SUPPLEMENTARY MATERIALS

SECTION S1. TABERNAS BADLANDS

The climatological conditions and the sparsely vegetated landscape of the study area justify the local name of “Desierto de Tabernas” (Tabernas Desert) (Lázaro, Rodrigo, Gutiérrez, Domingo, & Puigdefábregas, 2001). However, it does not meet the demanding climatic criteria for entry into the desert category. The main argument that can be given for it is that the climate of the zone is semi-arid. In addition, the vegetation cover is thick where it can be. The asymmetry present in many of the small catchments integrating these badlands is linked to the vegetation pattern. North to east facing hillslopes are larger, more stable and less steep. Here plant cover ranges from 20% to 40% in the area (Puigdefabregas, Sole, Gutierrez, del Barrio, & Boer, 1999). The opposite slopes are affected by erosion, shorter, steeper, and bare (Calvo-Cases et al., 2014).

The Tabernas badlands cannot be considered as the result of a desertification process. There has been no misuse of resources here (at least until recently, see next section). In other words, this desolate landscape is not the result of overexploitation. The reason is that this territory, due to its complicated orography, has never harbored an economy capable of promote substantial land degradation. On the upper hillslopes, *M. tenacissima* used to be harvested for cellulose, while the footslope sedimentary fill was cultivated with rainfed cereal crops. Both types of land use ceased about 50 years ago (Puigdefabregas et al., 1999). It was also possible to find some irrigation confined to small areas by then. In Almería, the use of subsoil water in irrigation is a long-established and dominant practice (Sánchez-Picón, Aznar-Sánchez, & García-Latorre, 2011) and, although by far the greater part of the agricultural lands was not irrigated, irrigation has been the economic basis of Almería because of the high yields it produced (Latorre, García-Latorre, & Sanchez-Picón, 2001). In the case of Tabernas-Sorbas, irrigations are associated to the valley of the Andarax River and its tributary wadis, at the western end of our study area, and to the Aguas river on its eastern part. Water was used in Los Molinos in now-abandoned hydraulic mills (this means *molino* in Spanish), to produce flour and oil from the surrounding cereal crops and olive trees.

What mainly gives Tabernas the denomination of desert, besides the climatic anomaly that it represents in continental Europe, are its landforms, another of the main signs of distinction of deserts. The soft nature of the sediments that have filled the Tabernas Basin from 10 to 8 million years ago, the slow and continual uplift of the sierras that border it, and the arid yet stormy climate that has characterised this territory for a good part of the more recent Quaternary, have conditioned the model for one of the most spectacular erosive landscapes in continental Europe (Braga, Martín, & Martín-Penela, 2003). The characteristic morphology are escarpment landforms (see Fig. 3), that consist of inclined layers of hard material, normally sand and/or conglomerate, that protect the much weaker underlying material, usually marls, from erosion.

About eight million years ago (in the Miocene) the sea extended through the territory of the Tabernas Desert up to the foot of the Sierra de los Filabres. In the slopes of this ancient sea, submarine fans deposited a thick and extensive sedimentary package that the rivers eroded from the emerging relief. In this depositional environment, marine at times, lagoonal at others, the deposition of limestones, marls, muds and sands, and enclosed gypsum continued up until around two million years ago (in the Pliocene, almost at the start of the Quaternary), when the sea ultimately retreated, leaving the sediments exposed to the action of erosive agents (Braga et al., 2003).

In the soft and readily eroded foothills, the stream produces grooves, which grow towards rills and runnels, and terminate in furrows separated by sharp crests. This landscape is given the name ‘Badlands’, alluding to its difficulty for being worked or put into agricultural production (Villalobos, 2004).

Tabernas Desert is a mosaic of physiographic units concentrating most of the water erosion features of fluvial landscapes (Solé Benet, Lázaro, Puigdefábregas, & Cantón, 2009). This spectacular erosive landscape (Figure S1) is not, therefore, attributable to human action. The eroded landscape of the Tabernas desert is a consequence of the geological evolution of the region over the length of the last four million years, and more specifically, of its tectonic and climatic evolution in the past 150,000 years.

SECTION S2. DESERTS

Deserts are biomes (i.e., territories that share climate, flora and fauna) where the water balance is unfavourable for life. Deserts are mature ecosystems with very low productivity due to severe water limitations promoted by low rainfall and high evapotranspiration levels (Ward, 2016), and have evolved under this state for a long period. As an example, the Sahara Desert is estimated to be at least 4.6 million years old (Muhs et al., 2019). The reason for the existence of these biomes is merely climatic and it is on the basis of climatic criteria that the deserts of the world are defined (Ezquerra, 2006). Their expansion or retraction responds, therefore, exclusively to climatic drives that modify the aridity conditions experienced by a territory. Thus, for example, the extension of the Sahara has varied over time (Gasse, Téhet, Durand, Gibert, & Fontes, 1990; Liu, Washington, Meehl, Wu, & Potter, 2001).

There is no single criterion by which we can catalogue a site as desert, but there is a series of distinctive features. High temperatures are typical of deserts, but even more so is the enormous thermal amplitude. During the day temperatures can turn the dry desert land into a hell of 80°C. At night, however, the lack of cloudiness and humidity in the air causes temperatures to plummet to the point of freezing. With respect to precipitation, the 250 mm annual barrier is the commonly accepted threshold below which a territory can be referred to as desert (Meigs, 1953; Noy-Meir, 1973). However, there are more radical opinions, and some authors argue that in a desert no more than 100 mm a year can fall. In addition, the place has to suffer annual droughts of 10 or 12 month duration, and there even have to be years in which it doesn't rain at all (Evenari, Noy-Meir, & Goodall, 1986).

Precipitation and temperature are combined in the aridity index (AI). Aridity is perhaps the most appropriate criterion for determining what a desert is since this concept represents the lack of water, the main factor limiting biological processes. The AI is simply the ratio between mean annual precipitation (P) and mean annual potential evapotranspiration (PET), the amount of water that would be lost from water-saturated soil by plant transpiration and direct evaporation from the ground (Thornthwaite, 1948). Arid and hyperarid regions have a P/PET ratio of less than 0.20; that is, rainfall supplies less than 20 per cent of the amount of water needed to support optimum plant growth.

The desert biome can be defined climatologically as the sum of all the arid and hyper-arid areas of globe, but can also be defined biologically as the ecoregions that contain plants and animals adapted for survival in arid environments. Indeed, the map of the world's deserts can be drawn by lumping together all the ecoregions of the world that harbor desert vegetation (Olson et al., 2001), that is, the xerophilous life-forms and the general desert-adapted physiognomy of the dominant plants. A global map of deserts can also be drawn by considering large uniform regions with extremely low vegetation cover with ample extensions of bare soil. The Normalized Difference Vegetation Index (NDVI) divides the earth into different land-cover categories, pointing out that deserts and semideserts are below 10% of vegetal cover (Boussetta, Balsamo, Beljaars, Kral, & Jarlan, 2013).

Overlaying areas under these three criteria (climatological, biological, and physical) shows a composite definition of the world's deserts, occupying almost one-quarter of the earth's land surface, some 33.7 million km^2 (Ezquerra, 2006).

SECTION S3. DESERTIFICATION

Desertification is a process of degradation that deprives land of its capacity to maintain life and to provide essential ecosystem services to human populations, leading to the emptying of territories. The origin of desertification lies in the decoupling of the natural and economical systems (Javier Ibáñez, Martínez-Valderrama, & Puigdefábregas, 2008; Puigdefabregas, 1995). In other words, when the rate of consumption of resources exceeds that of regeneration for a sufficient period of time, certain irreversible thresholds may be exceeded.

There are numerous examples of desertification in literature, and the same pattern can be observed in all of them: an increase in the production rate, due to technological changes (that allow access to the resource), political changes (that create the conditions for its exploitation), climatic changes (periods more humid than normal), or a combination of all of them, leading to the economic and demographic growth of a certain area that becomes a pole of attraction or hotspot. After a few years of prosperity, the ecosystem begins to suffer and the degradation of the territory begins. If the productive paradigm is held, then the territory is desertified.

The Dust Bowl case (Lockeretz, 1978; Schubert, Suarez, Pegion, Koster, & Bacmeister, 2004) brings together all the elements to illustrate the phenomenon well. The North American Midwest is an arid region characterized by strong windstorms. Until a hundred years ago, buffaloes grazed on the green meadows that covered the ground. Population density was low and resource use sustainable. In a short period of time, three facts changed the landscape. On one hand, the iron plough made it easy to pass through the leathery mantle of grass. On the other hand, the new varieties of wheat were designed to withstand the harsh winters. One ingredient, the market, was missing for the new technology to show its potential. The Bolshevik revolution of 1919, which collapsed Russian exports, created that opportunity. Then, thousands of hectares of natural grassland became wheat fields. The soil was exposed to windstorms and literally flew through the air. Farmers were forced to migrate and the abandonment of the land was the epilogue to an ephemeral episode of wealth of large-scale cultivation of an area unsuitable for it.

Slight variations of this scheme explain the disappearance of the Aral Sea (Glazovsky, 1995) and the North African steppe rangelands (Martínez-Valderrama et al., 2018). In these cases, state policies aimed at turning large regions into first-rate production centers wiped out soil fertility within a few decades. The conversion of pastures to agricultural land in Inner Mongolia (Yin, Pflugmacher, Li, Li, & Hostert, 2018), the salinization of crop fields in Sumeria (Jacobsen & Adams, 1958) or the depletion of aquifers in Saudi Arabia (Elhadj, 2004) are just a few examples to check the temporal and geographical transversality of desertification.

Drastic changes in land use explain all these cases (Bestelmeyer et al., 2015; Lambin & Meyfroidt, 2011). The need to produce more food in a context of demographic expansion, loss of soil fertility, and global warming have all intensified land use. The conversion of pastures into croplands, rainfed into irrigated land, or the increase of the stocking rate in the rangelands are signs of this dangerous dynamic. Agricultural activities or agrarian land uses are the leading proximate cause associated with nearly all cases of desertification (Geist & Lambin, 2004).

Groundwater use is the explanation for some of these large-scale transformations in drylands. The boom in groundwater exploitation started in 1950 when major advances in geological knowledge, well drilling, pump technology, and rural electrification extended over the world (Foster, Chilton, Moench, Cardy, & Schiffler, 2000). Since then it has only increased its dependence on this resource. Total groundwater withdrawals are estimated to be in the range of 600–1100 $km^3\ yr^{-1}$ (Siebert et al., 2010) or between one fifth and one third of the total global freshwater withdrawals (Döll, 2009; Shah, Burke, & Villholth, 2007). Over two billion people rely on groundwater as their primary water source (Alley, Healy, LaBaugh, & Reilly, 2002) providing at least 50% of current potable water supplies (70% of piped water supply in the European Union) (UNESCO, 2004) and half or more of the irrigation water used to produce the world’s food (Famiglietti, 2014).

Generally, the rates of groundwater recharge in drylands are low, so, in the absence of alternative sources of water, groundwater withdrawals can exceed aquifer recharge and lead to aquifer depletion (Ahmed & Umar, 2009; Rodell, Velicogna, & S Famiglietti, 2009; Scanlon, Jolly, Sophocleous, & Zhang, 2007; Shah et al., 2007; Siebert et al., 2010; Wang, Huang, Rozelle, Huang, & Zhang, 2009). Therefore, the overexploitation of aquifers coupled to the expansion of irrigated agriculture is one of the main causes of desertification.

SECTION S4. NEWS IN THE SPANISH PRESS USING THE IMAGE OF THE TABERNAS DESERT TO INFORM ABOUT DESERTIFICATION

- "2090: España será el nuevo Sáhara" (2090: Spain will be the new Sahara). – *El Mundo,* Jul. 31, 2017. https://www.elmundo.es/papel/historias/2017/07/31/5979f9a0e2704efb638b468e.html
- "Camino al desierto: la erosión se come más de 500 millones de toneladas de suelo al año en España" (On the way to the desert: erosion eats up more than 500 million tons of soil a year in Spain). – *Eldiario.es*, Apr. 12, 2019. https://www.eldiario.es/sociedad/Camino-desierto-millones-toneladas-Espana_0_897660994.html
- "El 37% de la superficie de España se encuentra en riesgo de desertificación" (37% of the surface area of Spain is at risk of desertification). – El Mundo, Sep. 4, 2008. https://www.elmundo.es/elmundo/2008/08/31/ciencia/1220198277.html
- "La desertificación y la erosión del suelo afectan a 169 países" (Desertification and soil erosion affect 169 countries). – *Agencia EFE*, Jun. 15, 2018. https://www.efeverde.com/noticias/desertificacion-erosion-suelo-169-paises/
- "La desertización avanza en España y afecta ya a más del 30% del territorio" (Desertification is advancing in Spain and already affects more than 30% of the territory). *El Pais*, Jun. 16, 2006. https://elpais.com/sociedad/2006/06/16/actualidad/1150408807_850215.html
- "Un 30% del territorio español ya sufre desertificación" (30% of Spanish territory is already suffering from desertification). El Independiente, Sep. 15, 2018. https://www.elindependiente.com/desarrollo-sostenible/2018/09/15/un-30-del-territorio-espanol-ya-sufre-desertificacion/

FIGURE S1. Typical landscape of the Desert of Tabernas where the contrast between the steepest and bare hillsides and the presence of esparto grass (*Macrochloa tenacissima*) in more stable and less steep hillslopes can be appreciated. (Source: J. Martinez-Valderrama)

FIGURE S2. Traditional dryland olive groves benefiting from the higher humidity naturally found in the “ramblas”.

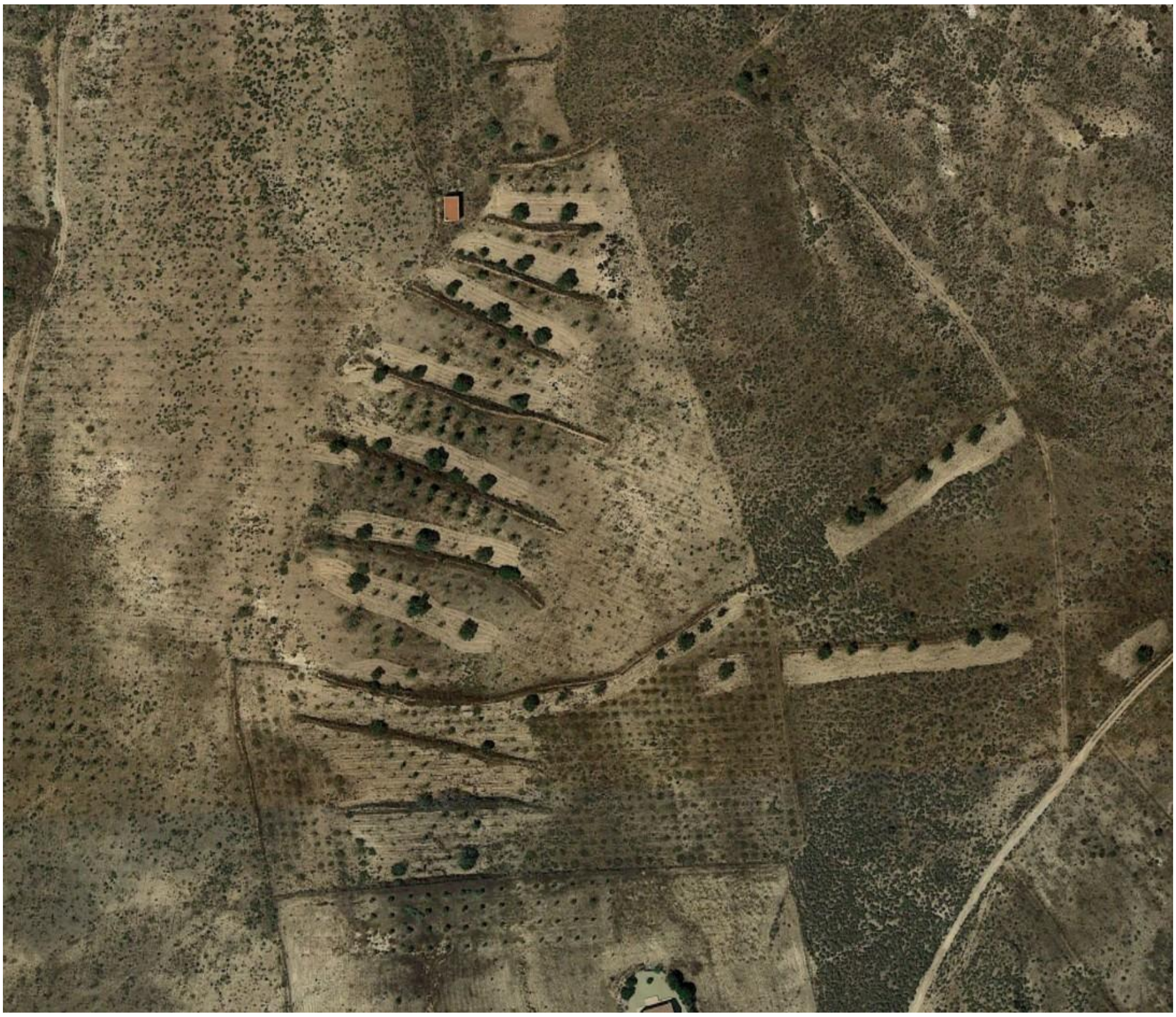

FIGURE S3. Traditional dryland olive groves on the edge of cultivation terraces.

A. 2013

B. 2019

FIGURE S4. Satellite observations show an intensification of the olive grove. (**A**) In 2013 (image above) the whole area was covered by olive trees under intensive irrigation. (**B**) In 2019 (lower image) the lower right plot has been replaced by super-intensive olive grove.

FIGURE S5. New land in preparation for planting olive trees.

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