

Article

Mapping food production in hyper arid and arid Saharan Africa in the Holocene. A view from the present

Carla Lancelotti ^{1*}  and Stefano Biagetti ² 

¹ CaSEs Research Group, Department of Humanities, Universitat Pompeu Fabra, c/Trias Fargas 25, 08005, Barcelona, Spain; ICREA, passeig Lluís Companys 23, 08010, Barcelona, Spain; carla.lancelotti@upf.edu

² CaSEs Research Group, Department of Humanities, Universitat Pompeu Fabra, c/Trias Fargas 25, 08005, Barcelona, Spain; School of Geography, Archaeology and Environmental Studies (GAES), University of the Witwatersrand, 1 Jan Smuts Ave, Johannesburg, 2000, South Africa; stefano.biagetti@upf.edu

* Correspondence: carla.lancelotti@upf.edu

Abstract: The reconstruction of land use practices in hyper arid Saharan Africa is often hampered by the accuracy of the available tools and by unconscious biases that see these areas as marginal and inhospitable. Considered for a long time the living space of pastoral mobile communities, new research is showing of agriculture might have been more important in these areas than previously thought. In this paper, after a review of present-day land use strategies in Saharan Africa, we show how ethnographic and ethnoarchaeological data can offer us a different point of view and help in better defining land use and food production strategies in this area. Ultimately, these insights can be integrated into the ongoing effort of reconstructing past land use globally.

Keywords: drylands; land use; aridity index; ethnography; ethnoarchaeology; pastoralism; agriculture; LandCover6K

1. Introduction

The Sahara is the largest hot desert on Earth. It includes a variety of ecological and environmental settings, such as rocky plateaus, mountains, dune fields, (mostly dried) river valleys, and stony surfaces (*hamada/serir*). Like all deserts, it has always evoked images of an inhospitable land, devoid of resources, where human life is harsh at the least; a place where only few tribes of seasoned mobile societies could win over the barren land and make it their home. In this empty landscape, the presence of water in the form of rivers or oasis, has always been seen as the lifeline providing coveted places of abundance and life. Indeed, the Sahara is so overlooked as a place for human life that in modern geopolitics the African continent is divided into “North Africa” and “sub-Saharan Africa”, both including countries whose territory falls almost completely into the limits of the desert ecosystem. However, the capitals of these countries, as well as the living places for the dominant elites in the past, are all close to fresh water, either alongside major rivers or at the margins of the desert, where the annual precipitations increase, the vegetation cover becomes more abundant, and the land can be fully cultivated. Thus, the desert as a space for living disappears from many narratives, to remain associated with a land to cross, home of pastoral mobile societies or few, small sedentary communities living in the oases. In this paper we transcend the qualitative, social and geographical definitions and we overcome the dichotomy of North *versus* Sub-Saharan Africa by capitalizing on a climatic index, the Aridity Index (AI), which classify a territory according to the proportion between rainfall and potential evapotranspiration [1,2]. In this paper, after a general consideration on modern-day land use in the Sahara, we report on modern and historic examples of three specific forms of land use within extremely arid areas

characterized by an AI up to 0.07 (Figure 1), specifically pastoralism, oasis agriculture and rainfed agriculture. Ultimately, starting from ethnographic observations and models, we will discuss how to extend land use classification in the past for these specific cases, by applying the recent framework developed by the PAGES LandCover6K initiative [3,4].



Figure 1. Aridity Index [1,2] map of the area considered in this study: (1) Fazzan, (2) Central Sudan. Note that by using this Index we indicate with the term Sahara also areas that are not normally considered part of this desert as the Nile Valley and coastal areas of Egypt (map elaborated with QGIS-LTR 3.16).

2. Present day land use in Saharan Africa

Our understanding of land use in Saharan Africa is, at present, driven by two main constraints: the availability of data and models and the focus, in the research effort to ensure food stability in drylands, on crops and cropland. The constant improvement of satellite and remote sensing data has allowed the creation of multiple datasets and models that are currently used, principally, to monitor land cover and derive cropland potential at both regional and global level [for a complete list see, 5,6]. One of the latest, the NASA *Making Earth System Data Records for Use in Research Environments* (MEaSUREs) *Global Food Security-support Analysis Data* (GFSAD) product, provides global cropland extent data for year 2015 at 30m resolution [7]. Recent research has compared this and other datasets to understand the level of agreement between them, at global and regional levels [see for example 5,6,8]. These studies highlighted a certain lack of agreement between the various datasets, which is particularly significant in certain areas. For example, Pérez-Hoyos and colleagues [6] found that, over 9 different datasets, full agreement is reached in the whole of Africa only in 2.15% of cases. Conversely, there are areas, such as the Nile delta in Egypt where full or high agreement (6-8 out of 9 datasets) is reached in a surprisingly high percentages of cases (42.6% of cases) [6, p.11 and Figure 1]. A similar study that concentrates only on Africa reached almost identical conclusions and highlighted that inconsistencies in crop mapping are particularly significant in the Sahel and in west Africa [5]. All these studies seem to agree on the fact that the Sahara is mostly bare, mainly based on the seminal landcover publication of FAO that characterizes the entire Sahara as bareland [9].

The main problems associated with cropland definition at global and regional level are determined by gaps in the baseline information, the lag between research and operational implementation, cloud cover, resolution, and data update amongst others [8]. For Africa specifically, Nabil and colleagues [5]) stress the limitations due to cell resolution, highlighting that the use of 30m resolution image size is

not enough to detect small (<1.5 ha) and very small (< 0.15 ha) parcel size, which mainly characterize agricultural land in Africa and suggested that the ideal resolution would be between 5 and 10 m. Amongst the available datasets, the Spatial Production Allocation Model (SPAM) uses a different array of inputs to provide plausible estimates of crop distributions within disaggregate units, for 42 crops and different cultivation strategies (irrigated, rainfed, high/low input etc.) and it is being updated every five years [10]. According to the latest version of this dataset [11], the irrigated and rainfed cultivated area in North and Saharan Africa can be seen in Figure 2. Based on these estimates, cultivation in the Saharan belt is based mainly on rainfed practices 2b and the main products are tropical fruit (date palms most probably) and some small instances of wheat, barley and rice in the desert, whereas sorghum and vegetables are prevalent along the Nile. Interestingly there seems to be no record of rainfed cultivation of pearl millet, which was the main crop we observed during fieldwork [12].

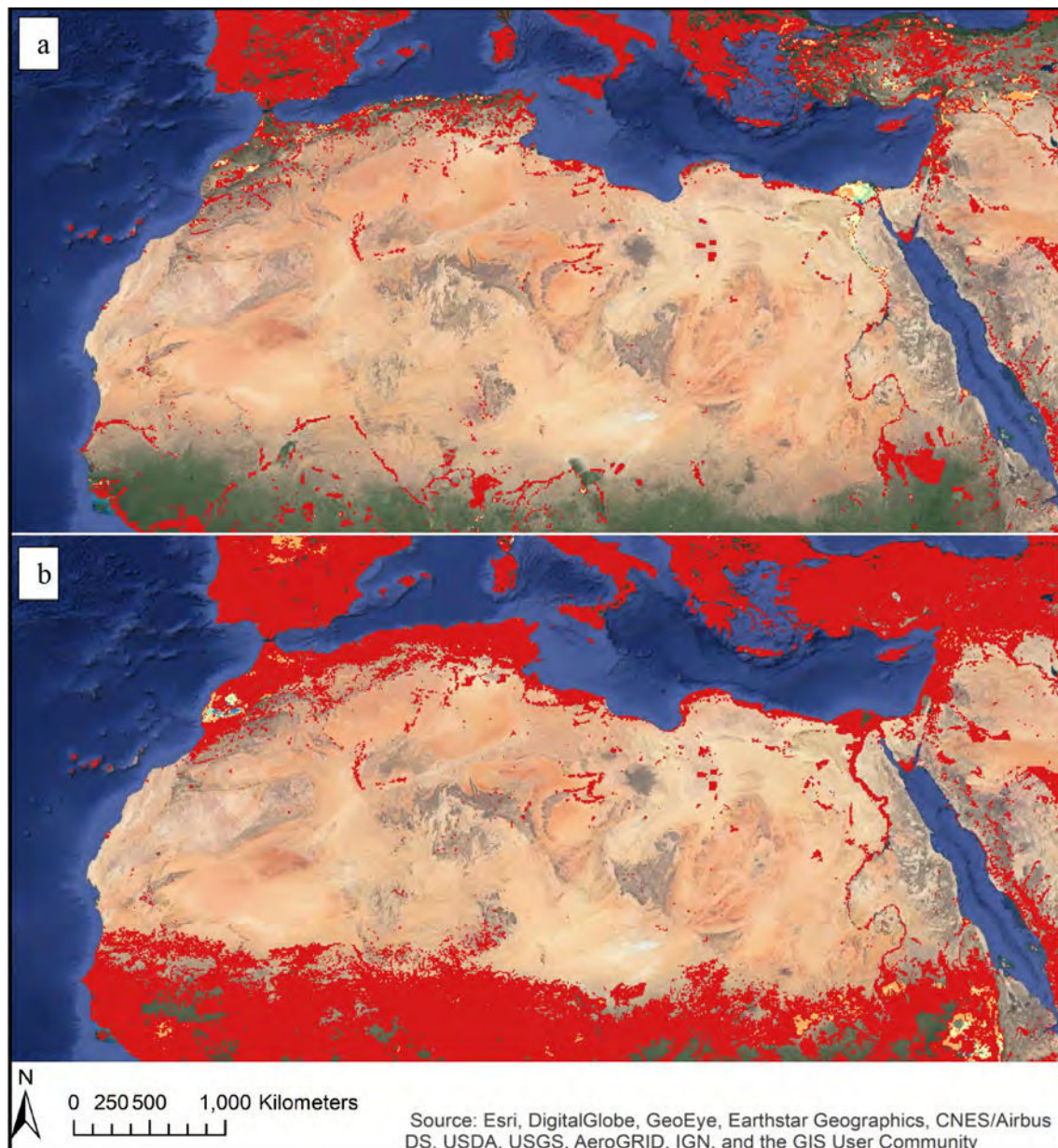


Figure 2. Aggregated maps for all 42 crops produced using Harvest Choice data [11]: (a) total area irrigated. (b) rainfed. Areas in red show presence of cultivation of at least one crop at the lower end of the scale. Areas not shaded indicate that no data is available. Zeroes (cells where there are available data but no cultivation) have been removed (maps elaborated with ArcGIS).

The above-mentioned issues also affect the reconstruction of grazing lands and pasture areas. Phelps and Kaplan [13] have recently pinpointed the difficulties in the study of pastoral land use. Along with the intrinsic problems in defining both terms, the authors indicate that the attempts at classifying land use for pastoral uses have been mostly performed on remotely collected data [e.g. 14,15] or on available inventory data [e.g. 9]. Only few approaches have adopted a combination of both datasets [16,17]. The classification of pastoral land use is largely based on the identification of natural vegetation (land cover) in areas where agriculture is allegedly neither practiced nor practicable. Being therefore an indirect measure of potential pastoral land use, the various definitions of pastureland and grazeland largely depend on the capacity of detecting such a patchy vegetation canopy, typical of hyper arid and arid areas. Remotely sensed land cover reconstructions, in fact, can hardly capture such erratic 'natural' vegetation [see 18], where shrubs often represent the base of the livestock nourishment [19].

Not surprisingly, following the classification of FAO [9] previously mentioned most of the Sahara is classified as treeless and barren by those engaged with the design of remotely sensed land use models through time [e.g. 17,20] (Figure 3). To overcome this limitations, Phelps and colleagues [21] provided maps of climate suitability for animal husbandry at 500-year intervals for the last 10k years, focusing on the modeling of niches suitable to pastoralism at the continental level. This work represents an exceptional attempt at modeling the extension on areas suitable to pastoral societies in Africa.

In the next section we will show how ethnoarchaeological data, both extracted from ethnographic observations produced between the end of the 19th and the beginning of the 20th century, as well as collected more recently, can provide valuable insights on land use in hyper arid and arid areas.

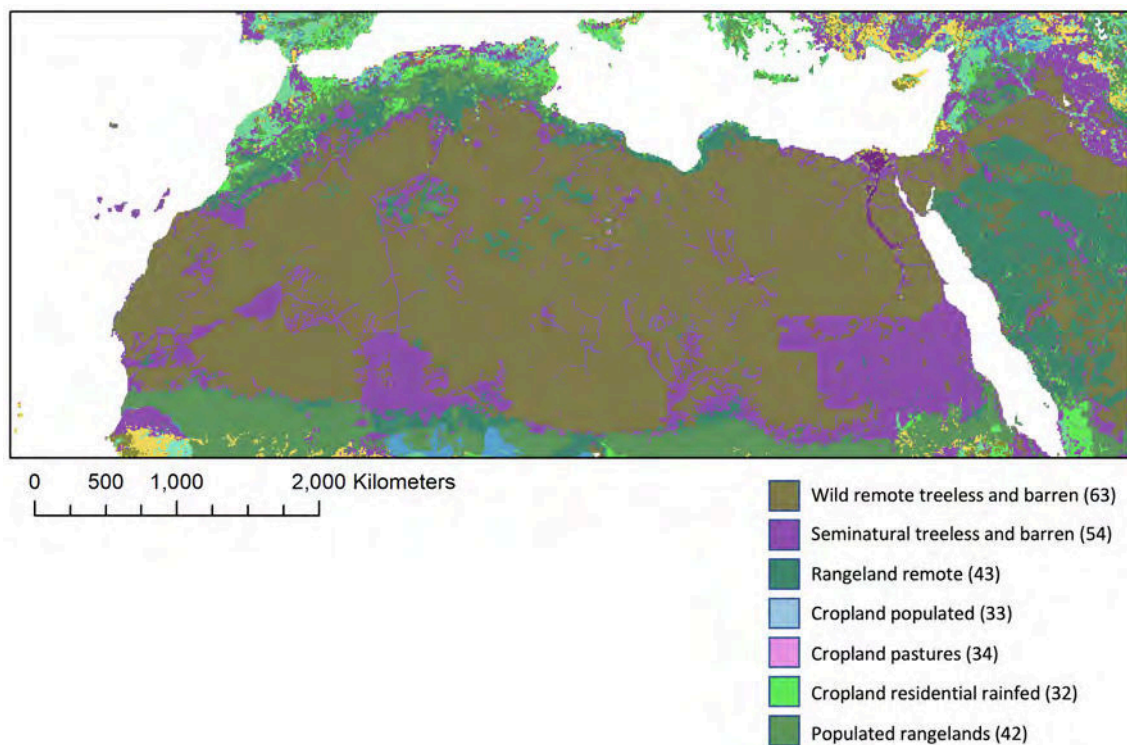


Figure 3. Elaboration from data published by Klein Goldewijk, Dr. ir. C.G.M. (Utrecht University) [20]. Anthropogenic land-use estimates for the Holocene; HYDE 3.2. DANS. Legend displays the original classification of the anthromes (with numbers) as proposed by Ellis and Ramankutty [22]. The legend includes the most represented anthromes as visible in the map (map elaborated with ArcGIS).

3. Three examples of present and modern land use in arid and hyper arid Sahara: pastoralism, oasis agriculture and rainfed agriculture

In this paper we concentrate on the Fazzan in SW Libya and the Nile Valley, which are probably the best-known areas in the Sahara and North Africa. Both regions have attracted multidisciplinary teams of archaeologists, ethnographers, biologists, and geologists that, from the 19th century onward began to explore their past and present. As a result, these stand out as some of the few areas of the Sahara where long sequences of occupations have been reconstructed for the last 10k years [23,24]. Current reconstructions suggest that from 7000 years ago onward, pastoralism was the only form of food production adopted in Fezzan, up to c. 3000 years ago, when cultivation was introduced in the oases [25]. Pastoralism in this view represents the earliest form of food production in the Sahara, and its development was largely affected by Holocene climatic shifts. Not differently, Holocene climatic fluctuations largely affected social dynamics and the development of food production in the Nile Valley [24], where the exploitation of a broad range of resources characterized past societies between the tenth and the 6th millennia BC [26]. Standing as a long green strip crossing the eastern part of the Sahara, the Nile represented a center of attraction for past human communities gravitating around it. Farming

was considered, up to recent times, to date back to 5200 BC in the Fayum area [27], and to have reached Sudan a few centuries later [26,28]. In the Nilotic Nubian Neolithic (4500–3000 BC) subsistence was based on fishing and pastoralism, integrated by wild sorghum and millet [29]. Wild sorghum was likely cultivated [30,31], while emmer and barley, both of Near Easter origin, were adopted as far south as Al Khiday [32]. Connections between Central Sahara and the Nile Valley were recognized by Arkell as early as the beginning of the 20th century [28]. In both regions, the advent of food production occurred during the Middle Holocene (c. 7k years ago) and was later propelled by the advent of more arid conditions 5k years ago that, in turn, paved the way to the rise of social stratification [24].

3.1. Pastoralism

It is nowadays widely acknowledged that pastoralism represents a suitable practice to achieve food security in semi-arid to hyper-arid environments, due to its flexibility and adaptability to changing natural resources (both in time and in space). Pastures and rangelands represent the most extensive form of land use, adding up to a quarter of the earth ice-free land surface [13, and references therein], although quantification and classification of pastureland or rangeland has proven to be a difficult task (see section 2). On the other hand, ethnographic accounts can provide important insights on past and recent land use of pastoral societies, though the majority of pastoral landscape have been cartographed as a series of points connected by arrows, displaying thus the year round cycles of movements of a given society [33]. In terms of land use reconstruction, this type of information is intrinsically problematic, as it does not convey the extent of the territory used by pastoralists at the time of the generation of the map. Aware that any cartography of pastoralists, especially in drylands, is an indicative tool that can portrait some coarse contours including customary lands used by pastoralists, we will discuss here the case of the Fazzan, where military administration from the 1930s, coupled with direct field observation from one of the author (SB) can lead to the estimation of some facts about recent and current land use.

Pastoral activities during 1930s, as reported by colonial age accounts, covered vast areas from SW Fazzan. All the five areas included in the reports (see Table 1) represent important hotspots in the region, and host oases and towns. Along with sedentary settlements, Tuareg and Tebu nomads have traditionally grazed their livestock. In 1930s, accurate census of the nomads and sedentaries was carried out under the Italian and, later, French administrations. The Italians [34–36] collected precise data on the nomadic herders and their customary grazing areas (see Figure 4 and Table 1). Tuareg and Tebu from the Fazzan roamed through hyper arid locations (Figure 4b), where only few spots of ‘grazing areas’ have been identified by the HYDE 3.2 map of land use (Figure 4c and d). The authors refer to those herders as nomadic, and hint at some differences in their patterns of yearly movements [34–36]. Those living in area 4 and 5 looked more prone to longer transhumances, while those living in the large Wadi Shati (area 1), Wadi el Ajal (area 2), and Wadi Berjuj (area 3) were characterized by more regular movements, though still opportunistic and variable, and this may explain the occurrence of ‘other’ stock, mainly poultry, that fits with a semi-nomadic lifestyle. Allegedly pure nomads were rising only ovicaprids (OC in Table 1, dromedaries, and, in the case of the Tuareg living in the area of wadi Tanezuft (area 5) also some donkeys (Equines in Table 1). Field research in the Tanezuft area reported the presence of contemporary Tuareg pastoralists in the area, exploiting the erratic pastures that are to be found along the wadis [19]. Similarly, field trips to Wadi el Ajal and Wadi Berjuj confirmed the persistence of pastoralism, although a general trend toward a progressive sedentarization -already stressed in the 1930s- was noticed [19]. In the 2000s - 2010s, up to the 2011 turmoil, pastoralism in those areas was characterized by strong opportunism. Families of herders exploited customary grazing areas and were ready to move to more distant pastures in case of good rain. Flexible movements and rapid decisions represent the key to thrive in the Fezzan, where the climate is hyper arid with almost no rainfall (ranging between 0 and 20mm per year) and the natural resources for livestock (water and pastures) are erratic and patchy.

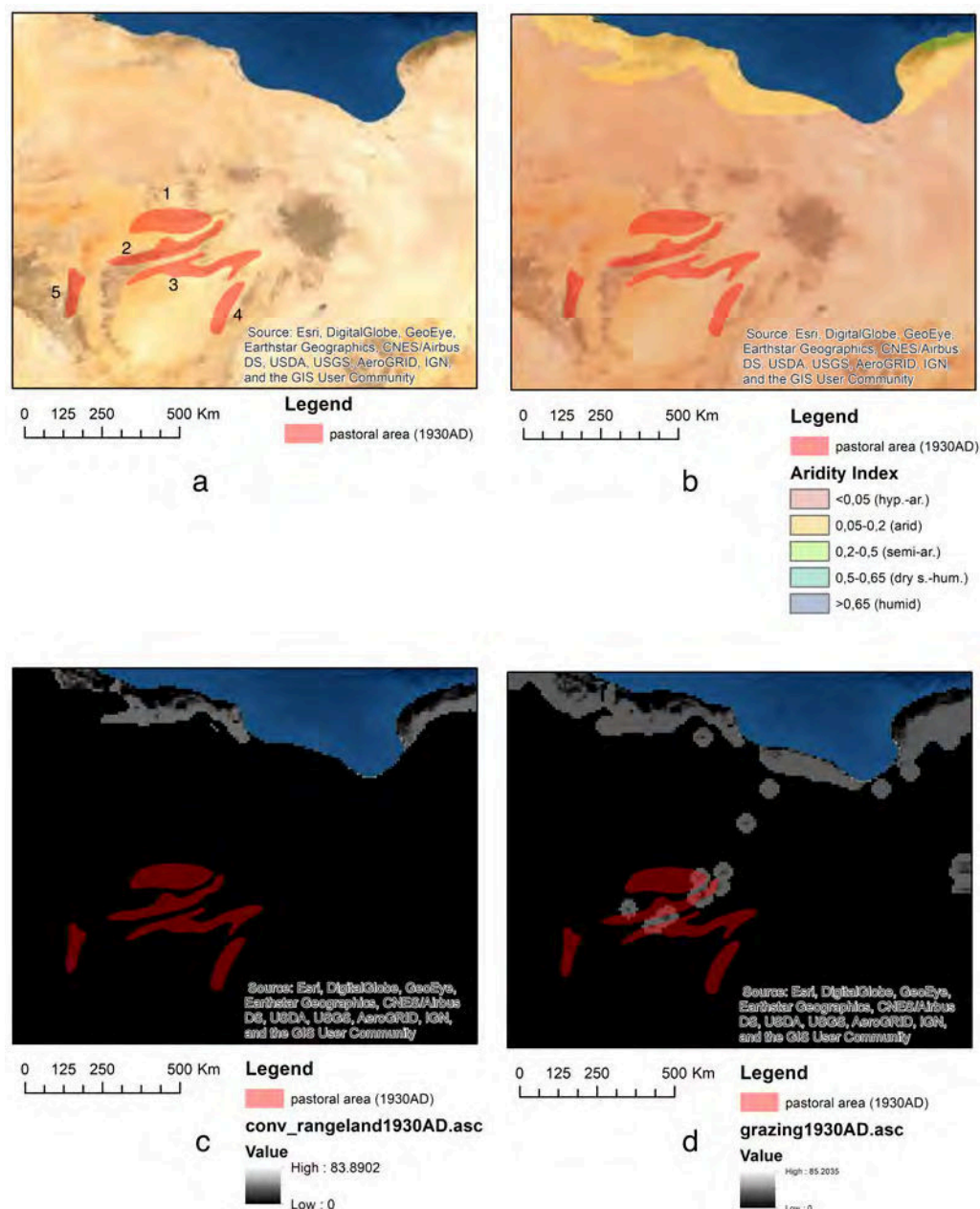


Figure 4. Pastoral areas in Fezzan according to ethnographic sources [34–36]. (a) the five areas discussed in this paper. Key: 1 Wadi Shati, 2 Wadi el Ajal, 3 Wadi Berjuj, 4 Wadi Hikma, 5 Wadi Tanezuft. (b) superimposed to the Aridity Index values. (c) superimposed to rangeland values. (d) superimposed to grazing values. Legend in (c) and (d) displays the land use according to Klein [20]. Spatial resolution 5 arc-minutes (maps elaborated with ArcGIS).

Table 1. Demographic and livestock data in the areas of the Fazzan [34–36]. For the location of the areas, see Figure 4. OC = Ovicaprine; Equines = horses and donkeys.

Area	Group	LU1	LU2	Area (km2)	People	Dromedaries	OC	Equines	Cows	Others
1	Tuareg	Pastoralism	Mobile-irregular	15641	4106	1214	865	339	0	300
2	Tuareg	Pastoralism	Mobile-irregular	12396	611	335	375	48	0	150
3	Tuareg	Pastoralism	Mobile-irregular	15619	280	150	340	0	0	50
4	Tebu	Pastoralism	Mobile-irregular	7286	260	240	410	nd	0	nd
5	Tuareg	Pastoralism	Mobile-irregular	5463	500	509	1137	308	25	nd

3.2. Oasis agriculture

Oasis agriculture in Fazzan is dated as early as c. 3k years [for a recent review see 25], and was practiced with traditional technologies until very recently. Ethnographic studies on local agricultures were carried out under the French and the Italian colonial administrations [34–37]. In the first half of the 20th century, those authors reported that the Fazzani oases presented favorable characteristics for the cultivation of crops. In fact, water table was generally shallow. Scarin [35] noticed that in many areas the water table could be reached only a few meters below the surface. Therefore, traditional shallow wells were reported in use during 1930s and 1940s [35,37], representing the sole method for irrigating fields, being the ancient foggaras abandoned in historical times. Some colonial age publications report precise data on the list of species cultivated and their number in each oasis [34–36](Table 2. Oasis agriculture is described as being dependent on well irrigation although in some cases (e.g. in the Wadi el Ajal) portions of the ancient foggaras were still in use [38]. Fazzani gardens are generally square or rectangular, with sides that range between 30 and 200m. Every garden is crossed by a network of shallow irrigation channels made of mud. In the 1930s, the majority of those gardens were owned by some prominent families, who employed wage workers. Small holders, mainly former nomadic Tuareg or Tebu, owned smaller gardens and were running family enterprises with no employees. The gardens were being cultivated with palm trees (*Phoenix dactylifera* L. arabic *Nachla*), providing dates and plant material for crafting basketry, beds, saddles, and for construction as well. Palm trees in the Fazzani gardens did not need irrigation since the water table was often shallower than 5 m. Along with their byproducts, palm trees provided shade to wheat (*Triticum vulgare* Vill. in the original text, *syn. T. aestivum* L.) and barley (*Hordeum vulgare* L.) during winter and sorghum and millet (*Pennisetum americanum* (L.) Leeke in the original text *syn. Chenchrus americanum* (L.) Morrone), along with legumes and vegetables. Occasionally, those reports are associated with some sketches of selected oases [35,36], that allow to reconstruct the extent of the inhabited area and the size of the cultivated areas (Table 2).

Table 2. Demographic and crop data for selected oases in the Fazzan [34–36]. For the location of the oases, see Figure 4. Areas are expressed in ha; garden area includes settlement area. * system formed by three oasis Tamzaua-Es Zueia-Zeluaz

Area	Oasis	LU1	LU2	People	Mobility	Settlement area	Garden area	Palms	Pams/pax
1	Brak	Agriculture	Annual crops	730	sedentary	5.9	54	17000	23
1	Tamzaua	Agriculture	Annual crops	1329	sedentary	23,74	1200	22600	17
2	Greifa	Agriculture	Annual crops	541	sedentary	14.5	50	3000	6
2	Brach	Agriculture	Annual crops	257	sedentary	5	69	7800	30
2	El Abiad	Agriculture	Annual crops	266	sedentary	0.9	9	2800	23
4	El Gatrun	Agriculture	Annual crops	404	sedentary	24	160	39000	97
4	Tegerhi	Agriculture	Annual crops	140	sedentary	1.1	90	7000	50

3.3. Rainfed Agriculture

For the purpose of this paper, we consider rainfed agriculture as the cultivation of domestic or semi-domestic crops that rely exclusively on rain, where no additional water (irrespective of its origin) is provided to the plants before or during the growth period, and that is practiced far from rivers or water basin that can create a flooding area during the rain period. The crops that can be cultivated with this kind of agricultural practice are obviously dependent on the environment where they are grown with wetter areas providing better ground for this practice. Rainfed agriculture is usually deemed unviable in areas that receive less than 300 mm of annual rainfall in the absence of water harvesting structures [39] even when considering drought-tolerant crops such as millets and sorghum, which not only require less water than other crops (such as wheat, barley, rice and maize) but have also a shorter growing periods, making them more adapted to grow in drylands. As Figure 2 shows, rainfed agriculture is extremely limited in Saharan Africa and is mainly concentrated in the Sahel, on the northern coast and along the banks of the river Nile, that is in areas with higher rainfall (and Aridity Index values) or on the floodplain of a major river. Between 2015 and 2019 the authors have conducted

ethnoarchaeological surveys in the area south of Omdurman on the west bank of the white Nile within the frameworks of the Al Khiday (directed by D. Usai and S. Salvatori) and the RAINDROPS projects. At present this area can be classified as borderline hyper arid, having an Aridity Index of 0.07. Here we recorded several instances of rainfed cultivation of pearl millet, as far as 15 km west of the river bank [12,40]. These types of cultivation are visible on satellite images, and temporal series, provided freely by GoogleEarth. However, because the individual plants are widely spaced and a great amount of ground is visible between them, this type of cultivation is practically undetected by automatic systems of vegetation reconstruction. A visual scanning of the satellite images of the area surveyed, and of neighbouring areas where local collaborator had additional fields, suggested that this type of practice, though highly variable and uncertain, is viable not only when rainfall is abundant (i.e. around 350 mm) but also when its values are much lower than what is considered the minimum required for this crop to grow. Indeed, observation of temporal series have shown the presence of fields in years where average rainfall is around 150 mm [40, Figure 2]. According to the Harvest Choice data [11], rainfed cultivation of pearl millet in our study area, is limited to a small area on the banks of the Nile where it can benefit from the seasonal river flooding. The areas that we identified during fieldwork are not included in their maps (Figure 5) and indeed, traditional rainfed cultivation of pearl millet is not recorded in the Khartoum state (where our study area is located) in the latest reports on agricultural productivity in Sudan [41].

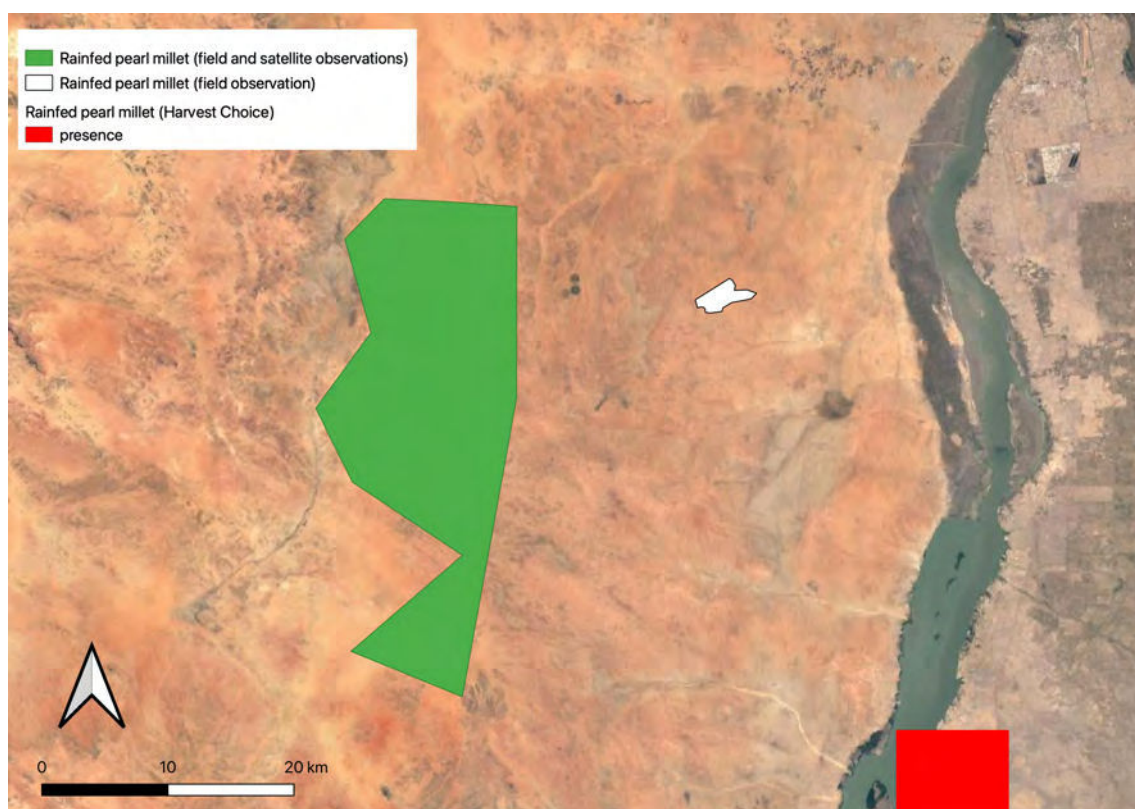


Figure 5. Map showing the location and extent of rainfed pearl millet fields, observed both during ethnographic fieldwork and remotely (map elaborated with QGIS-LTR 3.16, base image GoogleEarth satellite 2014).

Interestingly, although we have not personally visited the area where Harvest Choice places pearl millet rainfed cultivation, in our research we have never encountered this crop cultivated on the floodplain of the river. This area is usually cultivated in sorghum and vegetables, making the most of the higher soil moisture and organic content provided by the flooding of the river. The fields of pearl millet, are usually located further inland from the Nile, in areas where the soil has lower quantities of

organic matter and less moisture. Notwithstanding the ethnographic interviews conducted in this area have revealed that this type of cultivation can provide the farmers with enough crops to cover their annual needs and in times of good rainfall (.e. above 15 mm) even with surplus to sell at the market and the possibility to cultivate cash crops [12,40] (Table 3).

Table 3. Demographic and crop data collected during ethnographic interviews in Central Sudan [12,40]. Filed area is expressed in ha; Production of millets only (pearl millet and sorghum) is expressed in kg and is an estimation based on average plants per area and average production per plant (except in the case marked with *) and on last 5 years’ average production of traditional rainfed cultivation [41]

Area	LU1	LU2	Field area	Floodplain	Crop	Production
Al Khiday	Agriculture	Herbaceous/Ground crops	16.8	no	Pearl millet	1600
Al Khiday	Agriculture	Herbaceous/Ground crops	19.7	no	Pearl millet	2000*
El Gos	Agriculture	Herbaceous/Ground crops	12.6	no	Pearl millet	1260
El Gos	Agriculture	Herbaceous/Ground crops	10	no	Pearl millet, watermelon	1000
Atwal	Agriculture	Herbaceous/Ground crops	4.6	yes	Sorghum, vegetables	2100
Atwal	Agriculture	Herbaceous/Ground crops	7.6	yes	Sorghum, vegetables	3500
Atwal	Agriculture	Herbaceous/Ground crops	16.8	yes	Sorghum, vegetables	7700
Samrah	Agriculture	Herbaceous/Ground crops	1.7	yes	Sorghum, vegetables	782
Samrah	Agriculture	Herbaceous/Ground crops	6.3	yes	Sorghum, vegetables	2900
Samrah	Agriculture	Herbaceous/Ground crops	16.8	yes	Lady fingers	nd
Samrah	Agriculture	Herbaceous/Ground crops	13.9	yes	Sorghum, vegetables	6400
Umm Habib	Agriculture	Herbaceous/Ground crops	2.1	no	Pearl millet	2100
Umm Habib	Agriculture	Herbaceous/Ground crops	6.3	no	Pearl millet, watermelon	630

4. Discussion

The reconstruction of past land use in hyper arid and arid environments will certainly keep challenging the scientific community for the next years. As noted, technological advances, especially in the acquisition of data through remote-sensing, are enabling a better understanding of present and past land use activities. However, there are still many issues that hamper our ability to fully and correctly identify the types of practices discussed in this paper. First and foremost the scanty remains they leave behind makes it difficult to directly trace their existence far back in the past. With the exception of oasis agriculture, which are geographically tied to features whose presence can be identified in the paleoenvironmental record, the trajectories of pastoralism and rainfed agriculture can only be reconstructed through interpretation of indirect evidence. Both these practices are usually inferred through the analysis of archaeological macroscopic, and in few cases microscopical, evidences such as architectural remains, settlement location and bioarchaeological remains and the contexts in which all these evidences are found is usually what drives their interpretation. Late Holocene occupation evidences (monuments and settlements) widespread from Mauritania’s coast to the Nile Valley have been recently analysed through remote sensing [18,42,43]. In spite of the almost total inaccessibility of many regions in North African and the Sahara after the 2011 turmoil, large inventories of endangered sites have been and are being compiled, by various international efforts (e.g. the [EAMENA project](#) or also the *Mapping Africa’s Endangered Archaeological Sites and Monuments project*). Still, the majority of available data come from the Fazzan region and from the Nile Valley. In these areas, the onset of current arid conditions determined a deep economic and geographic reorganization of the human communities. In North Africa and the Sahara the general trend toward present day aridity began around 5k years ago [44,45]. Post 5k aridification was a main driver in opening new pastures to domestic livestock, fostering the diffusion of pastoralism into sub-Saharan Africa [21]. Nevertheless, the Sahara was not abandoned 5k years ago, and pastoral societies responded to climate change with the adoption of different types of stock and changing their settlement patterns [46,47]. Since the adoption of animal domesticates (c. 7000 years ago) African pastoralists could cope with variations in yearly rainfalls, not dissimilarly to what current pastoral societies do [48,49]. Such climatic variability likely prompted the adoption of flexible strategies of land use from 5000 years ago onwards [46]. Reconstruction of archaeological land use of pastoral areas may be inferred by the distribution of archaeological

sites unequivocally related to ancient herders (e.g. dung deposits, recognizable burial monuments or material culture associated to ancient pastoral communities), although pastures might have well extended beyond the recorded archaeological evidence [18]. In the 'customary' areas considered in this paper inhabited by pastoralists in the 1930s, evidences of past frequentations by herders society have been noticed in the form of burial tumuli [18,50], of archaeological deposits [49,51], rock art [52,53], or scatters of materials [54]. With the advent of the historical Garamantian age (c. 3000-1400 years ago), oasis cultivation and long-range pastoralism became the main components of a mixed system that lasted practically up to modern times [19]. Recent research [25,55] has shown that the oases of the Fazzan were intensively exploited by agriculturalists and, in some cases, densely inhabited as early as Garamantian times (BC1000-700AD, c. 3000-1400 years ago) [56]. Thanks to the work of both British and Italian teams (1990s-2011), with the support of Libyan institutions and colleagues, an outstanding dataset of remotely identified sites, selected foot surveys, and dozens of C14 dates allows to reconstruct past human activities within the five areas of the Fazzan discussed in the previous paragraph. Through these data, oasis agriculture in the Fazzan is dated to c. 3k years ago [for a recent review see 25] and featured the use of foggaras (qanats) underground channels and dug wells. Foggaras were likely introduced in Gramantian times during the last centuries BC and were in use until the medieval period, and probably no later than the end of the first millennium AD [57]. In Garamantian times, major crops included palm trees, pearl millet, and sorghum [58,59], the latter apparently absent today according to the spatial allocation model for crops of Harvest choice [11]. The combination of farming in the oases, pastoralism in their surrounding and in the mountains, and the long distance trans-Saharan trade, allowed the Garamantian kingdom to flourish in the rugged terrains of the Sahara for centuries. The ability to cope with variation in rainfall and, thus, in the exploitation of different ecological niches, was key to enhance the resilience of past Central Saharan population throughout the Late Holocene, up to present days. In this perspective, the demographic decrease postulated after the end of the AHP [60] may be better read as the concentration around some oasis, where most tangible evidence of human frequentations are to be found in the forms of forts [61–63], necropoleis [18,56,64–66], and oasis fields [25,55]. Not surprising, colonial accounts from the 1930s report the existence of *ksur* (forts) of uncertain date (ranging from Garamantian to Islamic age) in the oases, testifying to the temporal depth of human exploitation of such niches. In Central Sudan, the area immediately adjacent to the Nile has provided innumerable examples of successful adaptation to otherwise hyper-arid conditions. The debate on whether southwest Asian cereals, i.e. wheat and barley, were introduced together with domestic animals between the end of the 7th and the beginning of 6th millennium BCE, or the two events were separate and sequential is still open [67]. However, an holistic view of the archaeobotanical remains identified mostly in cemeteries, is slowly pushing the use and consumption of crops such as wheat and barley (C3 plants) to the second half of the 6th millennium BCE (5620–5480 cal BC) [68]. These results are particularly significant as the wild ancestors of these crops are missing from the region [69], which led the authors of the study to suggest that they were imported from the north of the Nile Valley [68, p.5]. However, they do not exclude the possibility of a local cultivation of these crops that relied on the flooding of the river [68, p.6]. The widespread presence of phytolith and starch from millets (used in the widest sense to include several types of millet and sorghum, C4 plants) found in the necropolis at Ghaba, suggests also that Neolithic people were consuming a wide spectrum of local cereals [32]. The existence of a broad-spectrum diet is somehow confirmed by the stable isotope analysis conducted on human bone remains found at Al Khiday [70], which showed that the diet of pre-Mesolithic people was composed of a mixture of C3 and C4 plants, whereas the Mesolithic diet seems to shift towards C4 species only. It is most likely that the C3 signature of the pre-Mesolithic individuals derives from legumes rather than cereals. Although it was not possible to fully ascertain whether the millets remains recovered from Ghaba pertained to wild or domestic species [68], it was noted that the morphology and patterns of fragmentation of the silica skeletons (phytoliths in anatomical connections) did not follow the natural contour of individual cells [32]. This led the authors of the study to suggest that millets were at least partly processed

using a sharp tool but no further indications on whether these were wild or domestic were proposed. Taken together these finds challenge the traditional interpretation of the Neolithic of the Sudanese Nile Valley as characterised mainly by pastoralism and introduce the presence of domestic cereals from c. 500 years earlier than so far considered [32]. Thus agriculture had a more important role than previously thought, at least in the Nile Valley. Our ethnographic research, described in section 3.3, might suggest that alternative methods of cultivation could have coexisted with floodplain agriculture and might offer a hint on whether millets remains found at Ghaba, but also at Kedada [71], could be domestic rainfed plants. Archaeologically, crop water management is usually hypothesised on the basis of geography, economy and degree of social organisation. Thus, sites that are (or were) located in the vicinity of a major watercourse, such as the Nile, are usually believed to rely on floodplain agriculture. Similarly, when archaeobotanical remains are found in locations that are far from any permanent water source, crops are believed to be grown under rainfed condition or imported. This is the case, for example, of the recent research by di Lernia and colleagues [72] on the possible presence of rainfed cultivation in the Tadrart Acacus in the past. Advances in the analytical methods available to archaeologists provide a method to infer plant water availability directly from archaeobotanical remains through the application of stable isotope and phytolith analyses [see 12, for a review on the subject]. This has been established and widely tested for C3 plants but is still being developed for C4 species. Preliminary results on phytolith extracted from sediments collected in modern fields of rainfed pearl millet in the area of Al Khiday suggest that this could be a viable approach to identify past water management practices for C4 crops [12] but more research is ongoing that will create the necessary baseline values for the study of archaeobotanical remains. The reliable classification of pastoral and agricultural practices in the past is of paramount importance for the reconstruction of past land use scenarios that can be integrated into climate modelling. To this effect, the present research is a first step towards the introduction of different, or more nuanced, models of land use in hyper arid deserts. This effort is frameworked within the wider context of the LandCover6k action of PAGES [4] and especially the Archaeology/History land use reconstruction group, which aims at providing the climate modeling community with information on past land use reconstructed from archaeological proxies. In particular, this work contributes to a better definition of two land use categories [3]:

1. LU1 Agriculture > LU2 Herbaceous/Ground crops (with variables: "CULTIGEN" = wheat, barley, pulses, sorghum, millets, orchard/trees crops and "WATER AND LANDSCAPE MODIFICATIONS" = rainfed, flood, qanats)
2. LU1 Pastoralism > LU2 Mobile irregular (with variable: "SETTLEMENT MODE" = dispersed, non sedentary)

5. Conclusions

Along with a variety of proxies hinting at a general trend toward aridification in Saharan Africa [31,44], more recent research has remarked the role of local sequences for the understanding of landscape units and human communities responses to climatic shifts [73,74]. The available data points to a marked variation in yearly rainfall over the last four millennia, within the context of increasing aridity [75,76]. People's response to aridification was likely mediated by local geomorphological factors, such as for example the existence and size of near-surface aquifers or of areas of increased rain water retention, that enhanced or mitigated the effect of climate change. Moreover, if climatic events are global, 'change' is likely experienced in regional or local terms (e.g. the flooding a given plain, the shrinking of a lake, the reduction of pasture). The ethnographic present provides insights on how human societies cope with the available resources and thrive in allegedly unsuitable regions. In this paper we have aimed at re-examining ethnographic and ethnoarchaeological data that represent, in our vision, an overlooked source of information. Often vague and largely descriptive, many ethnographic reports deserve an in-depth analysis to extract valuable facts and figures that can indicate possible land use practices. In this work we have focused on primary sources, i.e. those produce by direct observation on the field, and their role in providing usable data for understanding contemporary

and sub-contemporary forms of land use in hyper-arid environments. The data presented in this paper, coupled with a recent review [12] are providing new information on forms of land use that escape traditional views on drylands ecosystems. Rainfed agriculture in hyper arid and arid areas represent a well-rooted cultivation practice characterized by its sustainability. The use of the scanty and erratic rainfall in drylands for agricultural purposes, in fact, highlight the role of traditional ecological knowledge for food production. In terms of land use, data on oasis cultivation in the Old World drylands are extremely scarce [20]. In this paper we attempted a first quantification of agricultural production in an hyper arid region, that may help refining land use study of similar areas set between North Africa and the Middle East, up to arid areas of South East Asia. Ultimately, the knowledge on agro-pastoral practices, coupled with data on type and the quantity of livestock and crops, supplement the qualitative information that often characterizes the pure ethnographic literature, contributing to a better characterization of land use in hyper arid areas, where remote-based modeling does not detect potentially usable lands for pastoral and, agricultural communities. Data collected in the present can be used to build general models for the interpretation of the past, in a genuine and data-informed ethnoarchaeological perspective, focusing on less evident (or less studied) elements of the drylands' archaeological landscape

Author Contributions: Both authors have contributed equally to every part of this research from conception to the writing of the paper.

Funding: This research and the APC were funded by the European Research Council, grant number ERC-Stg-2017 759800, RAINDROPS project.

Acknowledgments: We are deeply indebted to Donatella Usai and Sandro Salvatori for giving us the opportunity to carry out ethnographic fieldwork under their research licence and to NCAM for providing such licence. This work could not have been performed without the support and help of Mongeda Khalid Magzoub and Yassen Ibrahim who accompanied us during our interviews and also collected data for us when we could not visit Sudan. Both authors are members of the research group CaSEs (recognised by AGAUR SGr-212) and this paper has benefited from long and fruitful discussion with all its members, in particular Marco Madella and Abel Ruiz-Giralt. CaSEs is associated unit of the IMF-CSIC. Lastly we want to thank the editors of this volume to invite us to participate in this Special Issue. This study was undertaken as part of the Past Global Changes (PAGES) project (and 1047 working group LandCover6k), and the Human and Biosphere Commission of INQUA (the Global Holocene Land Use - HoLa - International Focus Group and related projects).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

1. Zomer, R.J.; Bossio, D.A.; Trabucco, A.; Yuanjie, L.; Gupta, D.C.; Singh, V.P. *Trees and water: smallholder agroforestry on irrigated lands in Northern India*; Vol. 122, IWMI, 2007.
2. Zomer, R.J.; Trabucco, A.; Bossio, D.A.; van Straaten, O.; Verchot, L. Climate Change Mitigation: A Spatial Analysis of Global Land Suitability for Clean Development Mechanism Afforestation and Reforestation. *Agric. Ecosystems and Envir.* 126: 67-80. *Agriculture, Ecosystems and Environment* **2008**, 126, 67–80.
3. Morrison, K.; Hammer, E.; Boles, O.; Madella, M.; Whitehouse, N.; Gaillard, M.J.; Bates, J.; Vander Linden, M.; Merlo, S.; Yao, A.; Popova, L.; Hill, C.; Biagetti, S. Mapping past human land use using archaeological data: a new classification for global land use synthesis and data harmonization. *PLoS ONE*.
4. Gaillard, M.J.; Morrison, K.; Madella, M.; Whitehouse, N. Editorial: Past land-use and land-cover change: the challenge of quantification at the subcontinental to global scales. *Past Global Changes Magazine* **2018**, 26. doi:10.22498/pages.26.1.3.
5. Nabil, M.; Zhang, M.; Bofana, J.; Wu, B.; Stein, A.; Dong, T.; Zeng, H.; Shang, J. Assessing factors impacting the spatial discrepancy of remote sensing based cropland products: A case study in Africa. *International Journal of Applied Earth Observation and Geoinformation* **2020-03**, 85, 102010. doi:10.1016/j.jag.2019.102010.
6. Pérez-Hoyos, A.; Rembold, F.; Kerdiles, H.; Gallego, J. Comparison of Global Land Cover Datasets for Cropland Monitoring. *Remote Sensing* **2017-11**, 9, 1118. doi:10.3390/rs9111118.
7. Congalton, R.; Yadav, K.; McDonnell, K.; Poehnel, J.; Stevens, B.; Gumma, M.; Teluguntla, P.; Thenkabail, P. *NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Global Food*

- Security-support Analysis Data (GFSAD) Cropland Extent 2015 Validation Global 30 m V001*; NASA EOSDIS Land Processes DAAC, 2017.
8. Fritz, S.; See, L.; Bayas, J.C.L.; Waldner, F.; Jacques, D.; Becker-Reshef, I.; Whitcraft, A.; Baruth, B.; Bonifacio, R.; Crutchfield, J.; Rembold, F.; Rojas, O.; Schucknecht, A.; Van der Velde, M.; Verdin, J.; Wu, B.; Yan, N.; You, L.; Gilliams, S.; Mùcher, S.; Tetrault, R.; Moorthy, I.; McCallum, I. A comparison of global agricultural monitoring systems and current gaps. *Agricultural Systems* **2019-01**, *168*, 258–272. doi:10.1016/j.agry.2018.05.010.
 9. FAO. *FAO statistical pocketbook.*, 2015.
 10. Yu, Q.; You, L.; Wood-Sichra, U.; Ru, Y.; Joglekar, A.K.B.; Fritz, S.; Xiong, W.; Lu, M.; Wu, W.; Yang, P. A cultivated planet in 2010 – Part 2: The global gridded agricultural-production maps. *Earth System Science Data* **2020-12**, *12*, 3545–3572. doi:10.5194/essd-12-3545-2020.
 11. Institute, I.F.P.R. Spatially-Disaggregated Crop Production Statistics Data in Africa South of the Sahara for 2017, 2020. doi:10.7910/DVN/FSSKBW.
 12. Lancelotti, C.; Biagetti, S.; Zerboni, A.; Usai, D.; Madella, M. The archaeology and ethnoarchaeology of rain-fed cultivation in arid and hyper-arid North Africa. *Antiquity* **2019**, *93*, 1026–1039. Edition: 2019/08/12 Publisher: Cambridge University Press, doi:10.15184/aqy.2019.109.
 13. Phelps, L.N.; Kaplan, J.O. Land use for animal production in global change studies: Defining and characterizing a framework. *Global Change Biology* **2017**, *23*, 4457–4471. doi:10.1111/gcb.13732.
 14. Bartholomé, E.; Belward, A.S. GLC2000: a new approach to global land cover mapping from Earth observation data. *International Journal of Remote Sensing* **2005-05**, *26*, 1959–1977. doi:10.1080/01431160412331291297.
 15. Arino, O.; Ramos Perez, J.J.; Kalogirou, V.; Bontemps, S.; Defourny, P.; Van Bogaert, E. Global Land Cover Map for 2009 (GlobCover 2009). © European Space Agency (ESA) & Université catholique de Louvain (UCL) **2012-08**. doi:10.1594/PANGAEA.787668.
 16. Ramankutty, N.; Evan, A.T.; Monfreda, C.; Foley, J.A. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles* **2008**, *22*. doi:10.1029/2007GB002952.
 17. Ellis, E.C.; Goldewijk, K.K.; Siebert, S.; Lightman, D.; Ramankutty, N. Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecology and Biogeography* **2010**, *19*, 589–606. doi:10.1111/j.1466-8238.2010.00540.x.
 18. Biagetti, S.; Merlo, S.; Adam, E.; Lobo, A.; Conesa, F.C.; Knight, J.; Bekrani, H.; Crema, E.R.; Alcaina-Mateos, J.; Madella, M. High and Medium Resolution Satellite Imagery to Evaluate Late Holocene Human–Environment Interactions in Arid Lands: A Case Study from the Central Sahara. *Remote Sensing* **2017**, *9*. doi:10.3390/rs9040351.
 19. Biagetti, S. *Ethnoarchaeology of the Kel Tadrart Tuareg. Pastoralism and Resilience in Central Sahara*; SpringerBriefs in Archaeology, Springer International Publishing, 2014.
 20. Klein Goldewijk, C. *A historical land use data set for the Holocene; HYDE 3.2 (replaced)*; Data Archiving and Networked Services (DANS), 2016.
 21. Phelps, L.N.; Broennimann, O.; Manning, K.; Timpson, A.; Jousse, H.; Mariethoz, G.; Fordham, D.A.; Shanahan, T.M.; Davis, B.A.S.; Guisan, A. Reconstructing the climatic niche breadth of land use for animal production during the African Holocene. *Global Ecology and Biogeography* **2020**, *29*, 127–147. doi:10.1111/geb.13015.
 22. Ellis, E.C.; Ramankutty, N. Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment* **2008**, *6*, 439–447.
 23. Cremaschi, M.; Zerboni, A.; Mercuri, A.M.; Olmi, L.; Biagetti, S.; di Lernia, S. Takarkori rock shelter (SW Libya): an archive of Holocene climate and environmental changes in the central Sahara. *Quaternary Science Reviews* **2014-10**, *101*, 36–60. doi:10.1016/j.quascirev.2014.07.004.
 24. Kuper, R.; Kröpelin, S. Climate-Controlled Holocene Occupation in the Sahara: Motor of Africa's Evolution. *Science* **2006**, *313*, 803–807. doi:10.1126/science.1130989.
 25. Mattingly, D.J.; Merlo, S.; Mori, L.; Sterry, M. Garamantian Oasis Settlements in Fazzan. In *Urbanisation and State Formation in the Ancient Sahara and Beyond*; Mattingly, D.J.; Sterry, M., Eds.; Trans-Saharan Archaeology, Cambridge University Press, 2020; pp. 53–111.
 26. Haaland, R.; Haaland, G. Early Farming Societies Along the Nile. In *The Oxford Handbook of African Archaeology*, P. Mitchell, P. Lane ed.; OUP, 2013; pp. 541–553.

27. Ginter, B.; Kozłowski, J. Kulturelle und palaoklimatische sequenz in der Fayum Depression: ein zusammenfassende Darstellung der Forschungsarbeiten in der Jahren 1979–1981. *Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo* **1986**, *42*, 9–23.
28. Arkell, A. *Esh Shaheinab*; Oxford University Press, 1953.
29. Winchell, F.; Brass, M.; Manzo, A.; Beldados, A.; Perna, V.; Murphy, C.; Stevens, C.; Fuller, D.Q. On the Origins and Dissemination of Domesticated Sorghum and Pearl Millet across Africa and into India: a View from the Butana Group of the Far Eastern Sahel. *African Archaeological Review* **2018-12**, *35*, 483–505. doi:10.1007/s10437-018-9314-2.
30. Fuller, D.Q. Early Kushite agriculture: archaeobotanical evidence from Kawa. *Sudan & Nubia*, *8*, 70–74.
31. Hoelzmann, P.; Gasse, F.; Dupont, L.M.; Salzmann, U.; Staubwasser, M.; Leuschner, D.C.; Sirocko, F. Palaeoenvironmental changes in the arid and subarid belt (Sahara-Sahel-Arabian peninsula) from 150 kyr to present. *Past Climate Variability Through Europe and Africa* **2004**, pp. 219–256.
32. Out, W.A.; Ryan, P.; García-Granero, J.J.; Barastegui, J.; Maritan, L.; Madella, M.; Usai, D. Plant exploitation in Neolithic Sudan: A review in the light of new data from the cemeteries R12 and Ghaba. *Quaternary International* **2016-08**, *412*, 36–53. doi:10.1016/j.quaint.2015.12.066.
33. Chapelle, J. *Black nomads of the Sahara*; Human Relations Area Files, 1982.
34. Gigliarelli, U. *Il Fezzân*; Vol. 1, *Rapporti e Monografie Coloniali*, Governo della Tripolitania, Ufficio Studi, 1932.
35. Scarin, E. Nomadi e seminomadi del Fezzan. In *Il Sahara Italiano. Fezzan e Oasi di Gat. Parte prima*; Italiana, R.S.G., Ed.; Società Italiana Arti Grafiche, 1937; pp. 518–590.
36. Scarin, E. *Le oasi del Fezzan*; Zanichelli, 1934.
37. Despois, J. *Mission scientifique du Fezzan (1944-1946). III : Géographie Humaine*; Institut de Recherches Sahariennes, Université d'Alger, 1946.
38. Mordini, A. Etnografia e fatti culturali. In *Il Sahara Italiano. Fezzan e Oasi di Gat. Parte prima*; Italiana, R.S.G., Ed.; Società Italiana Arti Grafiche, 1937; pp. 449–491.
39. Allen, R.; Smith, M.; Pereira, L.; Pruitt, W. Proposed revision to the FAO procedure for estimating crop water requirements. II International Symposium on Irrigation of Horticultural Crops 449, 1996, pp. 17–34.
40. Biagetti, S.; Ruiz-Giralt, A.; Madella, M.; Khalid Magroub, M.; Meresa, Y.; Haile Gebreselassie, M.; Vesaar, G.M.; Alam Abro, T.; Chandio, A.; Lancelotti, C. No rain no grain? Ethnoarchaeology of sorghum and millets cultivation in drylands. *Ethnoarchaeology*.
41. FAO. *Special Report – 2019 FAO Crop and Food Supply Assessment Mission to the Sudan*, 2020.
42. Elfadaly, A.; A. R. Abouarab, M.; M. El Shabrawy, R.R.; Mostafa, W.; Wilson, P.; Morhange, C.; Silverstein, J.; Lasaponara, R. Discovering Potential Settlement Areas around Archaeological Tells Using the Integration between Historic Topographic Maps, Optical, and Radar Data in the Northern Nile Delta, Egypt. *Remote Sensing* **2019-01**, *11*, 3039. doi:10.3390/rs11243039.
43. Rayne, L.; Bradbury, J.; Mattingly, D.; Philip, G.; Bewley, R.; Wilson, A. From Above and on the Ground: Geospatial Methods for Recording Endangered Archaeology in the Middle East and North Africa. *Geosciences* **2017-12**, *7*, 100. doi:10.3390/geosciences7040100.
44. DeMenocal, P.; Ortiz, J.; Guilderson, T.; Adkins, J.; Sarnthein, M.; Baker, L.; Yarusinsky, M. Abrupt onset and termination of the African Humid Period: Rapid climate responses to gradual insolation forcing. *Quaternary Science Reviews* **2000**, *19*, 347–361.
45. Kröpelin, S.; Verschuren, D.; Lézine, A.M.; Eggermont, H.; Cocquyt, C.; Francus, P.; Cazet, J.P.; Fagot, M.; Rumes, B.; Russell, J.M.; Darius, F.; Conley, D.J.; Schuster, M.; Suchodoletz, H.v.; Engstrom, D.R. Climate-Driven Ecosystem Succession in the Sahara: The Past 6000 Years. *Science* **2008-05**, *320*, 765–768. doi:10.1126/science.1154913.
46. di Lernia, S. The emergence and spread of herding in Northern Africa: a critical reappraisal. In *Oxford Handbook of African Archaeology*; Mitchell, P.; Lane, P., Eds.; Oxford University Press, 2013; pp. 527–540.
47. Zerboni, A.; Biagetti, S.; Lancelotti, C.; Madella, M. The end of the Holocene Humid Period in the central Sahara and Thar deserts: societal collapses or new opportunities? *PAGES Magazine* **2016**, *24*, 60–61. doi:10.22498/pages.24.2.60.
48. Ellis, J.; Swift, D. Stability of African ecosystems: alternate paradigms and implications for development. *Journal of Range Management* **1988**, *41*, 450–459.

49. Cremaschi, M.; di Lernia, S. The geoarchaeological survey in the central Tadrart Acacus and surroundings (Libyan Sahara). Environment and cultures. In *Wadi Teshuinat. Palaeoenvironment and Prehistory in South-Western Fezzan (Libyan Sahara)*; Cremaschi, M.; di Lernia, S., Eds.; CNR, 1998; pp. 243–325.
50. di Lernia, S.; Manzi, G., Eds. *Sand, Stones, and Bones: The Archaeology of Death in the Wadi Tanezzouft Valley (5000-2000 BP)*; Number 3 in AZA Monographs, All'Insegna del Giglio, 2002.
51. Biagetti, S.; di Lernia, S. Holocene deposits of Saharan rock shelters: the case of Takarkori and other sites from the Tadrart Acacus Mts. (SW Libya). *African Archaeological Review* **2013**, *30*, 305–338.
52. Gallinaro, M. Saharan rock art: local dynamics and wider perspectives. *Arts* **2013**, *2*, 350–382. doi:10.3390/arts2040350.
53. Guagnin, M. Animal engravings in the central Sahara: A proxy of a proxy. *Environmental Archaeology* **2015-02-01**, *20*, 52–65. doi:10.1179/1749631414Y.0000000026.
54. Biagetti, S.; Cancellieri, E.; Cremaschi, M.; Gauthier, C.; Gauthier, Y.; Gallinaro, M.; Zerboni, A.; Di Lernia, S. The Messak Project. Archaeology and heritage management in SW Libya. *Journal of African Archaeology* **2013**, *11*, 55–74.
55. Mattingly, D.J.; Sterry, M. The first towns in the central Sahara. *Antiquity* **2013-06**, *87*, 503–518. doi:10.1017/S0003598X00049097.
56. Mattingly, D.; Macdonald, K. *Africa*; OUP Oxford, 2013; p. 28.
57. Wilson, A. Foggaras in Ancient North Africa or How to Marry a Berber Princess. *Foggaras in Ancient North Africa or How to Marry a Berber Princess* **2009**, pp. 1000–1021. doi:10.1400/137910.
58. Mercuri, A.M.; Bosi, G.; Buldrini, F. Seeds, fruits and charcoal from the Fewet compound. In *Life and death of a rural village in Garamantian times. Archaeological investigations in the Fewet oasis (Libyan Sahara)*, Lucia Mori ed.; Number 6 in AZA Monographs, All'Insegna del Giglio, 2013; pp. 177–190.
59. Pelling, R. Garamantian agriculture and its significance in a wider North African context: The evidence of the plant remains from the Fazzan project. *The Journal of North African Studies* **2005-09-01**, *10*, 397–412. doi:10.1080/13629380500336763.
60. Manning, K.; Timpson, A. The demographic response to Holocene climate change in the Sahara. *Quaternary Science Reviews* **2014**, *101*, 28–35.
61. Biagetti, S.; di Lernia, S. Combining intensive field survey and digital technologies: new data on the Garamantian castles of Wadi Awiss, Acacus Mts., Libyan Sahara. *Journal of African Archaeology* **2008**, *6*, 57–85.
62. Mattingly, D. Fortifications settlement and domestic architecture. In *The Archaeology of Fazzan: Volume 1. Synthesis*; Mattingly, D., Ed.; The Society for Libyan Studies, 2003; pp. 136–176.
63. Liverani, M., Ed. *Aghram Nadharif. The Barkat Oasis (Sha 'abiya of Ghat, Libyan Sahara) in Garamantian Times*; Vol. 5, AZA Monographs, All'Insegna del Giglio, 2005.
64. Leschi, L. La Mission scientifique du Fezzân. Archéologie. *Travaux de l'Institut de Recherches Sahariennes* **1945**, *3*, 183–186.
65. Mattingly, D.; Abduli, H.; Ahmed, M.; Cole, F.; Fenwick, C.; Fothergill, B.; González Rodriguez, M.; Hobson, M.; Khalaf, N.; Lahr, M.; Moussa, F.; Nikita, E.; Nikolaus, J.; Radini, A.; Ray, N.; Savage, T.; Sterry, M.; A., W. DMP XII: Excavations and Survey of the so-called Garamantian Royal Cemetery (GSC030-031). *Libyan Studies* **2011**, *42*, 89–102.
66. Mori, L.; Ricci, F.; Gatto, M.; Cancellieri, E.; Lemorini, C. The excavation of the Fewet necropolis. In *Life and Death of a rural village in Garamantian times*, Mori, L. ed.; Number 6 in AZA Monographs, All' Insegna Del Giglio, 2013; pp. 253–318.
67. Salvatori, S.; Usai, D. The neolithic and 'Pastoralism' along the Nile: A dissenting view. *Journal of World Prehistory* **2019**, *32*, 251–285.
68. Madella, M.; García-Granero, J.J.; Out, W.A.; Ryan, P.; Usai, D. Microbotanical Evidence of Domestic Cereals in Africa 7000 Years Ago. *PLOS ONE* **2014-10-22**, *9*, e110177. doi:10.1371/journal.pone.0110177.
69. Zohary, D.; Hopf, M.; Weiss, E. *Domestication of Plants in the Old World: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin*; Oxford University Press on Demand, 2012.
70. Iacumin, P.; Matteo, A.D.; Usai, D.; Salvatori, S.; Venturelli, G. Stable isotope study on ancient populations of central sudan: Insights on their diet and environment. *American Journal of Physical Anthropology* **2016**, *160*, 498–518. doi:10.1002/ajpa.22987.

71. Stemler, A. A scanning electron microscopic analysis of plant impressions in pottery from the sites of Kadero, El Zakiab, Um Direiwa and El Kadada. *Archéologie du Nil Moyen* **1990**, *4*, 87–105.

72. Di Lernia, S.; N’Siala, I.M.; Mercuri, A.M.; Zerboni, A. Land-use and cultivation in the etaghas of the Tadrart Acacus (south-west Libya): the dawn of Saharan agriculture? *Antiquity* **2020**, *94*, 580–600.

73. Lézine, A.M. Timing of vegetation changes at the end of the Holocene Humid Period in desert areas at the northern edge of the Atlantic and Indian monsoon systems. *Comptes Rendus Geoscience* **2009**, *341*, 750–759.

74. Gatto, M.C.; Zerboni, A. Holocene supra-regional environmental changes as trigger for major socio-cultural processes in northeastern Africa and the Sahara. *African Archaeological Review* **2015**, *32*, 301–333.

75. Cremaschi, M.; Pelfini, M.; Santilli, M. Cupressus dupreziana: a dendroclimatic record for the middle-late Holocene in the central Sahara. *The Holocene* **2006**, *16*, 293–303.

76. Cremaschi, M.; Zerboni, A. Fewet: An oasis at the margins of Wadi Tanezzuft. *Life and death of a rural village in Garamantian Times. Arid zone archaeology monographs* **2013**, *6*, 7–16.

,

,

,