ACTES DES XXXVIIIe RENCONTRES INTERNATIONALES D'ARCHÉOLOGIE ET D'HISTOIRE D'ANTIBES

FROM REFUGIA TO OASES

Living in arid environments from prehistoric times to the present day

DES REFUGES AUX OASIS

Vivre en milieu aride de la Préhistoire à aujourd'hui

Sous la direction de
Louise Purdue,
Julien Charbonnier,
Lamya Khalidi

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Introduction
Living in arid environments from prehistoric times to the present day : approaches to the study of refugia and oases

Louise Purdue, Julien Charbonnier, Lamya Khalidi

The history of human occupation in arid environments has always been inextricably tied to the history of water. From prehistory to the present day, populations have continuously occupied spaces in proximity to watering holes. The conditions that determine/d human occupation of these spaces and how they are/were modified stimulated the juxtaposition of two concepts that are both distinctive and coinciding. In anthropology, refugia are commonly regarded as isolated ecological niches where past populations retracted (allopatry) during hyperarid periods, while oases are commonly regarded as water-rich spaces in arid landscapes modified by humans (typically through cultivation and irrigation) in the form of artificial niches. However, the two concepts overlap, as they both insinuate refuge from a harsh environment and implicate man. Furthermore, an oasis is not necessarily cultivated and can act as a refuge. Similarly, a refugium can be a cultivated or natural oasis. The objective of the XVIIIes *Rencontres Internationales d'Archéologie et d'Histoire d'Antibes (France)* was to investigate the natural formation of these spaces, the conditions which determine/d their occupation by humans, and their construction and evolution as socio-economic, political and agricultural entities in a variety of arid landscapes across the world.

The themes developed in this volume are an illustration of human responses to social and ecological issues, as well as the impact of socio-environmental changes on human communities living in constraining environments. Oases and refugia are currently in full transformation and are endangered in many parts of the world because of combined social, political and environmental constraints. Conflict, climate change and urban migration have led to an abandonment of many of the

world's oases. The consequent loss of tradition and collective memory has also generated complex issues related to family heritage prompting the abandonment of many plots of land. Some oases have even become theme parks. When not abandoned, global climate change and the modernization of these spaces has led to an overexploitation of available resources and increased soil and salinity issues. A more holistic understanding of the world's oases and refugia is needed as they become increasingly threatened. This volume brings together new archaeological and environmental data that documents human-environment coevolution of this tangible and intangible world heritage in a variety of arid landscapes across time and space. Each contribution in this volume brings a unique perspective that is critical to our understanding of refugia and oases and to the preservation and durability of these fragile spaces.

Defining refugia and oases

One challenge we encountered in organizing the conference and this volume involved reassessing and redefining oases and refugia in a way that was not static (neither in space nor in time), and took account of the unique case-studies we brought together in this publication. A second related challenge lay in distinguishing the two concepts, which have a great deal of overlap as they can progressively or abruptly transition from one to the other and include similar features as mentioned above, but also because they allude to similar notions (fig. 1). For example, concepts of refugia and oases overlap in their dichotomous allusions to isolation and connectivity, and to mobility and stability. A refugium implicates population refuge from a harsh environment, whether a population takes refuge as a result of climate, geography or human activities (deforestation, over-hunting, etc.). While populations migrate to refugia, they find stability in isolating themselves, creating niches that are favorable to the maintenance of relict populations and to speciation. When there is an amelioration of the environment from which they took refuge, these refugia are once again linked and these relict populations expand. The same dichotomy is alluded to with regards to

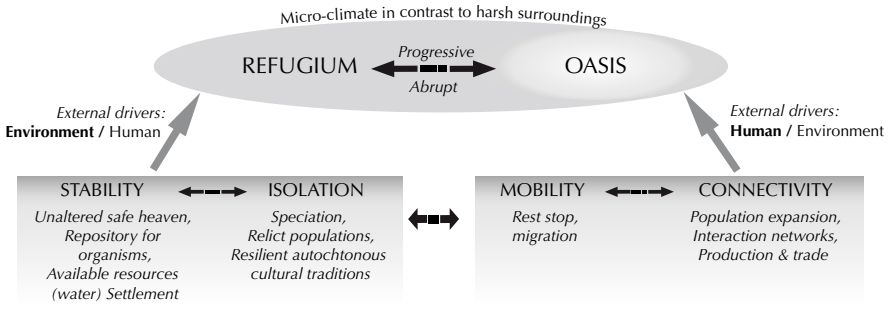

Fig. 1. *Schematic diagram illustrating the relationships, distinctions and overlap implied in concepts of refugia and oases and their utilization in anthropology.*

oases, whether natural or artificial. Oases are often synonymous with shade, and with rest-stops, or refuges. They are isolated by the aridity of their surrounding landscapes (Marshall, Lavie, 2017) and yet linked to other oases by migration and trade routes (f.e.: animal migration routes, incense trade routes, pilgrimage routes, etc.). Oases are also areas of stability and permanent settlement due to the presence of perennial water resources and intensive cultivation since the onset of agriculture. Their modification into water- and agro-scapes fosters new ecosystems attracting and favoring species that could not have otherwise survived or adapted, and turning these oases into artificial refugia.

From refugia…

The word refugium is defined by the Merriam Webster dictionary as an:

> Area of **relatively unaltered climate** that is inhabited by plants and animals **during a period of continental climatic change** (such as a glaciation) and **remains as a center of relict forms** from which a new dispersion and speciation may take place after climatic readjustment.[1]

Broadly implicit in this definition of refugium is an environment that is habitable and sustainable by organisms during a period and/or in a region that is not. This, in turn, insinuates a stable source of water – a prerequisite for all life-forms – during an arid period or in an arid region where water is scarce or unavailable. While not exclusive to periods of hyperaridity or hyperarid landscapes, a refugium is epitomized by the presence of a habitable environment in such contexts.

In arid landscapes like those of North and Northeast Africa, the Arabian Peninsula, Central Asia, and the deserts of Latin America, ecological niches are marked by perennial or stable water resources, particularly along certain mountain chains or coastal zones. Refugia may have functioned as isolated ecological niches during cold and arid oscillations, and as ideal settlement and gathering areas during humid phases, offering access to water and allowing human groups to exploit animal and plant resources over the long term. However, in anthropology the concept of refugia is more commonly applied to prehistoric populations, and namely to Pleistocene populations. Our reading of prehistory is often marked by the hydro-climatic fluctuations that affected exploitation and modification of the environment and territorial management by human groups and other species, globally, regionally and in so-called ecological niches. Concepts of niche were developed in the field of ecology to describe specific habitats adapted to and modified by organisms and can be applied to any environment or range of environments, community or area of the world. The ecological niche is therefore not specific to arid landscapes but is a term that is particularly applicable to refugia and oases, which are characterized in anthropology, by their relationship to arid periods or landscapes, respectively.

1. https://www.merriam-webster.com/dictionary/refugium

It is thus that the concept has often been used in the context of glaciation or hyperarid events in the fields of palaeontology and prehistoric archaeology. In the literature, refugia have mainly been referred to with regards to the Last Glacial Maximum (LGM) by paleogeneticists, paleoclimatologists and archaeologists (Achilli *et alii*, 2004; Cerny *et alii*, 2011; Pala *et alii*, 2012; Rose *et alii*, 2013; Hilbert *et alii*, 2015; Gandini *et alii*, 2016) but is also applied to studies on hominid population expansions and contractions (sometimes referred to as genetic bottlenecks), and in correlation with a host of glaciation and hyperarid events, and human activity in more recent periods (Lahr, Foley, 1994; Hawks *et alii*, 2000; Delson, Harvati, 2006; Basell, 2008; Stewart, Dalen, 2008; Preston *et alii*, 2012; Delagnes *et alii*, 2013). For example, it is used to explain the presence of Palaeolithic populations in parts of the world where human occupation seems to have been impossible as a result of hyper-arid conditions during the LGM, as well as to explain the persistence of Pleistocene haplotypes in Holocene populations (Gandini *et alii*, 2016; Gavashelishvili, Tarkhnishvili, 2016; Rose *et alii*, 2013). The 'Coastal Oasis Theory' (Faure *et alii*, 2002; Parker, Rose, 2008) suggests that currently submerged sources of water in the Persian Gulf also served as refugia during glacial periods. Since the Neolithic, the sedentarisation of human groups and the development of agro-pastoralism also occurred in these refugia, such as is the case for the highland plains of Yemen (Khalidi, Lewis, 2018), the 'lomas fog oases' in Peru (Beresford-Jones *et alii*, 2015) or for the large lakes of the Sahara or the Afar (Sereno *et alii*, 2008; Lesur *et alii*, 2014).

During historical periods, the voluntary and progressive management of these spaces heavily impacts their ecology and their socio-economic roles. Anthropisation is exponential from the Neolithic period onward, encouraging the development of long-distance exchange networks. Some of these niches, once refugia, progressively transform into cultivated oases.

…to oases

The word oasis, which derives from ancient Egyptian and is first mentioned by Herodotus around 450 BC, means "inhabited space" (Brunet, Ferras, Théry, 1992). The meaning has greatly evolved over time, and has almost taken a romantic turn. The Merriam Webster Dictionary for instance defines oases as:

> **Fertile** or **green** areas in arid regions, but also a place that provides **refuge**, relief, or **pleasant contrast**.[2]

Like many other definitions of oases, this one emphasizes the contrast between the oasis and its hostile surroundings (Marshall, Lavie, 2017). Geographers and agronomists have also provided their own definitions. Oases are generally classified based on their history (modern versus ancient oases), water management (groundwater, sources, floodwater, etc.) or hydro-climatic conditions (coastal,

2. https://www.merriam-webster.com/dictionary/oasis

plain, mountain oases) (Toutain *et alii*, 1990). The agronomist Lacoste (1985) defined oases as intensively cultivated spaces located in cold or hot climatic zones marked by water shortage. This anthropological definition considers oases as "terroirs" entirely managed by humans and dependent on the socio-technical management of water. In 1990, the geographer Toutain added that oases are complex systems of production in which agriculture and goat/camel farming closely interact. Small plots of lands containing three superimposed levels of vegetation including palm trees, fruit trees and cereals or fodder crops at lower levels, provide food for people or animals, while the herds supply manure to fertilize soils that have been cultivated for millennia. Irrigation is generally gravity fed. Biodiversity (floral and faunal) in oases has only recently been acknowledged.

These definitions consider oases primarily as agricultural spaces. They properly describe oasis agrosystems as places of production marked by the management of water resources and the mastery of hydraulic systems. At the same time, the construction of these spaces necessarily implies social organization, not to mention population densities large enough to maintain them. Oases are areas of residency and circulation. Anthropologists, such as Battesti (1998), added that an oasis is a combination between a human agglomeration and a cultivated area. Skouri (1990) also defined oases as intensively cultivated spaces in arid environments in which a settled population lives, but he also suggested that the agrosystem is often isolated, providing a specific microclimate that allows for intensive socio-economic activities.

Despite their precision, these definitions unfortunately fail to consider oases as strategic nodes with undeniable political and commercial significance. Archaeologists working in northern Africa and in the Middle East have identified oases that have been occupied for millennia (f.e.: Wellbrock *et alii*; Mattingly *et alii*, this volume). Their construction and long-term management involves territorial and population control as well as integration within exchange networks on a macro-regional scale. These numerous attempts to describe and define oases combine agricultural, social and economic factors. However, the functional diversity of oases makes their final classification complex (*e.g.* Kassah, 1996, 2010). Indeed, their spatial boundaries have evolved through time (Battesti, 2005) as a result of socio-environmental changes that have made them mobile and dynamic (Garcier, Bravard, 2014). Oases are not static. The history and management of oases and their hydroclimatic and geomorphic states have evolved for at least the last ten millennia.

State of research on refugia and oases

Preconceived ideas regarding refugia

In 1929, V. Gordon Childe published "The Most Ancient Near East", in which he developed the *Oasis Theory*, said to have been first coined by R. Pumpelly, a geologist and explorer, in 1908. Childe maintained that human populations contracted to oases (specifically the Nile valley) at the end of the last Ice Age in response to rapid

aridification, bringing them into close contact with abundant wild species. He argued that this led to relative crowding of populations and familiarity with growth cycles of wild flora and fauna stimulating the onset of food production and agriculture. With advances in radiocarbon dating and paleoclimatology, this environmentally deterministic theory has since been challenged, even dismantled. However, the situation he described as population contraction into oases was the precursor of what is referred to today as population contraction into refugia. Over the last decade, scientific articles dealing with human evolution, migration events, and human response to changing climates and environments in the past, have increasingly relied on the concept of human refugia as an explanatory model for hominid responses to harsh (synonymous here with hyperarid) climate and environments.

Despite theoretical advances in studies on human-environment relations, *environmental determinism* (environmental factors are responsible for human behavior) continues to be used to explain the evolution of these spaces, refugia included, and human societal transformation. Many scholars have made efforts to counter deterministic tendencies like those of Childe, by adopting models such as *possibilism*. This theory, first developed in the field of geography, maintains that human behavior and culture are determined by both the environment and human agency. While such models are developed in opposition to deterministic notions (environmental or geographic), their integration of human agency remains limited, even if indirectly, by environmental constraints.

Furthermore, while more and more scholars today challenge environmental determinism, recent advances in paleoclimatic studies and their correlation with paleogenetics and archaeology have had the inverse effect by subtly reinforcing deterministic tendencies. This resurgence in closet environmental determinism is shrouded by emphasis on pluridisciplinary approaches and comparison of multiple datasets that is meant to counteract such notions, but in reality, only conceal them. While climatic events are important parameters for refugia, these events and environmental response to them end up representing the only criteria for population refugium in most of the literature. Just as with possibilism, implications are that these spaces are solely determined by the environment, restricting the role of human agency (and that of other species) and coevolution in their existence and maintenance.

Preconceived ideas regarding oases

Like prehistoric refugia, the archaeological and historical study of oases has long been hampered by preconceived ideas regarding these spaces, ideas which were developed by the first travelers visiting North Africa, the Middle East and Arabia and propagated both by fiction and academic research. In much of the literature, oases are depicted as simultaneously archaic and timeless. Magee asserts that this is the vision of Arabia shared by many westerners, from the first travelers to contemporary scholars (2014: 367, 463). This antiquated view continues to resurface in scholarly work on the Libyan desert in Egypt (Garcier, Bravard, 2014: 30) as well as in the western Sahara. Veyrac-Ben Ahmed and Abdedayem note *"the layman sees an oasis as*

an untouched area, a potential refuge for men in a hostile environment, a place of serenity and eternity and a place where nothing ever changes" and emphasize the fact that this image is also propagated by present-day tourism advertising (2017: 4). We also owe the diffusion of this vision to orientalists, painters and novelists (Said, 1978).

This timeless vision of oases has and continues to be propagated by many archaeologists, notably those working in the Persian Gulf, as evidenced by Charbonnier (2017: 57). Although aware of the impact of long-term environmental change on agrarian and hydraulic landscapes, these scholars have tended to make direct analogies between past and present oases and in this way, to project current realities on the past, therefore denying oases of any diachronic dimension (Power, Sheehan, 2012: 296). Oases have also been regarded as timeless because they are assumed to be isolated from the outside world. This preconceived idea stems from the fact that oases are often separated from each other by deserts and other arid landscapes regarded as frontiers or obstacles to movement and therefore to advancement, just as seas are regularly regarded as frontiers between continents and islands. It is indeed a common metaphor to compare oases to islands and deserts to seas:

> *Oasis ! Elles flottaient sur le désert comme des îles ; de loin, la verdeur des palmiers promettait la source où leurs racines s'abreuvaient* […][3]

Furthermore, oases are frequently regarded as static landscapes because researchers have long assumed that their environmental contexts have been stable (Garcier, Bravard, 2014: 30). Environmental change during the Holocene and the fact that present deserts were greener in the past were long ignored. The single contributor to change in oases was thought to be hydraulic technology. These views maintained that the introduction of new techniques allowed the exploitation of new hydric resources leading to the growth of oases, and a lack of investment in infrastructure would be the main cause for their decline. It was thus assumed that human labor was driving the evolution of oases.

As Garcier and Bravard (2014: 30-31) rightly point out, this vision of oases was forged by colonialism. It is therefore the product of an ideology aimed to justify colonial policy. The objective was, and continues to be in many cases (Abu el Haj, 2001), to prove that indigenous people are incapable of properly managing their land, and that only colonizers can make the desert green again (Garcier, Bravard, 2014: 31).

Deconstructing these ideas

Human societies have occupied, managed, modified and constructed refugia, including oases. By doing so, they have heavily impacted future generations. The consequences of these short and long-term choices and their social, behavioral, ecological and biological transmission over time express themselves in long-term cycles of development, transformation, rupture and abandonment. Deconstructing the ideas of refugia and oases as static entities requires understanding them in an

3. A. Gide, Les nourritures terrestres.

integrated way and untangling the constant interactions and feedbacks that occur between endogenous and exogenous drivers. Through recent climatic, archaeological, historical, ethnological and geographical studies we now know that the climate fluctuated significantly over the course of the Pleistocene and Holocene, and that isolation of oases and refugia as it was perceived in the past is simply a myth. Oases and refugia are at the heart of the forging and maintenance of migration, trade and pilgrimage routes, simultaneously allowing and stimulating mobility and interaction. Consequently, both are dynamic landscapes in fluctuating environments. The cycles of evolution of these landscapes depend on endogenous drivers, such as the fragile balance between humans and resources within oases. They also depend on exogenous drivers, such as environmental change, evolution in trade patterns, and conquest and integration in new political bodies. The constant interaction of these drivers at various spatial and temporal scales does not support the idea that oases are static and isolated entities.

Several and new theoretical approaches combined with new field results allow us to deconstruct these preconceived ideas about refugia and oases, and better integrate most, if not all of the above-mentioned driving factors. Recent work carried out by multi-disciplinary teams, including many contributions in this volume, highlight the dynamic nature of these spaces and the drivers and choices that influence their formation and transformation.

New approaches to the study of refugia and oases?

Anthroposystems, adaptative cycles and socio-hydrology

In France, the concept of anthroposystems was first proposed in the early 2000s. Bertrand (1968) and Levêque *et alii* (2003) define natural or artificialized systems that societies exploit and/or manage as anthroposystems. In anthroposystems, socio-systems co-evolve with eco-systems over the *longue-durée* at various embedded temporal (from the event to long-term trends) and spatial scales (local to regional) (Redman, 2005). This evolution can be visualized as mobile loops, structured around phases of stability and shifts (Purdue, this volume). Understanding the driving factors (social versus environmental) of these cultural changes in an integrated way is key to understanding past societies and hyper-anthropogenic landscapes such as oases.

The interactions between societies and their environment can also be modelled following concepts of Panarchy (Gunderson, Holling, 2002), resilience and adaptative cycles, used most often in the Anglo-Saxon world. Adaptative cycles, initially used in the natural sciences, suggest that ecosystems are regulated cyclically around phases of growth, conservation, restructuring and renewal (Holling, 2001; Redman, Kinzig, 2003). When considering socio-ecosystems, adaptative cycles are connected to one another by embedded spatial and temporal scales. This is referred to as Panarchy. Different phases are linked by "memory" and "revolt". At smaller spatio-temporal levels, socio-ecosystems innovate and change while longer scale processes stabilize and exploit human memory to keep the system stable.

This concept of Panarchy entirely integrates mutations and change within the cycle (Resalliance.org, consulted in 2018). The identification of the drivers of change can provide insight into emergent processes such as the appearance of new social configurations. In fragile and constraining environments that are very sensitive to environmental shifts, this approach allows us to identify complex patterns and how they generate adaptation and resilience in agricultural communities.

The concept of socio-hydrology was introduced more recently (Sivapalan *et alii*, 2012 ; DiBaldassarre *et alii*, 2013). It aims to understand the interactions and feedbacks, specifically between humans and water systems (Pande, Sivapalan, 2017), with the aim of identifying emergent behaviors (see Purdue, this volume). In intensively irrigated landscapes, highly subject to resource fluctuation, this approach has great potential and should be applied more often to archaeological contexts.

Niche Construction Theory (NCT)

Niche Construction Theory, which originated as a branch of evolutionary biology (Laland *et alii*, 2000 ; Kendal, Tehrani, Odling-Smee, 2011 : 785), conceptualizes the capacity of organisms to modify their own environments and, in turn, to influence their own evolutionary trajectories, or fitness, as well as those of other organisms through feedback relationships. This conceptual framework allows the integrated study of the co-evolution of spaces and the communities which occupy or shape them.

Since its conception, NCT has developed to integrate culture as a potentially determinant factor in evolutionary trajectories of humans and other organisms, and has been applied to many fields. Cultural Niche Construction Theory maintains that *"Niche construction from all ontogenetic processes modifies human selective environments, generating a legacy of modified natural selection pressures that are bequeathed by human ancestors to their descendants"* (Laland *et alii*, 2000). This inherited legacy includes ecology, culture and genes, and has been termed the triple inheritance approach. There are several convincing example of cultural and ecological modification of selective natural pressures that have in turn modified genes traceable in a number of descendant lineages. These include certain cases of dairy farming that created the selection pressure that led to the spread of alleles for adult lactase persistence (see Gerbault *et alii*, 2011). Another example is the case of yam cultivation in West Africa which promoted the spread of malaria in populations and led to the selection of an allele resistant to malaria in these same populations (Laland, 2008).

Refugia are often used as explanatory frameworks that take account of phenomena we can trace genetically through relict or resilient haplotypes and alleles, but that we have a dearth of archaeological evidence for. The application of NCT is therefore useful to understanding and interpreting refugia as it naturally bridges the gap between the environment, genetics and the legacy of human activities (both tangible as in artifacts and intangible as in oral tradition, symbolism and

know-how) while empowering all organisms, and specifically humans, with agency, and doing away altogether with determinism. Its popularity and widespread application to archaeology (Laland, O'Brien, 2010) is demonstrated in the dedication of an entire volume of the *Journal of Archaeological Method and Theory* (17(4)) to "Archaeological Perspectives on Niche Construction Theory".

In arid areas, oases are constructed niches '*par excellence*'. As mentioned previously, hydraulic technologies have long been considered the prime movers in the evolution of oasitic niches. Conversely, recent studies highlight the fact that climatic fluctuations and the evolution of the environment had an impact on oases over the course of the Holocene. The application of a NCT perspective (or the Anthroposystem/Panarchy perspective) neutralizes anthropocentric explanations and environmentally deterministic tendencies by focusing on the complex interactions between social and environmental factors (including hydraulic technologies and climate) to explain the development, fluctuation and decline of oases. Natural oases are in effect refugia supported by available surface water resources, such as springs or lakes, within landscapes that are lacking. Such oases can be modified by human activity to different degrees. Oases can also be entirely artificial, created and developed by humans by bringing water to arid zones or by diverting water streams or hauling groundwater to the surface. Once an oasis has been transformed or artificially created by humans, it becomes a space where the cultivation of crops that would normally not tolerate desert climates becomes possible, hence becoming a veritable (man-made) refugia. Water management improves its spatial distribution as the humidity collected by irrigation canals encourages the growth of wild plants and attracts wild animals. This, in turn, contributes to trapping moisture and fostering pedogenesis. The formation of soils, which are as rare as water in arid areas, benefits crops and wild plants and contribute to the increase of yields. In the Sahara and the Middle East, oases are usually characterized by the cultivation of date palms. The arrangement of palm trees in palm groves creates ideal conditions (using the shade of the palm rows) for the cultivation of other crops that require reduced heat and evaporation. These positive outcomes initiate a cycle that has the effect of creating a new ecosystem favorable to cultivation and human settlement (Laureano, 1998; Riou, 1990). Another positive feedback is the fact that oases play the role of nodes in caravan trade, thus fostering long distance exchange. In some cases, oases were even developed and maintained for this purpose. Furthermore, the development of these intensively cultivated gardens and waterscapes involves the establishment of collective rules for sharing water and maintaining irrigation systems. This usually leads to the implementation of a 'water administration' with specialists managing hydraulic issues. Ultimately, this will have an impact on the social structuration of these hydraulic communities. On the other hand, negative feedbacks to the establishment of oasitic ecosystems are numerous. Tackling the evolution of the environment and its deterioration linked to human activity (surface or groundwater depletion, salinization of soils, sand dunes, pests and locusts etc.) can imply continuous maintenance and innovation (adoption of new hydraulic

techniques, canal dredging, soil cleaning, etc.). These actions also contribute to the construction of oasitic niches.

The investigation of these actions and retroactions through a diachronic and socio-environmental perspective (from the perspective of socio-hydrology to applications of NCT theory) has enormous potential, for example in identifying genetic adaptations to such feedback relationships within oasitic populations.

Presentation of the themes of the volume

This volume is structured into four different themes. Addressing these themes allows for a better understanding of the dynamics of refugia, oases and niches that have developed in arid environments from the prehistoric period until now, and specifically tackles the adaptation of past societies to continuous and/or abrupt climatic and hydrological changes over the long term. With the multiplication of archaeological studies in arid regions of the world, it is now possible to renew our knowledge of their history and compare their trajectories. We begin to do this in this volume by covering a large geographical area over a long period of time (from the late Pleistocene to the present-day), as well as including studies from specialists in various disciplines.

Articles from this volume range from the Pacific coast of America (Clément and Beresford-Jones *et alii*) to the steppes of Central Asia (Brunet), and include

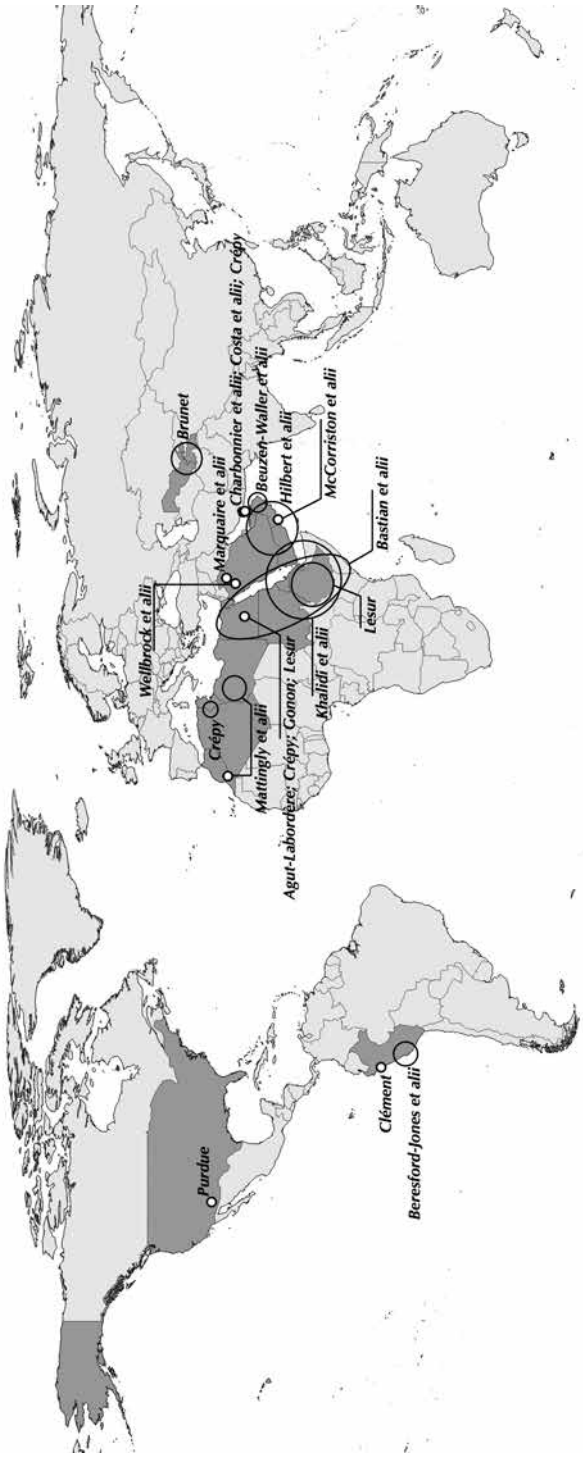

Fig. 2. *Location of study areas corresponding to the different contributions in this book. Specific archaeological sites, refugia and oases are indicated by dots, while broader study regions are indicated by ovals and circles.*

case-studies in Arizona (Purdue), the Maghreb and Central Sahara (Mattingly *et alii*), the Egyptian desert (Agut-Labordère, Crépy, Gonon and Lesur), the Horn of Africa (Bastian *et alii*, Khalidi *et alii* and Lesur) and the Arabian Peninsula, from the North (Marquaire *et alii*, Wellbrock *et alii*) to the South (Hilbert *et alii*, Khalidi *et alii* and McCorriston *et alii*) and in the Arabo-Persian Gulf area (Beuzen-Waller *et alii*, Charbonnier *et alii*, Costa *et alii*, and Crépy) (fig. 2).

The wide chronological context provided by these different articles provides clues on the development and evolution of niches in arid regions over the long-term. Late Pleistocene to middle Holocene hunter-gatherer and pastoral communities are discussed in the first theme entitled ***Refugia and oases: environment, resilience and mobility*** and the Late Neolithic to Bronze Age early oasitic communities in the second theme entitled ***The emergence of oases***. The third and fourth theme entitled ***Oases as waterscapes*** and ***Oases as agroscapes*** include case-studies ranging from the Iron Age to the present-day.

Interdisciplinarity is key to moving research and debates forward. We therefore chose to represent different disciplines and new methodological developments in the study of arid regions in this volume. These include combined perspectives in hydro-climatology, geomorphology, hydraulic engineering, archaeozoology, archaeobotany, genetics, geoarchaeology, archaeology, ethnoarchaeology, and epigraphy.

THEME 1 – Refugia and oases: environment, resilience and mobility

The first theme aims to better define and develop concepts of refugia and oases in prehistory through investigations into the conditions that determined or encouraged human occupation of these spaces, and the cultural, ecological and biological niches that developed within them (autochthonous cultures, resilience and biological adaptations).

Refugia functioned as veritable socio-environmental niches during glacial periods, heightening the resilience of human groups (maintenance of relict population and speciation). Palaeoclimatic and palaeoenvironmental studies and reconstructions have strongly suggested the presence of different types of refugia and oases (natural and/or submerged water sources, highland zones with high precipitation rates, etc.; Faure *et alii*, 2002; Wilkinson, 2009), which certainly facilitated the settlement or mobility of human groups during arid and hyperarid periods. Moreover, marriage between the fields of archaeology and palaeogenetics have enabled researchers to identify regions where the persistence of ancient haplogroups amongst current populations suggest the presence of human refugia during hyperarid periods (Gandini *et alii*, 2016; Pala *et alii*, 2012; Rose *et alii*, 2013). These phenomena often correlate with populations in regions where we find autochthonous cultural traditions during the late prehistoric periods, despite the intensification of mobility and human interactions and the introduction and intensification of herding during the Holocene (Crassard, Khalidi, 2017; Khalidi, Lewis, 2018).

In this section, we explore this theme by addressing and developing the following:

1. the identification of refugia and oasitic niches using palaeoclimatic, palaeogenetic and material culture data (Bastian *et alii*; Hilbert *et alii*; Khalidi *et alii*);
2. the application of concepts of refugia and niche-construction approaches to better understand and interpret the evolution of dynamic human-environment landscapes in prehistoric archaeology (Hilbert *et alii*; Khalidi *et alii*; McCorriston *et alii*);
3. the transformation of refugia and oases with the onset of herding and early plant management (Khalidi *et alii*; Lesur; McCorriston *et alii*).

Bastian and colleagues begin the section with a summary of the Northeast African palaeoclimatic record over the last 30,000 years using data from Nile delta and African Rift lake cores. They highlight the need to correlate high-resolution hydro-climatic and archaeological data in order to accurately interpret the impact of gradual and abrupt climatic oscillations (humid/arid/hyper-arid) on the environment, human populations and their adaptations, and vice versa. The authors set the stage for the volume by detailing the hydro-climatic conditions that generate refugia and natural oases, and that may have encouraged their occupation and management by human groups.

Hilbert and colleagues correlate the great number of new and dated Upper and Late Palaeolithic occupation sites in South Arabia with genetic, cultural and paleoclimatic evidence, demonstrating the validity of at least one if not several refugium scenarios in South Arabia during the LGM. Through detailed techno-typological studies of South Arabian industries and radiocarbon dates, they argue for population and cultural continuity and indigeneity in the region despite abrupt climatic and environmental changes, and despite the lack of acculturation at the onset and during the South Arabian Neolithic.

Khalidi and colleagues detail the indigeneity of culture and tradition in Southwest Arabia and the African Horn from the Late Pleistocene to the mid-Holocene, through a Niche Construction perspective, adding that oasitic landscapes facilitated both human innovation and contact as well as cultural resilience and isolation. Using case studies from settled coastal (Yemen) and lakeside oases (Afar triangle) on opposite shores of the Red Sea, the authors illustrate a parallel coevolution between these populations and their carefully managed wild oasitic environments. With increased aridification at the end of the African Humid Period, they hypothesize that by complementing wild resources with domesticated herds and increased mobility, and interaction and trade that served to connect them, these populations maintained these sensitive oasitic niches.

Lesur presents two Northeast African case studies (the Kharga oasis in Egypt and the Afar in Ethiopia and Djibouti) to highlight the important role of animal

domestication in human adaptation to increasingly constraining desert environments and to the development of oases. She argues that these arid-adapted herds were crucial to linking oases as their introduction as a food security measure engaged humans in seasonal mobility between perennial watering holes.

McCorriston and colleagues demonstrate that the development of pastoral landscapes in the Dhufar region of Oman is the consequence of dynamic cycles of niche construction. They highlight the importance of mobile herding and the dynamic landscapes that sustained and perpetuated it, to our understanding of the ecosystem history and lack of early agriculture in the region but also to the foundations of early Arabian oases.

THEME 2 – The emergence of oases

The second theme aims to develop our understanding of the emergence of oases in different regions of the world: from Southern America to Central Asia, via the Sahara and Southeast Arabia. In that respect, the four papers presented here call into question many ideas regarding the origins of oases. They suggest that their development began much earlier than previously thought and was more gradual, albeit at different times and at different rhythms depending on the region. The definition given to oases by geographers and agronomists insinuates sedentarism and intensive irrigated agriculture. However, it is demonstrated early on in this volume that hunter-gatherer communities living in arid areas were already constructing potent niches. They had a significant impact on their environment, and were thus already transforming refugia into oases. Furthermore, it is also demonstrated that long-distance interaction and exchange was already a feature of the first emergent oases and was a key part of their social make-up and economy since prehistoric times. Oases were therefore never isolated nor were they marginal places. Instead, they appear to have quickly become economic hubs that attracted populations as a result of the resources available and/or their role as transit points for raw materials, commercial goods, people and ideas.

Beresford-Jones and colleagues reassess the role of *lomas*, natural oases created by ocean mists along the arid Pacific coast of Peru, during the Preceramic Period. They demonstrate that the exploitation of these seasonal green areas, in association with marine resources, allowed for increased sedentism well before the advent of an agricultural economy. Populations took advantage of *lomas* by exploiting what they naturally offered, but also modified these niches by managing the mists and the environments they produced, sometimes overexploiting them. Not only do the authors demonstrate the capacity of hunter-gatherers to organize their societies around and manage natural mist oases but also their capacity to create seasonal artificial oases that complemented other resource economies.

The fact that the anthropization of oases began before the introduction of agriculture is also emphasized by Brunet whose research focuses on the valley of

Zeravchan (Uzbekistan and Tajikistan). The author demonstrates the evolution from managed fluvio-lacustrine oases to proto-urban ones from the Neolithic to the Chalcolithic period in this region of Central Asia. In this arid zone, Neolithic communities of hunter-gatherer-fishermen were established along river systems composed of multiple channels and lakes that formed a natural oasis, interacting and trading with the Eurasian steppe cultures. With the onset of aridification during the Chalcolithic period, proto-urban agropastoralist populations settled at the site of Sarazm, intensifying and enlarging their exchange networks. This contribution demonstrates the transition from natural to anthropized oases and the key role that exchange played in the oasitic economy of this arid region of the world since prehistory, growing in importance over time.

By combining geomorphological, geomatic and archaeological approaches, Beuzen-Waller and colleagues identify, based on predictive modeling, the earliest potential oases in several regions of Oman. They hypothesize that these proto-oases, dated to the Early Bronze Age, were not yet characterized by sophisticated hydraulic practices, but instead opportunistically took advantage of water and soil-rich areas that form the core of different agropastoralist communities' territories. Archaeological and environmental data tend to validate their innovative model, which could therefore be applied to other arid regions in the world.

The development of man-made oases are a later occurrence in the Western and Central Saharan desert of Morocco and Libya. However, through a reassessment of available evidence and new absolute dating, Mattingly and colleagues push the origin of these oases back in time and challenge the model of the development of oases and trade in the Central Sahara prior to the Islamic period. The authors demonstrate that in the region of Fezzan (Libya), the Garamantian oases were settled since the early 1st millennium B.C. These oases were nodes in a long-distance exchange network connecting sub-Saharan regions to the Mediterranean region.

THEME 3 – Oases as waterscapes

By the proto-historic and early historic periods, oases became fully anthropized landscapes, dedicated to agriculture and characterized by complex irrigation systems that aimed to compensate the lack of or irregularity of rainfall. Water is thus one of the structural elements of oases, and this theme emphasizes the role of hydric resources in its distribution and evolution. One focus of this theme is therefore the hydrological and climatic context in which human communities developed, with the objective of understanding the evolution of resource availability and its exploitation over the long-term in arid regions. In this regard, it stresses the need for a multidisciplinary approach to these heavily managed "*waterscapes*". This theme is also devoted to the reconstruction of hydraulic technical systems, from a range of perspectives. Contributions focus on the complex rules of water management necessary for the durability of these niches, on the spatial organization of these systems and on putting past and current practices into perspective.

Wellbrock and colleagues succeed in reconstructing the evolution of the Tayma oasis, located in Northwestern Saudi Arabia, from the mid-Holocene until today. The authors use an archaeohydrological approach, which combines multiple methodologies drawn from the sciences and the humanities. This innovative approach allows them to show that the Tayma oasis owes its existence to important groundwater resources available at shallow depth, and which could be exploited without sophisticated hydraulic technologies. Their results also lend support to the hypothesis of an emergence of Northern Arabian oases related to the process of aridification after the mid-Holocene.

The contribution of Marquaire and colleagues also concerns northern Saudi Arabia. The study of a Nabatean period rainwater collection system excavated near the oasis of Dumat al-Jandal demonstrates the importance of anthropogenic watering places for pastoral/nomad populations living in the desert, who also played a major role in the economy of oases.

The study of the Kharga area in Southwestern Egypt by Gonon is dedicated to the long-term evolution of oases through archaeological (excavation and survey), hydrological and hydraulic investigations. It demonstrates that human settlement, initially conditioned by water availability (artesian springs) is then maintained using a hydraulic innovation: the development of *qanat* galleries during the Persian period. Aridification combined with overexploitation of resources probably led to the lowering of the water table and the drying out of *qanats* at the end of Antiquity. After this period, settlements and gardens were organized around wells. This contribution illustrates the delicate balance that must be maintained by human populations to cultivate in arid regions.

Clément presents research on the irrigation systems in the Chicama valley, located on the north coast of Peru, and emphasizes the sophistication of hydraulics during the Chimú period, which were necessary for survival in this arid environment. He combines archaeology (field survey) with remote sensing and ethnohistory to show that the sociopolitical organization of Chimú communities is mirrored by the network of canals. The latter seems to have strengthened relationships among communities, delineated their respective territories but also fostered hierarchical relationships between them. For example, groups exploiting minor downstream canals were dependent upon upstream groups controlling the main canals. Lastly, this study points out the role of local water governance in the management of these important coastal oases.

An ethnoarchaeological and palaeoenvironmental approach is used by Charbonnier and colleagues to study two oases located on the Gulf coast of the United Arab Emirates. The authors advocate that the collection of data on water and soil management in present-day oases is crucial to understanding those of the past and propose to lay the foundation for an ethnoarchaeology of water systems.

THEME 4 – Oases as agroscapes

Refuge zones, like oases, have been exploited and intensively transformed by humans. The typical system of production, which combines goat, sheep and camel farming with agriculture, has evolved with time due to the combined effect of the needs of populations, the availability of water/soil resources and of technological and social capacities. The last theme of this volume aims to understand the spatial and temporal dynamics of these spaces, and more precisely their transformation into food production systems. Numerous paleo-botanical studies have been conducted to reconstruct the evolution of the vegetation cover and crops grown, mainly in Middle Eastern oases. However, there are still numerous lacunae in the study of oases if we consider them as agricultural, social and geographical entities. How can we recognize oases as agricultural landscapes and what are their limits? How are they socially and spatially organized? How were resources other than water managed through time? What was the impact of climate change on resource availability, management, and thus on the social and spatial structure of oases? The four papers in this section provide some answers to these questions by developing theoretical backgrounds (Crépy and Purdue), and by putting forward new approaches and methods of interpretation (Costa *et alii* and Agut) for a better understanding of oases as *"agroscapes"*.

Costa and colleagues focus on the agricultural, geoarchaeological and chemical study of cultivated gardens (oasis of Masafi, United Arab Emirates) in order to understand the evolution of soil management over the last five millennia. The manuscript relies on the construction of a modern reference collection to identify markers in soils of irrigation, manuring, land abandonment, and crops grown. The results provide new methods and keys for the identification of ancient agricultural practices in semi-arid environments.

The historical approach developed by Agut aims to reconstruct the evolution of an agricultural village (oasis of Kharga, Egypt) based on the study of legal documentation. The author identifies the role of family, inheritance and internal social control in the construction of oases. He also emphasizes the importance of written agreements, the increasing importance of institutions and consequent conflicts (land organization, resource depletion) when maintaining these spaces. This contribution provides unique perspectives on the socio-environmental constraints that impacted the structure and durability of these *agroscapes*.

Crépy emphasizes the advantages of combining geoarchaeology and geomorphology with a Niche Construction Theory approach to study the transition from refugia to oases in arid environments. Based on examples from Egypt, Tunisia and the United Arab Emirates, he proposes a new typology of oases integrating interactions and retroactions between societies and their environments. His classification is structured around the processes responsible for the formation of oases/refugia (aeolian, hydrological and/or anthropogenic) and the consequent landforms visible at various spatial scales.

Using a theoretical background that also integrates long-term socio-environmental interactions, Purdue focuses on the construction of a socio-hydrological and resilience background to study the evolution and dynamics of *agroscape*s in the American Southwest (City-oasis of Phoenix, Arizona) over the last two millennia. Based on a rich archaeological, historical and paleoenvironmental dataset, she discusses the constant interactions between agricultural landscapes, human adaptations and climate change and identifies the driving factors of change (and their combination).

Conclusion and research perspectives

The various papers in this volume reveal and confirm the diversity of refugia and oases, with examples ranging from *lomas* in South America to underground water fed oases in the Arabian Peninsula. This further impels us to provide new ideas on how to define refugia and oases in a more integrated way by taking into account the concepts of stability/isolation and connectivity/mobility and by discussing the environmental versus social/economic/political driving factors of change. We propose that a new working definition and classification be based on the following three considerations:

Refugia and oases as socio-environmental entities

As revealed by recent studies (*e.g.* Charbonnier *et alii*, 2017; Costa et *alii*, this volume), refugia and oases are mobile and dynamic spaces. Their structure and management has evolved through time as a result of complex interacting social and/or environmental processes. They have been abandoned for similar reasons. Many driving factors, for instance climate, hydrology, demography, economy, and politics, can transform these landscapes into anthropogenic and technology driven spaces, or into areas where environmental dynamics are the main controlling factors of change. This perspective is key to understanding oases and refugia in a diachronic and integrated way.

Refugia and oases as spatial and social entities

We consider that the definition of refugia and oases should integrate their geographical limits at various scales. The area of contrast between the arid environment surrounding them and the luxurious gardens composing them often marks their boundaries. However, intensively connected areas along fluvial systems such as the Nile Valley, or isolated hyper-specialized cultivated spaces such as mountainous oases supplied by runoff water, are also considered refugia or oases. This implies that they do not have a specific morphology or scale and can be entities stretching thousands of kilometers or limited to a small area fed by a spring. Furthermore, how do we define the boundaries of refugia or intensively transformed oases? Should we consider their environmental, agricultural, socio-political

and/or economic boundaries or those linked to the management of resources, such as water, with geographical limits established by the collective use of water?

Oases as complex systems of production

Like many geographers and agronomists, we believe that the definition of oases should consider their production systems. While date palm cultivation is often synonymous with agricultural oases, the multiplicity of other crops grown and managed are indispensable to an integrated definition of these spaces (Clément and Purdue, this volume). Likewise, the extent and management of pastoral activity in and around oases is often neglected, as are water management systems. Lastly, the variable intensity of the production system that can range from food crops to cash crop for export should be considered, as these often attest to the environmental and socio-economic backgrounds of oases.

We therefore propose an updated working definition of oases which considers these aspects: ***oases are long-term socio-environmental refugia (or niches) supported by perennial sources of water in otherwise harsh environments with dynamic boundaries dependent on the structure of the collectively or individually-managed complex hydro-agro and pastoral production system, integrated within a local to global economic system, and subject to decisive short-term and long-term climatic change***.

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