *Atlas*, this paper explores the remarkable complexity of desertification, a phenomenon that may lead to irreversible environmental degradation, biodiversity loss, and a decline in the productive capacity of ecosystems. While the impacts of historical desertification can, to some extent, be mitigated, addressing contemporary desertification driven by the intensification of human activities is considerably more difficult and costly. Nevertheless, both proactive and restrictive management measures are urgently needed to prevent society from becoming trapped between the environmental legacies of the past and the increasing pressures exerted by national and international markets on water resources and land-use systems.

Desertificación: atrapados en el tiempo y en el espacio. Reflexiones sobre el Atlas de la desertificación en España

RESUMEN. Se presentan y discuten los rasgos más sobresalientes del *Atlas de la desertificación de España*, una obra de excepcional valía científica y operativa que explica los factores más destacados que confluyen en los procesos de desertificación. Los autores del Atlas demuestran que la desertificación no es solo un problema de aridez o erosión y consiguiente degradación de la cubierta vegetal. Tampoco es solo un problema relacionado con las actividades humanas, aunque son estas últimas las que de manera más determinante influyen en el deterioro de los suelos y de los recursos hídricos. A partir de los resultados incluidos en el Atlas, este artículo discute la extraordinaria complejidad de la desertificación, que puede conducir a situaciones irreversibles y a una pérdida de la biodiversidad y de la capacidad productiva de diferentes ecosistemas. Hay soluciones lentas para la desertificación heredada, pero son más difíciles y costosas para la desertificación propiciada por la intensificación de ciertas actividades humanas en la actualidad. Sin embargo, la adopción de decisiones proactivas en unos casos y limitantes en otros es imprescindible para evitar que quedemos atrapados entre las herencias derivadas del pasado y el resultado de la presión ejercida por los mercados nacionales e internacionales sobre los recursos hídricos y sobre los modos de aprovechamiento del territorio.

Key words: Desertification, Soil erosion, Aridity, Markets, Water resources, Soils, Spain.

Palabras clave: Desertificación, Erosión, Aridez, Mercados, Recursos hídricos, Suelos, España.

Received: 29 June 2026

Accepted: 24 August 2026

***Corresponding author:** Estela Nadal-Romero, Instituto Pirenaico de Ecología (IPE-CSIC), Campus de Aula Dei, P.O. Box 13034, 50080 Zaragoza, Spain. Email: estelanr@ipe.csic.es

1. Introduction

The recent publication of the *Atlas de la desertificación de España* (Atlas of Desertification in Spain) (Martínez-Valderrama *et al.,* 2025a) provides an excellent opportunity to highlight the main processes and drivers contributing to environmental degradation in the Mediterranean region, and particularly in Spain. A careful reading of the text and examination of the outstanding cartographic material included in the *Atlas* reveal that the complex process referred to as *desertification* results from the deterioration of hydrological, geomorphological, edaphic, and biogeographical characteristics, operating in close interaction with human activities and climate trends across different spatial and temporal scales. For many years, the expansion of desertification-affected lands has been associated with global warming, which increases atmospheric evaporative demand (Vicente-Serrano *et al.,* 2014), as well as with growing human pressure on vegetation cover and soils, thereby accelerating soil erosion processes (García-Ruiz and López-Bermúdez, 2009).

Spanish technicians and scientists have long been aware of soil and vegetation degradation in Mediterranean semiarid environments, where the risk of desertification is particularly high. Evidence of this concern can be found in the *Proyecto de Lucha contra la Desertificación en el Mediterráneo* (Mediterranean Desertification Control Project) (*Proyecto LUCDEME*), launched in 1981 with the primary objective of promoting research aimed at understanding land degradation processes in the Region of Murcia, the Province of Almería, and the Mediterranean sector of Granada Province (Carrera Morales, 1990). In 1990, the study area was expanded to encompass the entire Spanish Mediterranean region, incorporating erosion prevention and control measures within the framework of hydrological and forest restoration projects. From a scientific perspective, the LUCDEME Project fostered the establishment of the Experimental Network for Monitoring Erosion and Desertification (*RESEL*), created in 1995 (Rojo Serrano and Sánchez Fuster, 1997). Within this network, experimental plots were monitored to quantify runoff and soil erosion under different vegetation covers and land-use types, while experimental catchments were established to analyse the spatial variability of runoff generation and erosion processes, as well as the hydrological and sediment connectivity between hillslopes and channels. Among the former, the El Ardal Experimental Station in Murcia (Castillo *et al.,* 1997; Albaladejo *et al.,* 1998) and the Aísa Valley Experimental Station in the Central Pyrenees (Nadal-Romero *et al.,* 2013) are particularly noteworthy. Among the latter, notable examples include the nested experimental catchments of Vallcebre (Llorens *et al.,* 2005), the catchments operated by the Pyrenean Institute of Ecology in the central-western Pyrenees (García-Ruiz *et al.,* 2008; Nadal-Romero *et al.,* 2025), the Guadalperalón catchment within the Extremadura *dehesa* ecosystem (Ceballos and Schnabel, 1998; Maneta *et al.,* 2007), the Picarcho catchment in Murcia (Castillo *et al.,* 2000), the El Cautivo catchment in Tabernas (Almería) (Cantón *et al.,* 2001), the agricultural catchments of central Navarre (Casalí *et al.,* 2008), the Rinconada catchment in the Central Spanish Range (Martínez-Fernández *et al.,* 2005), and the Can Revull catchment in Mallorca (Estrany *et al.,* 2009).

However, until recently, no systematic attempt had been made to synthesize the processes directly associated with desertification. It is true that, in 1995, the Spanish National Research Council (CSIC) launched the *Programa Interáreas del CSIC sobre Desertificación en Ambientes Mediterráneos* (CSIC Interdisciplinary Programme on Desertification in Mediterranean Environments) (García-Ruiz *et al.,* 1996), which was intended to establish a broad research framework on desertification in Spain by bringing together the scientific activities of leading institutions working on natural resources, agronomy, and social sciences. That initiative defined several key concepts related to desertification and its driving factors and, most importantly, identified the scientific challenges that required immediate attention, including the creation of research positions and the acquisition of field and laboratory equipment. As has often been the case, however, the initiative failed to gain momentum and gradually faded into obscurity. Fortunately, a group of scientists has recently re-established desertification as a major scientific, technical, and socioeconomic issue, and their efforts have culminated in the publication of the Atlas of Desertification in Spain, a work of extraordinary present and future value. Remarkably, despite its strategic importance, outstanding cartographic and visual quality, and considerable media attention, the *Atlas* has not yet prompted a substantial shift in the prevailing paradigms of geography and ecology. We are confident that among its readership there will be scholars willing to take up the valuable legacy left by the authors of the Atlas.

It is also worth emphasizing that the core contribution of the *Atlas* lies in its first section, where the drivers of desertification are comprehensively examined and a wide range of maps of Spain are presented, culminating in a national map depicting the probability of land degradation. The second section is no less valuable. It presents sixteen case studies that illustrate some of the most pressing environmental challenges facing Spain and demonstrate the capacity of Spanish scientists to explain and address them. Furthermore, these sixteen case studies have also been published as a separate volume (Martínez-Valderrama and Olcina Cantos, 2026), further underscoring the collective significance of these contributions.

This paper reviews the most important aspects of the *Atlas of Desertification in Spain* as a starting point for understanding one of the most critical environmental challenges affecting the Mediterranean region. At the same time, we offer a number of reflections and nuances regarding some of the interpretations and proposals advanced in the *Atlas*, with the aim of contributing to the geographical perspective that should underpin future research on desertification. From the outset, we wish to convey both a sense of urgency, as do the authors of the *Atlas*, and a sense of caution and balance. Although these two perspectives may appear contradictory, both are essential for understanding and addressing the complexity of desertification.

2. What do we mean by desertification?

There is broad, albeit largely implicit, agreement among scientists regarding the meaning of desertification. Admittedly, it is an extremely complex phenomenon; nevertheless, it can be conceptualized in a simple way as a process of degradation resulting from disturbance. The *Atlas of Desertification in Spain* (hereafter, the *Atlas*) adopts the definition established by the United Nations Convention to Combat Desertification (UNCCD), approved in Paris on 17 June 1994 and signed by Spain on 14 October 1994. According to this definition, desertification is the "degradation of arid, semiarid and dry sub-humid areas resulting from climatic variations and human activities", leading to a decline in biological productivity, economic deterioration, and biodiversity loss.

However, contrary to the widespread perception that desertification is a set of processes leading inexorably to desert conditions, the authors of the *Atlas* repeatedly stress that "desertification is not the advance of the desert, nor are deserts the final stage of a desertification process" (p. 15). This position is based on the recognition that desertification "manifests itself in different ways, ranging from visible erosion on vegetation-free slopes to the gradual degradation of an ecosystem's ecological functioning" (p. 13). Consequently, the authors emphasize the distinction between *desert* and *desertification*. True deserts are primarily the result of climatic conditions linked to large-scale atmospheric circulation patterns, whereas desertification refers to the degradation of ecosystems that, until relatively recently, were productive.

This degradation may involve groundwater overexploitation, agricultural abandonment resulting from soil deterioration or from alterations in infiltration and soil water-holding capacity, as well as the adverse effects of land-use changes driven by the evolution of national and international markets, particularly in Mediterranean regions and especially in Spain. The authors of the *Atlas* are even more explicit when describing the consequences of desertification: loss of soil fertility, depletion of surface and groundwater resources, reduced vegetation cover and its protective role against erosion, and an increased risk of wildfires.

According to Puigdefábregas (2001), desertification is the outcome of "a disturbance occurring in arid climates that drives the system, composed of human populations and their renewable natural resources, towards an irreversible loss of sustainability." Similarly, Puigdefábregas and Lázaro (2000) argue that desertification occurs "when an ecosystem is pushed beyond its resilience threshold by the socioeconomic activities it supports." In this sense, desertification reflects a long-term mismatch between the management of natural resources and their actual availability. These concepts provide an excellent framework for discussing the factors that explain desertification in a country such as Spain and constitute a recurring theme throughout the interpretation accompanying the maps presented in the *Atlas*.

A necessary clarification before proceeding further is the distinction between **desertification** and **desertization**, two terms that, according to Puigdefábregas and Lázaro (2000), have often been incorrectly used interchangeably. These authors argue that *desertization* is the result of natural processes, mainly associated with increasing climatic aridity driven by rising temperatures, greater atmospheric evaporative demand, and, potentially, declining precipitation, particularly in regions located near existing deserts. In contrast, *desertification* is primarily driven by human-induced processes, which in turn promote the activation of hydrological, geomorphological, and biogeographical mechanisms of environmental degradation. In one of the contributions included in the second section of the *Atlas*, Olcina Cantos and Martí Talavera (2025) explicitly emphasize that aridity "is not synonymous with desertification" (p. 167) and that the latter necessarily involves human intervention. Thus, although climatic factors may create conditions conducive to land degradation, desertification itself cannot be understood without considering the role of human activities and their impacts on ecosystem functioning.

In this context, the authors of the *Atlas* emphasize another key idea: "Desertification is not a problem of the future. It is a reality that is already shaping our landscapes" (p. 13). Its impacts are manifested through declining soil quality, and hence reduced productivity, degradation of vegetation cover (although it should be noted that this is not always a prerequisite), depletion of water resources, and an increased incidence of wildfires, particularly large and high-severity fires characterized by extreme temperatures and extensive burned areas (Cunningham *et al.,* 2024). Given the central role of human activities, desertification does not occur as a uniformly advancing front across the landscape. Rather, its spatial expression depends on the intensity of human pressures and their interaction with variations in soil properties, lithology, and topography. As a result, desertification tends to develop in a fragmented and heterogeneous manner, forming patches of degraded land that may expand irregularly over time.

The final maps are the product of a rigorous and carefully executed effort and constitute an essential resource for both scientists and land managers. Although it remains uncertain what their ultimate scientific and technical impact will be, the Atlas brings together an extraordinary collection of maps that progressively document aridity patterns, water resources, soil characteristics, disturbances in forest ecosystems, biodiversity loss, and the demographic and land-use attributes of Spanish territory, culminating in maps depicting the risks of land degradation and desertification.

Admittedly, some maps are presented at a scale that may limit their usefulness for detailed local analyses. Overall, however, their high spatial resolution and excellent cartographic quality allow those with a good knowledge of the territory to readily identify both critical hotspots and areas facing comparatively lower levels of risk. The specific desertification maps presented on pages 140 and 141 clearly highlight the regions where the most pressing challenges and the highest short- and medium-term risks are concentrated: the Ebro Depression, the central Duero Basin, parts of the Iberian Range (both the Aragonese and Castilian sectors), eastern Castilla-La Mancha, the Guadalquivir Valley, southeastern Spain (particularly Almería, Murcia, and Alicante), the Mediterranean coastal region, and several areas of the Canary Islands and Mallorca. The development of these final maps was based on ten predictors, including five biophysical variables (aridity, water stress, wildfires, land productivity, and forest-cover loss), three socioeconomic variables (population density, irrigated agriculture, and livestock farming), together with the Human Influence Index and the occurrence of extreme drought events.

The editors of the *Atlas* draw upon extensive and distinguished experience in the fields of desertification research, global change, climatology, natural hazards, remote sensing, and land-use planning. An agronomist (Javier Martínez-Valderrama), two geographers (Jorge Olcina Cantos and Javier Martí-Talavera), and two environmental scientists (Emilio Guirado Hernández and Juanma Cintas) are responsible for a remarkable body of work that represents a milestone in desertification studies in Spain. Beyond its scientific value, the *Atlas* should encourage critical reflection on the most appropriate strategies for mitigating the landscape, biogeographical, soil, and geomorphological degradation affecting large areas of the country.

Much can still be done to address these challenges, particularly because their causes are not exclusively environmental or biophysical. As repeatedly emphasized throughout the *Atlas*, responsibility ultimately lies in human activities and in the way societies organize and manage their territories. Consequently, effective responses to desertification require not only environmental measures but also changes in land-use practices, resource governance, and territorial planning.

3. The importance of the problem in Spain

Martínez-Valderrama *et al.* (2025a) present in the *Atlas* a broad range of factors that explain both the occurrence of desertification in Spain and the diversity of its spatial expressions.

In the comprehensive collection of maps that the authors present as an introduction to the cartography of land degradation and desertification in Spain ("maps for understanding desertification", p. 33), particular emphasis is placed on climatic information. These maps include the spatial distribution of mean annual temperature and precipitation, the Köppen climate classification, average annual sunshine duration, mean annual evapotranspiration, the balance between precipitation and potential evapotranspiration (negative across most of Spain except for Galicia, the Cantabrian coast, and the northernmost sector of the Pyrenees), and a comparison of the mean aridity index for the periods 1961-1990 and 1991-2020 (pp. 46-47).

A comparison of the two aridity maps reveals a contraction of the areas classified as "non-arid" and an expansion of semiarid environments, particularly in Castilla y León, Castilla-La Mancha, and Andalusia, largely at the expense of territories that until 1990 could be considered dry subhumid. It should be acknowledged, however, that the first reference period includes an initial phase characterized by relatively cool and wet conditions, which may affect the comparison and potentially exaggerate the observed trend towards increasing semiaridity. Nevertheless, future observations will determine whether this tendency, which currently appears evident, becomes firmly established over time.

Indeed, the authors also incorporate the projections of Beck *et al.* (2023), illustrating the expected shifts in Köppen climate zones for the periods 2041-2070 and 2071-2100. These projections suggest a substantial expansion of hot desert climates, particularly in Alicante, Murcia, and Almería, as well as a marked increase in the extent of hot steppe climates, especially in western Castilla-La Mancha and the central Ebro Valley. At the same time, they indicate a reduction in the area occupied by temperate climates without a dry season in the Iberian Range of Burgos and La Rioja. Such projected changes underscore the potential role of ongoing climate warming in increasing environmental vulnerability and reinforcing the conditions that favour desertification across large sectors of Spain.

Naturally, factors other than climate are also involved, and these are addressed extensively throughout the *Atlas*, particularly those related to water resources. The map of water stress in Spain vividly illustrates the magnitude of the problem, highlighting Andalusia, southeastern Iberia, Castilla y León, and the Catalan coast as the most affected regions, followed by Castilla-La Mancha and the Ebro Valley. Water stress is a valuable indicator of the balance between available freshwater resources and their level of consumption. Extremely high-water stress indicates that water withdrawals exceed 80% of available resources, whereas high water stress corresponds to consumption levels between 40% and 80% of available resources. The large number of reservoirs constructed throughout Spain has enabled agricultural, urban, and industrial water demands to be met. However, the recurrence of drought periods increasingly compromises the stability of water supplies in the face of steadily rising demand. Given the environmental and social constraints associated with building new dams, growing water requirements are being addressed in part through water reuse, particularly for agricultural purposes, as well as through the desalination of seawater and brackish groundwater.

The maps presented in the *Atlas*, together with their accompanying analyses, clearly indicate that Spain faces a serious water-resource challenge. Available water resources show a declining trend, not primarily because of a long-term reduction in precipitation, which has not been demonstrated for the Mediterranean basin (Vicente-Serrano *et al.,* 2025), but rather as a consequence of vegetation expansion following the decline of traditional farming and livestock activities in mountain regions (Beguería *et al.,* 2003; Gallart and Llorens, 2004; García-Ruiz *et al.,* 2011). The expansion of shrublands and forests has increased water consumption by vegetation and enhanced rainfall interception, thereby modifying the partitioning of precipitation within the hydrological cycle (Llorens and Domingo, 2007).

Demand growth, however, appears relentless, and competition for water resources is intensifying among the agricultural, urban (including tourism-related activities), and industrial sectors (Arnáez *et al.,* 2026). This trend is particularly evident in southern Spain, where traditional crops such as vineyards, almond orchards, and olive groves are increasingly being replaced by subtropical plantations. These new crops are often cultivated on terraced slopes and require irrigation, even in areas characterized by steep topography and limited water availability. At the same time, the rapid expansion of tourism, together with ongoing urban development, is generating steadily increasing water demands and escalating competition for available water resources (Gallardo Olmedo, 2025; Nadal-Romero and García-Ruiz, 2025). This situation is especially acute in Mediterranean coastal regions, where seasonal peaks in water consumption often coincide with periods of greatest water scarcity. In addition, the globalization of markets and the relocation of agricultural production away from consumption areas have further intensified water demand. The need to increase production in order to supply ever-larger national and international markets encourages the expansion of water-intensive agricultural systems, often in regions already experiencing significant hydrological stress (Martínez-Valderrama *et al.,* 2025b).

The increasing water consumption associated with the expansion of irrigated agriculture also has profound implications for groundwater resources. As the authors of the *Atlas* rightly emphasize, the map presented on page 64 reveals the poor condition of aquifers in eastern Castilla-La Mancha, the Guadalquivir Valley, Doñana, the Province of Almería, and the central sector of the Duero Basin. Perhaps the clearest evidence of this problem is the severe degradation affecting two of Europe's most important wetland ecosystems: the National Parks of Las Tablas de Daimiel and Doñana. The former has, in most years, been reduced to a fraction of its natural extent, while the latter is increasingly threatened by the expansion of greenhouse agriculture and rice cultivation (see also Green *et al.,* 2017). As a consequence, most of Doñana's temporary ponds now remain dry for much of the year (De Felipe *et al.,* 2023). As the authors of the Atlas correctly point out, these processes should also be regarded as manifestations of desertification. The chapters by Martínez-Fernández (2025) and Barberá and Castillo (2025) included in the second part of the Atlas reinforce the argument that irrigated agriculture can, in some cases, conceal the underlying imprint of desertification in Spain. By artificially compensating for water deficits, irrigation may temporarily mask environmental degradation while simultaneously intensifying pressure on increasingly scarce water resources. Furthermore, the impacts of irrigation extend beyond groundwater depletion. In many areas, irrigation practices contribute to soil salinization and to the development of piping processes (Romero-Díaz *et al.,* 2007), both of which can lead to severe and often irreversible declines in soil quality and biological productivity. These effects illustrate how strategies designed to sustain agricultural production in water-limited environments may inadvertently accelerate land degradation and increase the vulnerability of ecosystems to desertification.

Other processes affect the interactions between vegetation and soils. Soil erosion, often associated with vegetation degradation, has frequently been linked to desertification, and there are compelling reasons for this association. Erosion reduces the productive capacity of both natural ecosystems and agricultural lands, diminishes the soil's ability to infiltrate and store water, and generates severe environmental impacts both *in situ* and downstream, affecting water quality and areas where sediments accumulate. In some cases, the consequences of erosion are difficult to reverse, such as when extensive gully networks become established. In others, they may be effectively irreversible, particularly when erosion exposes large areas of bedrock at the surface, especially where the substrate is composed of resistant lithologies. Marginal agricultural practices with limited conservation measures, intensive grazing pressure that promotes soil compaction and reduces vegetation cover, and recurrent wildfires all contribute to increased surface runoff and accelerated erosion, processes that are further intensified in rugged terrain.

Over the long term, even commercially profitable crops cultivated on slopes steeper than 10% can result in substantial soil losses, particularly where plantations provide limited ground cover, as is often the case for almonds, olives, and vineyards (Gómez, 2025). Furthermore, changing national and international market demands may encourage the expansion of these crops onto increasingly marginal hillslopes, thereby increasing erosion risks. A clear example is the construction of terraces to facilitate vineyard mechanization, a practice that has resulted in severe soil degradation and numerous landslides in some Mediterranean regions (Cots-Folch *et al.,* 2006). The *Atlas* addresses these issues in considerable detail and supports its analysis with highly informative maps. Nevertheless, one may note the absence of a national map explicitly identifying the areas most severely affected by soil erosion. Such a map is admittedly difficult to produce, since erosion rates are strongly dependent on spatial scale, measurement duration, and the methods used to quantify soil loss, factors that often lead to substantial conceptual and methodological uncertainties (García-Ruiz *et al.,* 2015). In particular, the RUSLE-based map of sheet water erosion presented on page 81 should be regarded primarily as a broad indicator rather than as a tool with strong practical applicability. As the authors themselves acknowledge, estimating erosion through modelling approaches remains highly challenging, and model outputs must therefore be interpreted with appropriate caution.

Historical agricultural expansion, extensive deforestation, intense grazing pressure between the twelfth and nineteenth centuries, and recurrent wildfires have all contributed to the progressive transformation of many landscapes into shrub-dominated and steppe-like environments, as reflected in both the text and the Spanish Forest Map included in the Atlas (p. 93) The result has been the widespread occurrence of open landscapes, with large areas characterized by sparse vegetation cover and a tendency toward sclerophyllous plant communities. These conditions help explain the high rates of soil loss observed in the Ebro Depression, southeastern Spain, the Guadalquivir Basin, and numerous mountain areas that still bear the legacy of past periods of intense demographic and land-use pressure. The high intensity of Mediterranean rainfall events further destabilizes the relationship between vegetation and erosion, while the relatively low annual precipitation across much of Spain promotes spatial vegetation patterns that maximize the efficiency with which different species compete for limited water resources (e.g., Puigdefábregas, 2005). For this reason, it will be necessary to analyze trends in the most extreme precipitation events on the Iberian Peninsula (Olcina Cantos *et al.,* 2024; Peña-Angulo *et al.,* 2025).

Mining activities have also contributed significantly to vegetation degradation in many parts of Spain. One of the most compelling chapters in the Atlas illustrates this problem in the Province of Almería, where lead mining, beginning in the second decade of the nineteenth century, led to the extensive depletion of holm oak forests in the Sierra de Gádor. In addition, mining operations consumed large quantities of esparto grass, further exacerbating pressures on local ecosystems (Sanjuán and del Barrio, 2025).

These examples highlight how present-day patterns of land degradation are often the cumulative outcome of long-standing interactions among agriculture, livestock grazing, fire, and extractive activities. Consequently, understanding desertification in Spain requires not only the analysis of contemporary environmental pressures but also consideration of the historical processes that have shaped landscape structure, vegetation dynamics, and soil resilience over centuries.

4. The importance of spatial and temporal scale

One of the major challenges in understanding desertification in Spain is that it is not solely a spatial phenomenon but also a temporal one. Anyone studying desertification or erosion processes must confront spatial variability, the scale at which analysis should be conducted, and time itself, understood here as the period that has elapsed since the onset of soil and water-resource degradation. These issues are particularly important because they place desertification within a more rigorous conceptual framework and help distinguish what should and should not be considered desertification. In other words, they compel us to ask how extensive land degradation must be before it can legitimately be classified as desertification rather than as the consequence of local failures in resource management at the scale of a municipality or a small region. Several additional questions arise: Is every form of degradation an expression of desertification? How can we distinguish environmentally induced degradation associated with climate change from genuine desertification? How should we interpret landscapes that were severely degraded by human activities centuries ago but now display signs of stability or even recovery? Some of these issues are addressed, either directly or indirectly, in the chapter by Nadal-Romero and Calvo-Cases (2025). These authors focus on the intense hydromorphological activity of badlands, which are widely distributed throughout Spain and, in some cases, cover hundreds of square kilometres. Notable examples include the so-called Tabernas Desert (Almería), the Bardenas region (Navarre), Los Monegros (Huesca and Zaragoza provinces), the Fortuna and Mula basins (Murcia), and the Guadix and Baza depressions (Granada). Smaller badland areas also occur in locations such as the Inner Alto Aragón Depression (Huesca), the Tremp Basin (Lleida), Las Médulas (León), Los Agudos in the Autol-Calahorra area (La Rioja), and numerous other sites that reflect the interaction between specific lithological conditions and environmental and human processes.

All of these badland landscapes have developed in response to different controlling factors, and only the largest and most extensive examples can reasonably be associated with desertification. Even in such cases, their origins are likely to be very ancient, as appears to be true for the Guadix and Baza depressions and, albeit with greater uncertainty, for the Bardenas region. In the Tabernas Desert, and perhaps also in the Mula and Fortuna basins, neotectonic activity probably plays an important role through tectonic uplift and the associated river incision processes described by Harvey (2011). Nevertheless, the potential influence of long-term deforestation and centuries of intensive grazing cannot be excluded. In contrast, it is difficult to regard the pre-Pyrenean badlands as examples of desertification. These landforms generally occur as relatively small but intensely eroded patches surrounded by extensive areas where desertification cannot be inferred, owing to the presence of forests, dense shrublands, and cultivated fields. Furthermore, little information is available regarding their temporal evolution and age of formation (Nadal-Romero *et al.,* 2022). Consequently, although badlands represent some of the most spectacular examples of active erosion in Mediterranean environments, their occurrence alone should not automatically be interpreted as evidence of desertification. Rather, their significance must be evaluated within a broader spatial and temporal context that considers both landscape-scale processes and long-term environmental history.

In any case, spatial scale is a critical consideration. As the authors of the *Atlas* point out, “desertification is a problem that only makes sense at the landscape scale and therefore requires the identification of broader territorial footprints” (p. 135), rather than the mere presence of more or less pronounced erosion features in individual agricultural fields. In the latter case, one would be dealing with poor agricultural management or the effects of an intense storm event, but not with desertification itself.

Another important issue is that many of the areas currently characterized by degraded soils, intense erosion, and open vegetation cover with extensive semi-bare surfaces were formed centuries ago during periods of demographic expansion or in response to production systems driven by political decisions and changes in land-management practices. In some regions, vegetation degradation dates back to ancient times, particularly to the Bronze Age. This appears to be the case in Monegros, in the central Ebro Depression, where high population densities coincided with intense erosion processes that led to the infilling of numerous valley bottoms (Peña-Monné *et al.,* 2018; Peña Monné, 2025) and, subsequently, to the development of triangular facets around structural platforms under semiarid conditions characterized by frequent climatic fluctuations (Peña-Monné *et al.,* 2024). Today, apart from recently established irrigated areas, Monegros is characterized by open vegetation communities and highly eroded landscapes. However, most of these features result from a long history of environmental change rather than from contemporary human pressures, which are currently relatively low. A similar situation can be observed in the surroundings of Zaragoza, where gypsum hillslopes have largely lost their soil cover, perhaps since Roman times and certainly since the twelfth century, when large transhumant livestock operations became concentrated in the area (García-Ruiz *et al.,* 2020a). These activities severely depleted both soils and vegetation, giving rise to landscapes that bear a striking resemblance to many semiarid regions of the Near East.

The transformation of holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) forests in Extremadura and parts of Sierra Morena also has deep historical roots. Through the progressive thinning of tree cover, these woodlands were converted into systems that could support livestock grazing and, occasionally, agricultural activities. The resulting *dehesas*, these open woodland landscapes often regarded as examples of sustainable land use, are nevertheless exposed to a variety of pressures that may lead to their degradation and eventually trigger desertification processes. Schnabel *et al.* (2025) provide an excellent account of these issues in the second part of the *Atlas*. In general, *dehesas* are characterized by well-balanced landscapes in which widely spaced trees and moderate grazing pressure allow the integrated use of pastures and the products provided by holm oaks and cork oaks. However, long-term sustainability challenges are becoming increasingly evident and require management strategies that operate over extended temporal scales. In many cases, agricultural and livestock uses have become excessively intensive, while the regeneration of oak species is extremely limited. This frequently results in soil degradation and progressive tree senescence, with mature trees dying without adequate recruitment of new seedlings to replace them.

Some properties that functioned as *dehesas* only a few centuries, or even a few decades, ago now exhibit clear signs of degradation, including the near-complete absence of trees and the presence of relatively sparse pastures growing on shallow, impoverished soils. The current productivity of *dehesa* systems, their remarkable biodiversity, the high quality of their landscapes, their comparatively low wildfire risk, and the cultural heritage they represent all justify the implementation of measures aimed at ensuring tree regeneration and maintaining management practices based on a genuinely long-term perspective. Without such measures, these emblematic agro-silvo-pastoral systems may progressively lose the ecological and cultural characteristics that have historically made them among the most valuable landscapes of the Iberian Peninsula.

5. Concluding remarks

Desertification is a highly complex set of processes that contributes to land degradation and, consequently, to the loss of ecosystem productivity. The authors of the Atlas have confirmed the importance of soil erosion in semiarid and subhumid environments, while also demonstrating that other factors, predominantly of anthropogenic origin, play a crucial role in driving desertification processes. Soil erosion undoubtedly contributes to soil degradation, reduces the infiltration of rainfall, and promotes a more open vegetation structure. As a result, unless the underlying causes of erosion are eliminated or substantially reduced, positive feedback mechanisms may develop that progressively exacerbate environmental degradation over time.

However, erosion is not always the cause of desertification; in many cases, it is merely a symptom of unsustainable management practices. Recurrent wildfires, excessive grazing pressure, cultivation on steep slopes, and poorly designed terracing systems provide clear examples of activities that accelerate soil loss. Numerous historical examples demonstrate how the combined effects of human activities have promoted erosion over long periods and how their impacts have persisted as long as the driving forces remained active. The increase in grazing pressure during the Late Middle Ages and the demographic growth that began in the seventeenth century undoubtedly intensified deforestation and erosion processes. Their impacts were particularly severe in areas characterized by greater aridity and more intense rainfall events, where vegetation recovery was naturally constrained.

Some of the landscapes transformed by these historical pressures up to the mid-twentieth century have since undergone substantial recovery. The reduction of livestock pressure and the widespread abandonment of cultivated hillslopes have favoured vegetation regeneration, improved soil structure, and increased organic matter content. Shrublands and forests have expanded considerably, contributing to landscape homogenization and a reduction in soil erosion, as evidenced by declining sedimentation rates in reservoirs. Nevertheless, this increasing landscape homogeneity has often contributed to the occurrence of large wildfires, which reactivate erosion processes and, under certain climatic conditions, may redirect ecosystem trajectories towards desertification. Consequently, changes in landscape structure are essential for reducing the risk of large wildfires. Measures such as selective shrub and forest thinning, aimed at promoting the recovery of extensive livestock grazing systems, can generate more heterogeneous landscapes with a greater abundance of ecotones and ecological transitions (García-Ruiz *et al.,* 2020b; Lasanta *et al.,* 2019). Such landscape configurations are generally more resilient to environmental disturbances and may contribute to mitigating some of the processes associated with desertification.

Where land degradation reached its most extreme levels, conditions conducive to degradation and desertification have persisted to the present day, characterized by sparse vegetation cover, severe sheet erosion, and, in some cases, the development of gully systems. The poor condition of these soils, typically shallow, low in organic matter, and frequently compacted, limits the progression of vegetation recolonization towards more mature plant communities, to the extent that the trajectory towards desertification may become virtually unavoidable. However, the addition of organic amendments or urban organic waste can help reverse these trends (e.g. Prosdocimi *et al.,* 2016). Research has shown that, even in semiarid environments with very low rainfall and high evapotranspiration rates, the main constraint on vegetation recovery is often not water availability but soil fertility. This has been demonstrated by Albaladejo *et al.* (1998) in the Fortuna Basin of southeastern Spain and by Lasanta *et al.* (2000) in the central Ebro Depression. The restoration of these degraded landscapes is likely to be slow but remains feasible. It requires innovative approaches rather than major financial investments and offers opportunities for the design of more complex and resilient landscapes, a challenge in which geographers and ecologists have a central role to play.

The situations described above correspond to what may be termed legacy desertification. Contemporary desertification, however, is more complex and involves multiple interacting drivers, including: (i) market forces that encourage the expansion of traditional crops, such as almonds, olives, and vineyards, into marginal lands where soil erosion becomes the principal driver of land degradation and, ultimately, declining productivity; (ii) the same market pressures that promote the spread of subtropical crops, including avocado, mango, and cherimoya plantations, which require large volumes of water in regions already approaching the limits of available water resources and where they compete directly with other uses (Nadal-Romero and García-Ruiz, 2025); (iii) the unrestricted exploitation of groundwater resources, which under current extraction rates is unsustainable and, in some cases, threatens the stability and even the survival of wetlands of critical importance for biodiversity conservation (Green *et al.,* 2017); and (iv) the continued expansion of irrigated agriculture, which still relies on large-scale river regulation projects and may generate severe impacts on flow regimes and sediment transport dynamics, while also contributing in some areas to soil salinization and the deterioration of irrigation return flows (Tarolli *et al.,* 2024).

As the editors and contributors to the *Atlas* clearly argue, all these processes should be regarded as forms of desertification because they entail the depletion of natural resources and the progressive degradation of soils. Like legacy desertification, contemporary desertification is not irreversible and can be addressed through appropriate management measures. However, the available solutions are generally more difficult, more costly, and politically more challenging to implement. They require decisive actions aimed at reducing pressures on both water resources and soils in order to avoid irreversible environmental damage. Such measures include stricter control of groundwater abstraction, limits on the further expansion of irrigated land, and restrictions on agricultural cultivation in steep or topographically complex terrain unless effective runoff- and erosion-control measures are implemented.

The authors of the Atlas convey the impression that desertification is becoming almost inevitable, given the growing pressures on soil and water resources and the apparent need to intensify their exploitation in response to demands from national and international markets. These pressures are further compounded by rising agricultural input costs, instability in producer prices, and the increasing involvement of international investment funds in agricultural production systems, which are often driven by expectations of short-term economic returns.

The complexity of desertification arises not only from the legacy of past land-use practices, which continues to shape the hydrological and geomorphological functioning of contemporary landscapes, but also from the remarkable spatial diversification of present-day human activities. As a result, those most concerned with environmental issues in Spain, among whom the authors of the Atlas undoubtedly deserve a prominent place, may feel that society is caught between time and space. Historical legacies and contemporary pressures interact in ways that often appear to transcend both scientific understanding and territorial planning, creating the perception that the consequences of past and present mismanagement are already unavoidable.

Nevertheless, the reader will also find many positive and constructive perspectives throughout the *Atlas de la desertificación en España*. Beyond documenting environmental challenges, the work offers valuable insights into their causes and potential solutions. Through its comprehensive texts, outstanding cartography, and rich photographic documentation, the Atlas constitutes an essential reference for teaching and research in geography, ecology, environmental sciences, agronomy, and related disciplines. More importantly, it provides a robust foundation for future scientific debate and for the development of strategies aimed at mitigating land degradation and promoting the sustainable management of natural resources in Spain.

Referencias

Albaladejo, J., Martínez-Mena, M., Díaz, E., Castillo, V., 1994. Land rehabilitation by urban refuse amendments in a semi-arid environment: effect on soil chemical properties. *Soil Technology* 7, 249–260. https://doi.org/10.1016/0933-3630(94)90025-6

Albaladejo, J., Martínez-Mena, M., Roldán, A., Castillo, V., 1998. Soil degradation and desertification induced by vegetation removal in a semiarid environment. *Soil Use and Management* 14, 1–5. https://doi.org/10.1111/j.1475-2743.1998.tb00602.x

Arnáez, J., Nadal-Romero, E., Lana-Renault, N., García-Ruiz, J.M., 2026. Hydrological challenges and competing demands in the Mediterranean region. *Water Resources Management* 40, 96. https://doi.org/10.1007/s11269-025-04467-1

Barberá, G.G., Castillo, V., 2025. Encubriendo la desertificación con tecnología: Regadío y desequilibrio hídrico en el sur de España. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 243–248.

Beck, H.E., McVicar, T.R., Vergopolan, N. Berg, A., Lutsko, N.J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A.I.J.M., Miralles, D.G., 2023. High resolution (1 km) Köppen-Geiger maps for 1901-2099 based on constrained CMIP6 projections. *Scientific Data* 10, 724. https://doi.org/10.1038/s41597-023-02549-6

Beguería, S., López-Moreno, J.I., Lorente, A., Seeger, M., García-Ruiz, J.M., 2003. Assessing the effect of climate oscillations and land-use changes on streamflow in the Central Spanish Pyrenees. *Ambio* 32 (4), 283–286. https://doi.org/10.1579/0044-7447-32.4.283

Cantón, Y., Domingo, F., Solé-Benet, A., Puigdefábregas, J., 2001. Hydrological and erosion response of a badlands system in semiarid SE Spain. *Journal of Hydrology* 252, 65–84. https://doi.org/10.1016/S0022-1694(01)00450-4

Carrera Morales, J.A., 1990. El Proyecto LUCDEME: Lucha contra la desertificación en España. *Ecología* 1, 199-212.

Casalí, J., Gastesi, R., Álvarez Mozos, J., De Santisteban, L.M., Del Valle Lerchundi, J., Giménez, R., Larrañaga, A., Goñi, M., Agirre, U., Campo, M.A., López, J.J., Donézar, M., 2008. Runoff, erosion and water quality of agricultural watersheds in central Navarre (Spain). *Agricultural Water Management* 95 (10), 1111–1128. https://doi.org/10.1016/j.agwat.2008.06.013

Castillo, V., Martínez-Mena, M., Albaladejo, J., 1997. Runoff and soil loss response to vegetation removal in a semiarid environment. *Soil Science Society of America Journal* 61 (4), 1116–1121. https://doi.org/10.2136/sssaj1997.03615995006100040018x

Castillo, V., Gómez-Plaza, A., Martínez Mena, M., Albaladejo, J., 2000. Respuesta hidrológica en los medios semiáridos: las cuencas experimentales de la sierra del Picarcho, Murcia (España). *Cuadernos de Investigación Geográfica* 26, 81-94. https://doi.org/10.18172/cig.1064

Ceballos, A., Schnabel, S., 1998. Hydrological behaviour of a small catchment in the dehesa landuse system (Extremadura, SW Spain). *Journal of Hydrology* 210, 146–160. https://doi.org/10.1016/S0022-1694(98)00180-2

Cots-Folch, R., Martínez-Casasnovas, J.A., Ramos, M.C., 2006. Land terracing for new vineyard plantations in the north-eastern Spanish Mediterranean region: landscape effects of the EU Regulation policy for vineyards' restructuring. *Agriculture, Ecosystems & Environment* 115, 88–96. https://doi.org/10.1016/j.agee.2005.11.030

Cunningham, C.X., Williamson, G.J., Bowman, D.M.J.S., 2024. Increasing frequency and intensity of the most extreme wildfires on Earth. *Nature Ecology & Evolution* 8, 1420–1425. https://doi.org/10.1038/s41559-024-02452-2

De Felipe, M., Aragonés, D., Díaz-Paniagua, C., 2023. Thirty-four years of Landsat monitoring reveal long-term effects of groundwater abstractions on a world Heritage Site wetland. *Science of Total Environment* 880, 163329. https://doi.org/10.1016/j.scitotenv.2023.163329

Estrany, J., García, C., Batalla, R.J., 2009. Transporte de sedimento en suspensión en una cuenca mediterránea agrícola. *Cuaternario y Geomorfología* 23 (1-2), 9–28.

Gallardo Olmedo, F., 2025. Turismo y estrés hídrico: Una preocupante convergencia en tiempo y espacio. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 221–226.

Gallart, F., Llorens, P., 2004. Observations on land cover changes and water resources in the headwaters of the Ebro catchment, Iberian Peninsula. *Physics and Chemistry of the Earth* 29, 769–773. https://doi.org/10.1016/j.pce.2004.05.004

García-Ruiz, J.M., López Bermúdez, F., 2009. *La erosión del suelo en España.* Sociedad Española de Geomorfología, Zaragoza, 441 pp.

García-Ruiz, J.M., González Rebollar, J.L., Ibáñez Martí, J.J., López García, P., Martín Lou, P., Puigdefábregas Tomás, J., de la Rosa, D., Rubio Delgado, J.L., 1996. *Programa Interáreas del CSIC sobre Desertificación en Ambientes Mediterráneos: Aspectos físicos, culturales, sociales y económicos.* Instituto Pirenaico de Ecología, Zaragoza, 27 pp.

García-Ruiz, J.M., Regüés, D., Alvera, B., Lana-Renault, N., Serrano-Muela, P., Nadal-Romero, E., Navas, A., Latron, J., Martí-Bono, C., 2008. Flood generation and sediment transport in experimental catchments along a plant cover gradient in the Central Pyrenees. *Journal of Hydrology* 356, 245–260. https://doi.org/10.1016/j.jhydrol.2008.04.013

García-Ruiz, J.M., López-Moreno, J.I., Vicente-Serrano, S.M., Lasanta-Martínez, T., Beguería, S., 2011. Mediterranean water resources in a global change scenario. *Earth-Science Reviews* 105, 121–139. https://doi.org/10.1016/j.earscirev.2011.01.006

García-Ruiz, J.M., Beguería, S., Nadal-Romero, E., González-Hidalgo, J.C., Lana-Renault, N., Sanjuán, Y., 2015. A meta-analysis of soil erosion rates across the world. *Geomorphology* 239, 160–173. https://doi.org/10.1016/j.geomorph.2015.03.008

García-Ruiz, J.M., Tomás-Faci, G., Diarte-Blasco, P., Montes, L., Domingo, R., Sebastián, M., Lasanta, T., González-Sampériz, P., López-Moreno, J.I., Arnáez, J., Beguería, S., 2020a. Transhumance and long-term deforestation in the subalpine belt of the central Spanish Pyrenees: an interdisciplinary research. *Catena* 195, 104744. https://doi.org/10.1016/j.catena.2020.104744

García-Ruiz, J.M., Lasanta, T., Nadal-Romero, E., Lana-Renault, N., Álvarez-Farizo, B., 2020b. Rewilding and restoring cultural landscapes in Mediterranean mountains: opportunities and challenges. *Land Use Policy* 99, 104850. https://doi.org/10.1016/j.landusepol.2020.104850

Gómez, J.A., 2025. La desertificación del olivar: Un desafío complejo para un sistema agrícola diverso. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 239–242.

Green, A.J., Alcorlo, P., Peeters, E.T.H.M., Morris, E.P., Espinar, J.L., Bravo-Utrera, M.A., Bustamante, J., Díaz-Delgado, R., Koelmans, A.A., Mateo, R., Mooij, W.M., Rodríguez-Rodríguez, M., van Nes, E.H., Scheffer, M., 2017. Creating a safe operating space for wetlands in a changing climate. *Frontiers in Ecology and the Environment* 15 (2), 99-107. https://doi.org/10.1002/fee.1459

Harvey, A.M., 2011. The coupling status of alluvial fans and debris cones: a review and synthesis. *Earth Surface Processes and Landforms* 37 (1), 64–76. https://doi.org/10.1002/esp.2213

Lasanta, T., Nadal-Romero, E., García-Ruiz, J.M., 2019. Clearing shrubland as a strategy to encourage extensive livestock farming in the Mediterranean mountains. *Cuadernos de Investigación Geográfica* 45 (2), 487–513. http://doi.org/10.18172/cig.3616

Llorens, P., Domingo, F., 2007. Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. *Journal of Hydrology* 335, 37–54. https://doi.org/10.1016/j.jhydrol.2006.10.032

Llorens, P., Poyatos, R., Rubio, C., Latron, J., Gallart, F., 2005. El papel de los bosques en los procesos hidrológicos: ejemplos en las cuencas de investigación de Vallcebre (Prepirineo catalán). *Cuadernos de Investigación Geográfica* 31, 27–44. https://doi.org/10.18172/cig.1172

Maneta, M.P., Pasternack, G.B., Wallender, W.W., Jetten, V., Schnabel, S., 2007. Temporal instability of parameters in an event-based distributed hydrological model applied to a small semiarid catchment. *Journal of Hydrology* 341 (3-4), 207–221. https://doi.org/10.1016/j.jhydrol.2007.05.010

Martínez Fernández, J., 2025. El regadío como fuente de desarrollo y degradación. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 233–237.

Martínez-Fernández, J., Ceballos Barbancho, A., Hernández Santana, V., Casado Ledesma, S., Morán Tejeda, C., 2005. Procesos hidrológicos en una cuenca forestal del Sistema Central: cuenca experimental de Rinconada. *Cuadernos de Investigación Geográfica* 31, 7–25. https://doi.org/10.18172/cig.1171

Martínez-Valderrama, J., Olcina Cantos, J. (eds.), 2026. The Labyrinth of Desertification. Sixteen case studies in Spain. Cham, Springer, 177 pp.

Martínez-Valderrama, J., Olcina Cantos, J., Guirado, E., Martí-Talavera, J., Cintas, J. (eds.), 2025a. *Atlas de la Desertificación de España.* Sant Vicent del Raspeig, Publicacions de l'Universitat d'Alacant, 257 pp.

Martínez-Valderrama, J., Cintas, J., Varela Redondo, E., 2025b. El comercio mundial de la degradación distorsiona el ámbito de la desertificación. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-

Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 249–252.

Nadal-Romero, E., Lasanta, T., García-Ruiz, J.M., 2013. Runoff and sediment yield from land under various uses in a Mediterranean mountain area: long-term results from an experimental station. *Earth Surface Processes and Landforms* 38: 346–355. https://doi.org/10.1002/esp.3281

Nadal-Romero, E., Rodríguez-Caballero, E., Chamizo, S., Juez, C., Cantón, Y., García-Ruiz, J.M., 2022. Mediterranean badlands: their driving processes and climate change futures. *Earth Surface Processes and Landforms* 47(1), 17–31. https://doi.org/10.1002/esp.5088

Nadal-Romero, E., Vicente-Serrano, S., Lana-Renault, N., López-Moreno, J.I., Regüés, D., Lasanta, T., García-Ruiz, J.M., 2025. Plant cover determines runoff generation in response to dry and wet conditions. *Journal of Hydrology* 660 (Part B), 133495. https://doi.org/10.1016/j.jhydrol.2025.133495

Nadal-Romero, E., García-Ruiz, J.M., 2025. Market as a factor of soil erosion: the expansion of new and old crops into marginal Mediterranean lands. *Regional Environmental Change* 25, 16. https://doi.org/10.1007/s10113-024-02355-9

Nadal-Romero, E., Calvo-Cases, A., 2025. Geoformas, lo que no es desertificación. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España*. Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 227–231.

Olcina Cantos, J., Martí Talavera, J., Sánchez Almodóvar, E., 2024. Evolución reciente de precipitación y temperatura en la región mediterránea de la península ibérica: revisando la señal del calentamiento global a escala regional. *Cuadernos Geográficos de la Universidad de Granada* 63 (2), 51-73.

Olcina Cantos, J., Martí Talavera, J., 2025. Sequías, aridez y desertificación: El factor climático. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 167–172.

Peña-Angulo, D., Beguería, S., Trullenque-Blanco, V., González-Hidalgo, J.C., 2025. Variabilidad espacial y temporal de las precipitaciones extraordinarias en España (1916-2022). *Cuadernos de Investigación Geográfica* 51 (1), 105–126. https://doi.org/10.18172/cig.6634

Peña Monné, J.L., 2025. *Laderas, paleoambientes y geoarqueología del Holoceno en Aragón.* Discurso de ingreso en la Real Academia de Ciencias Exactas, Físicas, Químicas y Naturales de Zaragoza, pp. 3–55.

Peña-Monné, J.L., Sampietro-Vattuone, M.M., Longares-Aladrén, L.A., Pérez-Lambán, J.V., Sánchez-Fabre, M., Alcolea-Gracia, M., Vallés, L., Echeverría-Arnedo, M.T., Baraza, C., 2018. Holocene alluvial sequence in the val de Zaragoza (Los Monegros) in the palaeoenvironmental context of the Ebro Basin (NE Spain). *Cuadernos de Investigación Geográfica* 44 (1), 321–348. https://doi.org/10.18172/cig.3358

Peña-Monné, J.L., Sampietro-Vattuone, M.M., Picazo-Millán, J.V., Alcolea-Gracia, V., 2024. Block alignments/talus flatiron stages as response of lithological factors and dynamic slope changes in the Central Ebro Basin, NE Spain. *Quaternary Science Reviews* 340, 108864. https://doi.org/10.1016/j.quascirev.2024.108864

Prosdocimi, M., Tarolli, P., Cerdà, A., 2016. Mulching practices for reducing soil water erosion: A review. *Earth-Science Reviews* 161, 191–203. https://doi.org/10.1016/j.earscirev.2016.08.006

Puigdefábregas, J., 2001. Desertificación y erosión, ¿dos caras de la misma moneda? *Ecosistemas* 10 (3).

Puigdefábregas, J., Lázaro, R., 2000. Erosión y desertificación en Almería: Aclarando conceptos. En: M. Carmona Powell, M. Sánchez Villanueva (coords.). *Desertificación en Almería. De los tópicos y malentendidos a las causas y consecuencias.* Grupo Ecologista Mediterráneo, Almería, pp. 21–30.

Puigdefábregas, J., 2005. The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms* 30, 133–147. https://doi.org/10.1002/esp.1181

Rojo Serrano, L., Sánchez Fuster, M.C., 1997. *Red de estaciones experimentales de seguimiento y evaluación de la erosión y la desertificación, RESEL*. Madrid, Ministerio de Medio Ambiente, 298 pp.

Romero-Díaz, A., Marín-Sanleandro, P., Sánchez-Soriano, A., Belmonte-Serrano, F., Faulkner, H., 2007. The causes of piping in a set of abandoned agricultural terraces in Southeast Spain. *Catena* 69, 282–293. https://doi.org/10.1016/j.catena.2006.07.008

Sanjuán, M.E., del Barrio, G., 2025. Desertificación heredada: Minería deforestación y abandono en la sierra de Gádor (Almería). En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 227-231.

Schnabel, S., Pulido-Fernández, M., Lavado-Contador, J.F., 2025. La dehesa: un paisaje cultural que afronta los desafíos del futuro. En: J. Martínez-Valderrama, J. Olcina Cantos, E. Guirado, J. Martí-Talavera, J. Cintas (eds.). *Atlas de la desertificación de España.* Sant Vicent del Raspeig, Publicaciones de l'Universitat d'Alacant, pp. 209-214.

Tarolli, P., Luo, J., Park, E., Barcaccia, G., Masin, R., 2024. Soil salinization in agriculture: Mitigation and adaptation strategies combining nature-based solutions and bioengineering. iScience 27, 108830. https://doi.org/10.1016/j.isci.2024.108830

Vicente-Serrano, S.M., López-Moreno, J.I., Beguería, S., Lorenzo-Lacruz, J., Sánchez-Lorenzo, A., García-Ruiz, J.M., Azorín-Molina, C., Morán-Tejeda, E., Revuelto, J., Trigo, R., Coelho, F., Espejo, F., 2014. Evidence of increasing drought severity caused by temperature rise in southern Europe. *Environmental Research Letters* 9, 044001. https://doi.org/10.1088/1748-9326/9/4/044001

Vicente-Serrano, S.M., Tramblay, Y., Reig, F., González-Hidalgo, J.C., Beguería, S., Brunetti, M. et al., 2025. High temporal variability not trend dominates Mediterranean precipitation. *Nature* 639, 658–666. https://doi.org/10.1038/s41586-024-08576-6