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Holocene human adaptation in the Namib Desert: A model based on the concept of Holling's loop

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ABSTRACT

Climatic amelioration during the mid-Holocene Optimum is associated with hunter-gatherer occupation of remote sites in the Namib Desert. Subsequent changes in late Holocene site distribution suggest there were alternative responses to increasing aridity during this period. Abandonment or episodic occupation is evident in some areas, while others show an emphasis on mountain refugia and resource anomalies. Specialized coping strategies developed during this time allowed a broad re-occupation of the desert when conditions improved briefly during the Medieval Warm Epoch. Successive patterns of settlement and subsistence in the Namib Desert Holocene sequence exemplify the four moments of Holling's adaptive cycle.

1. Introduction

Although the Namib Desert is among the oldest and driest of the world's arid zones (Eitel, 2005), abundant evidence has been found of human occupation since at least the mid-Pleistocene (e.g. Shackley, 1985). There are, however, relatively few well stratified archaeological deposits, and correlation of occupation events with palaeoclimate records is limited, especially for the earlier part of the sequence (Heine, 2005). In hyper-arid environments such as the drylands of southern Africa, vicissitudes in temperature and moisture have marked effects on primary productivity (cf. Polis, 1991), and evidence of human responses to climatic variation may therefore cast some light on the coping strategies of desert communities and on the threshold limits of human tolerance under conditions of extreme aridity (Mitchell, 2017).

Aridity in the Namib Desert places narrow limits on water supplies and food resources, but hunter-gatherers and, in the last two millennia, nomadic pastoralists, showed a high degree of adaptive resilience, developing a range of unique specializations. Social and technological practices evident from the archaeological record include ritual intensification, food storage and extended exchange networks that mitigated some of the risks and uncertainties of desert life (Kinahan, 2001). A number of systematic studies have been undertaken and the Holocene archaeological sequence is known in some detail (e.g. Richter, 1991), but until now no general explanation has been offered for these developments or the relationship between shifts in human occupation patterns and the effects of climatic variation in this region.

Here, I examine the archaeological evidence for human responses to climatic variation in the Namib Desert during and after the mid-Holocene Optimum, the most recent climatic event affecting sea-levels on the coast of southern Africa (Miller et al., 1993). This phenomenon is broadly coincident with the Holocene African Humid Period, from ca 14.8–5.5ka, well documented in tropical Africa (Burrough and Thomas, 2013). Although less clearly apparent in environments such as the Namib Desert and its semi-arid margins, an array of palaeoclimatic proxy data show increased humidity in the first half of the Holocene. Predominantly arid conditions prevailed thereafter, with short pulses of climatic amelioration, most notably in the last 2000 years (Tyson, 1986).

This paper reviews the archaeological record from the Namib Desert against the generalized background of the palaeoclimate record, and presents a model to account for apparent responses in human occupation patterns. Thus, the Namib Desert was inhabited for short periods during the early Holocene, when environmental conditions were amenable; thereafter, human populations retreated or diminished as conditions became drier, and north of the 23rd parallel, mountain refugia became important nodes of occupation. Relative continuity of occupation still further north suggests that aridification was less severe than in the southern and central Namib Desert. A re-occupation of the southern desert during the Medieval Warm Epoch, after an hiatus of at least two millennia, is partly explicable as an opportunistic response reliant on new subsistence practices.

I will argue that human responses to climatic variation in the Namib Desert exemplify the four moments of the adaptive cycle model first proposed by Holling (1973), and subsequently applied as a fundamental concept in the study of resilience in social systems, and as a basis for archaeological models of human ecology (e.g. Redman, 2005). As a

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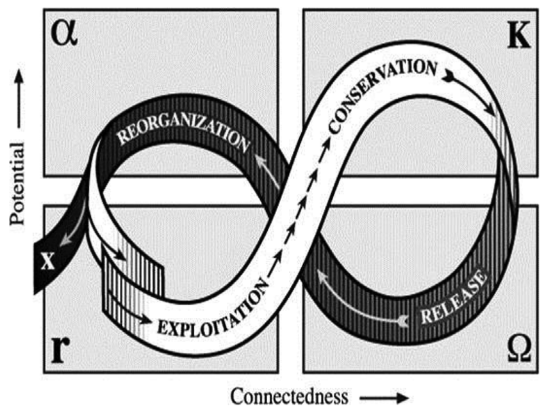

Fig. 1. Holling's adaptive cycle, from *Panarchy* edited by Lance H. Gunderson and C.S. Holling. Copyright © 2002 Island Press. Reproduced by permission of Island Press, Washington, DC.

metaphor of system dynamics, Holling's iconic lazy-eight loop (Fig. 1) comprises a succession of growth (r), equilibrium (K), release (Ω) and reorganization (α) stages. These provide a framework in which I examine archaeological evidence for hunter-gatherer expansion in the Namib Desert during the mid-Holocene Optimum, followed by the apparently equilibrial state reached under increasing aridity, as the first two stages of the cycle. The rise of specialized strategies, including nomadic pastoralism, and the most recent spread of innovative hunter-gatherer strategies during the Medieval Warm Epoch exemplify the last two stages of the cycle.

The adaptive cycle is well established elsewhere as an analytical tool (e.g. Bradtmöller et al., 2017), but it is new to the archaeology of southern Africa, where I will attempt to show that it has the potential to provide an integrated view of hunter-gatherers in the Holocene *longue durée* of environmental shifts and human responses. This approach has two main advantages over the predominantly technological characterization of Holocene archaeology in the Namib Desert: it relates the broad pattern of human settlement and resource use in this region to climatic variability in an unusually unpredictable environment, and it provides a unitary model based on a diversity of archaeological and palaeoclimatic proxy evidence. As such, the adaptive cycle model presents an alternative to both the stadial approach widely used in southern African Holocene archaeology, and to the common reliance on ethnographic analogies drawn from recent observations which largely do not reflect the diversity of the archaeological evidence.

2. The Namib Desert environment

The Namib Desert extends for over 2 000 km along the south-western coast of Africa, and approximately 200 km inland to a broken longitudinal escarpment (Fig. 2). In its northern and central parts the Namib comprises mixed rock and gravel desert with minor dune fields, which are abruptly replaced south of the !Khuiseb River by a vast sandy erg covering some 34 000 km^2 (Lancaster, 1989). Inselbergs, including syn- and post-tectonic granite massifs, are a major feature of the desert, as are extensive drainage systems, although all but two rivers, the Kunene and the Orange, are ephemeral, carrying surface water for short periods following heavy rain on the Namib escarpment.

The aridity of the Namib Desert is maintained by the cold, northward-flowing Benguela Current which only deviates from the coastline north of the Kunene River where it meets the warm, southward-flowing Angola Current. These conditions effectively retard the westward spread of rainfall associated with the semi-annual movement into this region of the Congo Air Boundary (CAB), a branch of the Inter Tropical Convergence Zone (ITCZ) (Tyson, 1986). Rainfall in the Namib is highly variable in quantity, timing and distribution, with an average precipitation of less than 100 mm per annum over much of its extent, and a rainfall coefficient of variation approaching 90% (Mendelsohn et al., 2002). The Namib Desert is therefore classed as hyper-arid and its inland margins as semi-desert (cf. Spellman, 2000).

Episodic weakening of the high-pressure cell along the Atlantic coast by equatorial Benguela Southern Oscillation (BSO) events (Nicholson and Entekhabi, 1986) allows convective storm systems to penetrate the Namib from the north and east, bringing scattered rainfall, mainly in the central and northern parts of the desert. It is thought that humid phases when they occurred in the past, were a consequence of sustained variation in these conditions (Eitel, 2005), bringing increased rainfall over the whole extent of the Namib. Although the southern Namib lies on the margins of the winter rainfall zone, it is also affected by these events, receiving rainfall in both summer and winter (Mendelsohn et al., 2002). Increased rainfall, in terms of both quantity and distribution would have had a marked effect on desert ecosystem productivity (Seely and Louw, 1980).

The climatic characteristics of the mid-Holocene Optimum in the Namib Desert are known from a series of palaeoenvironmental records. Key records are summarized in Table 1, which shows peak warm/moist conditions between 8.3 and 4.8ka, with an average date of 7.2ka. Although there are fewer records for the onset of cool/dry conditions thereafter, dates range between 4.2 and 5.6ka, and late Holocene arid conditions prevailed by 4.8ka. The climatic response is relatively consistent for pollen (Gil Romera et al., 2006), river silts (Brook et al., 2007; Vogel, 1989), microfauna (Brain and Brain, 1977) and speleotherm evidence (Sletten et al., 2013). This is matched by an array of coastal and marine data including beach levels (Compton, 2006, 2007; Kinahan and Kinahan, 2009), and evidence for the presence of tropical molluscan fauna during the mid-Holocene Optimum (Vogel and Visser, 1981).

Shifts in circulation patterns associated with the mid-Holocene Optimum and with the late Holocene aridification are presented in Fig. 3. The southward protrusion of the Angola Current and the reduced influence of the Benguela Current on the Namib Desert coast are associated with a marked westward advance of the 200 mm and 400 mm rainfall isohyets (following Eitel, 2005). The subsequent weakening of the Angola Current restored the coastal influence of the Benguela high pressure regime, and the 200 mm and 400 mm isohyets retreated north-eastward to occupy the position they hold today. Brief pulses of climatic amelioration occurred during the late Holocene (cf. Sletten et al., 2013); this resulted in the establishment of camelthorn trees in the Namib Desert during the Medieval Warm Epoch, and their widespread mortality under renewed aridity during the Little Ice Age (Kinahan, 2016a; b).

3. Holocene archaeology of the Namib Desert

Much of the Namib Desert has been archaeologically explored in the last few decades. Investigations in the southern and central parts of the Namib Desert (Wendt, 1972; Kinahan, 2001), and in the northern parts (Vogelsang and Eichhorn, 2011), established a Holocene sequence based on survey and excavation of more than 20 archaeological sites. In addition, more than 3000 sites have been documented by the Namib Desert Archaeological Survey, an on-going landscape-based project which is systematically exploring the desert as a wholei.

Fig. 4 presents a simplified distribution of known Holocene archaeological sites and available radiocarbon dates. The maps show that the distribution of archaeological sites, including dated finds, is representative of the geographical extent of the desert, with significant concentrations of sites as well as radiocarbon dates in the northern (A), central (B) and southern (C) parts. Densities in excess of 10 sites/km^2 occur in some parts of the central Namib and the overall distribution is somewhat biased towards specific areas of long-term research interest, where intensive survey and systematic excavation provide a firm basis for local sequence and settlement reconstruction. On the basis of these

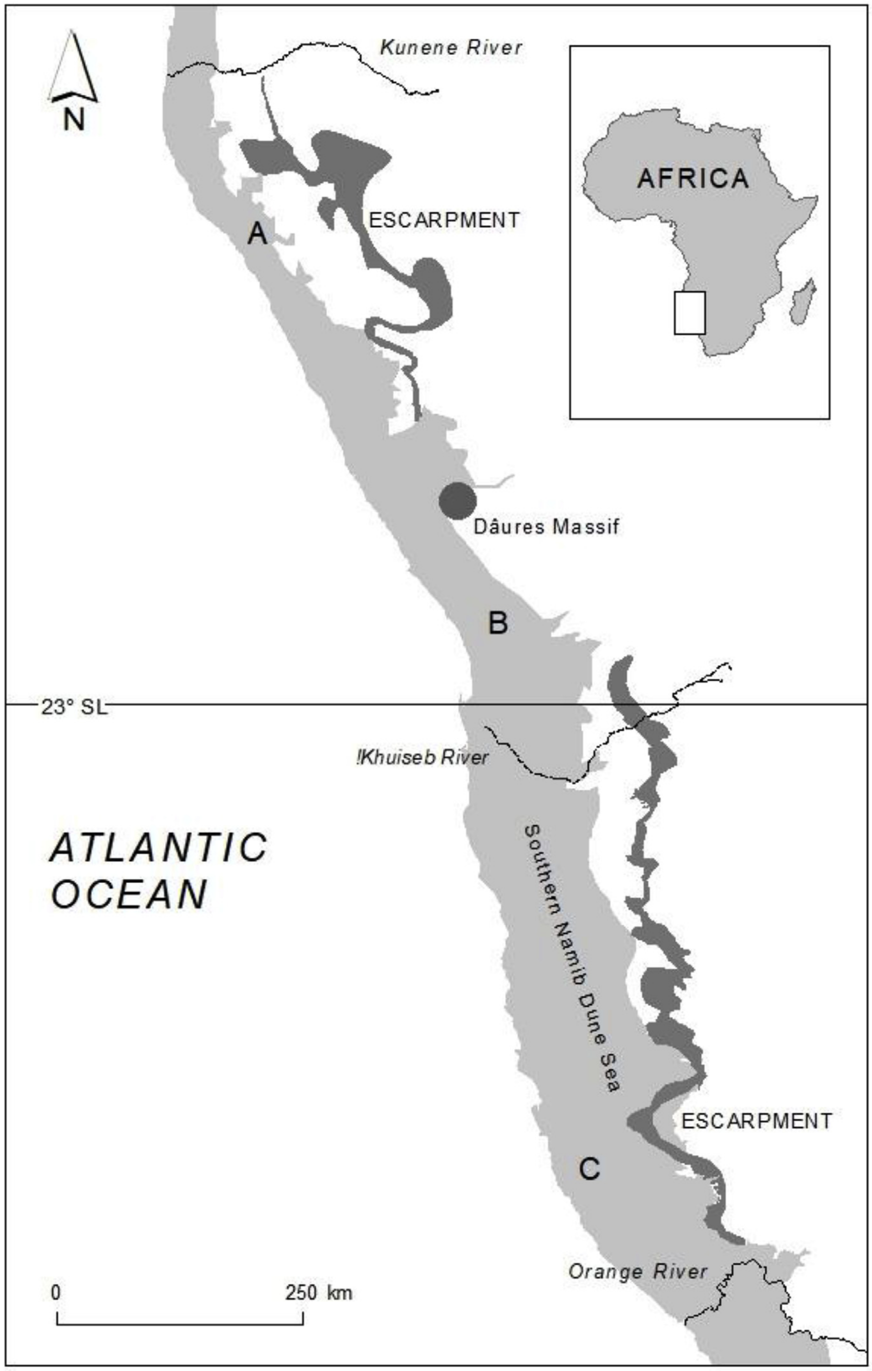

Fig. 2. The geographic setting of the Namib Desert (pale grey), northern (A), central (B) and southern (C) areas in relation to the Atlantic coast and inland escarpment (dark grey), based on spatial data from Mendelsohn et al. (2002).

data it is possible to present a general summary of the Holocene sequence for the whole extent of the Namib Desert.

The early to mid-Holocene is characterized by a wide but relatively thin distribution of hunter-gatherer occupation, represented at isolated rock shelter sites in the vicinity of localized springs, seepages and rainwater pools in outcropping bedrock. The sites appear to have been occupied for short periods, with evidence of hunting antelope and other species migrating into the desert. Archaeological assemblages comprise typical microlithic toolkits (Richter, 1991) suggesting a limited range of tasks but including evidence for the use of hunting bows with composite arrows. There is little indication of plant food exploitation at the sites and limited evidence for manufacture of bone and ostrich eggshell artefacts. Rock art is scarce among these sites, consisting of monochrome depictions showing a range of antelope, with occasional elephant and other large species, as well as human figures (Wendt, 1972).

Mid-Holocene sites present clearly contrasting characteristics; these are more densely clustered and show evidence of sustained residence, in the form of substantial ash accumulations and abundant food remains (Kinahan, 2001). The mid-Holocene diet represented at the sites includes large species but is dominated by non-migratory animals such as hyrax *Procavia capensis*, hares *Pronolagus randensis*, tortoise *Geochelone pardalis* and small, relatively solitary antelope such as klipspringer *Oreotragus oreotragus* and steenbuck *Raphiceros campestris*. There are indications of plant food gathering such as geophyte corm jackets, and

Table 1
Inferred peak warm/moist mid-Holocene Optimum conditions, and the subsequent onset of cool/dry conditions in the Namib Desert.

	Warm/moist	Cool/dry
Gil Romera et al., 2006	6.3–4.8ka	nd
Kinahan and Kinahan, 2017	6.3ka	5.6ka
Vogel and Visser 1981	6.7ka	nd
Compton 2007	7.0–6.3ka	5.3ka
Brook et al., 2006	7.0ka	nd
Compton 2006	7.3–6.5ka	4.2ka
Brain and Brain 1977	7.6–6.0ka	nd
Vogel and Visser 1981	7.6ka	nd
Chase et al., 2009	8.2ka	4.8–2.7ka
Vogel 1989	8.3–4.3ka	nd
Sletten et al., 2013	nd	4.6ka

the manufacture of wooden tools and vessels, as well as of vegetable fibre twine such as might be used for constructing snares. Stone tool assemblages from the sites are similar to those of the early to mid-Holocene (Breunig, 2003). However, the larger rock shelter sites exhibit remarkably high concentrations of rock art, showing increasing complexity of technique and subject matter.

In the last two millennia, thin-walled, highly burnished pottery appears, as does the first evidence for the acquisition of domestic sheep *Ovis aries* (Kinahan, 2016a; b). The settlement pattern gradually shifts towards open encampments with stone hut circles and livestock enclosures showing the development of strategies to exploit ephemeral desert pastures. At the same time, there is increasing use of marine resources, primarily shellfish, and an apparent simplification of the stone tool assemblage (Richter, 1991). A locally distinctive pottery style evolved, and large pointed base storage vessels are associated in the last millennium with intensive processing of wild plant foods including melons and grass seed, in both hunter-gatherer and nomadic pastoral contexts (Kinahan, 2001). Regional exchange is evidenced by the presence of copper, iron, ivory and cowrie shell artefacts in the centuries prior to the establishment of regular contact and trade with European vessels reaching the Namib Desert coast.

A set of 250 Holocene archaeological radiocarbon dates from the Namib Desert allows close comparison of human occupation evidence and the palaeoclimate data summarized in the previous section. The conventional and calibrated radiocarbon values, with 2 Sigma ranges (95.4% probability) and calculated median ages, are listed in Appendix 1. A total of 189 (75%) of the dates are from 24 stratified rock shelter contexts. The remaining dates are from open sites, including shell middens, burials and surface finds. The samples were predominantly charcoal, with some dates based on unburnt plant material, bone, bat guano, and in a few cases ostrich eggshell. Most are legacy dates based on conventional radiocarbon rather than AMS analysis. The radiocarbon dataset excludes dates based on questionable samples and dates considered to have excessively large standard deviations. The dates were calibrated using the ShCal13 curve (OxCal Version 4.3.2: Bronk Ramsey, 2017). The combined probability distributions of the dates are presented in Fig. 5.

Fig. 5 shows that in the northern Namib Desert (A) there is evidence of occupation over the whole span of the Holocene sequence, initially as a series of discrete pulses, followed by an hiatus between 3.8 and 5.8ka. In the central Namib Desert (B), Holocene occupation is initially sporadic, including some occupation of inselberg features, although this association becomes stronger after the onset of late Holocene aridification from 5.0ka. The radiocarbon evidence indicates a relative continuity of occupation at these sites, in contrast to the pattern in the southern Namib Desert (C), where mid-Holocene occupation is associated with isolated sites in a highly dispersed distribution which terminates with the onset of late Holocene aridification after 6.0ka. There is a strong radiocarbon signal in all three areas during the last three millennia; the absence of clear correlations with late Holocene neoglacial events (cf. Jerardino, 1995) may however reflect a dominant tropical influence over the climate of the Namib Desert.

Periodic dry conditions during the mid-Holocene Optimum would have prevented access to some desert sites, just as occasional rainfall in remote parts of the desert may have allowed brief incursions into areas that were otherwise unoccupied. Opportunistic response to short-term variation in desert conditions was essential to hunter-gatherer subsistence, although it might not be easily detected in the radiocarbon record. The result is that the pattern of occupation and abandonment,

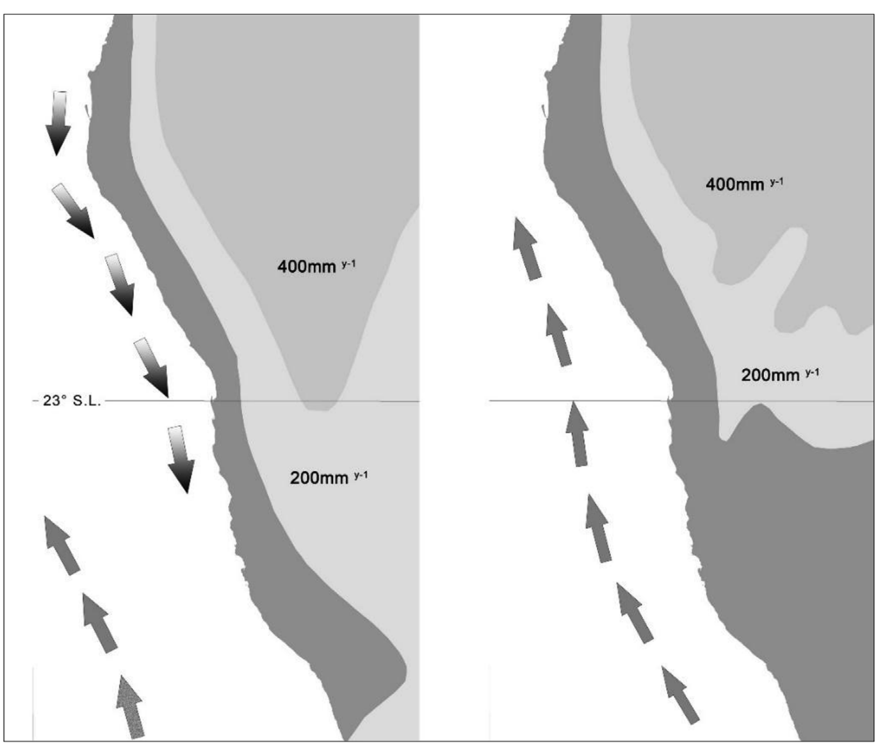

Fig. 3. Mid-Holocene (left) southward intrusion of the Angola Current (shaded grey arrows) to approximately 25° south latitude (after Kirst et al., 1999), with Benguela Current (solid grey arrows) displaced to the west. Late Holocene (right) with Benguela Current in normal alignment (after Mendelsohn et al., 2002). Variation in the 400 mm and 200 mm isohyets follows Eitel (2005).

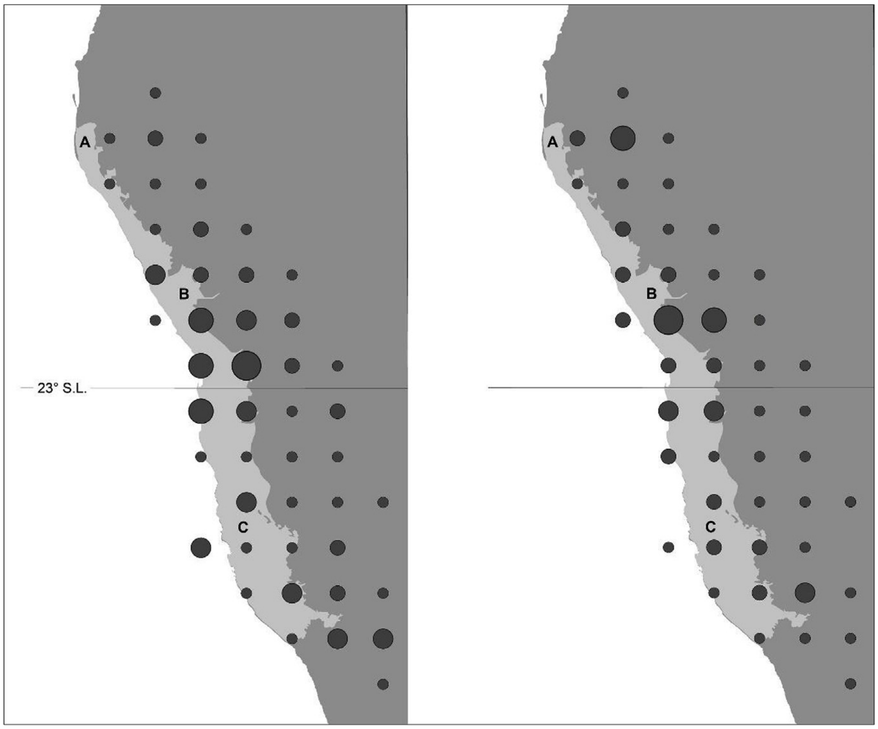

Fig. 4. The distribution by degree square of archaeological sites (left) and Holocene radiocarbon dates (right), showing the relative concentration of sites in the northern (A), central (B) and southern (C) Namib Desert, and the relative numbers of radiocarbon dates from the same areas. The maps are based on data from the Namib Desert Archaeological Survey (n sites = 3194), and a cumulative record of Holocene radiocarbon dates (n dates = 251) (see Appendix 1). The map symbols represent Jenks natural break values for numbers of archaeological sites: 21, 59, 176, 343, 904; and for numbers of radiocarbon dates 2, 7, 12, 51, 84.

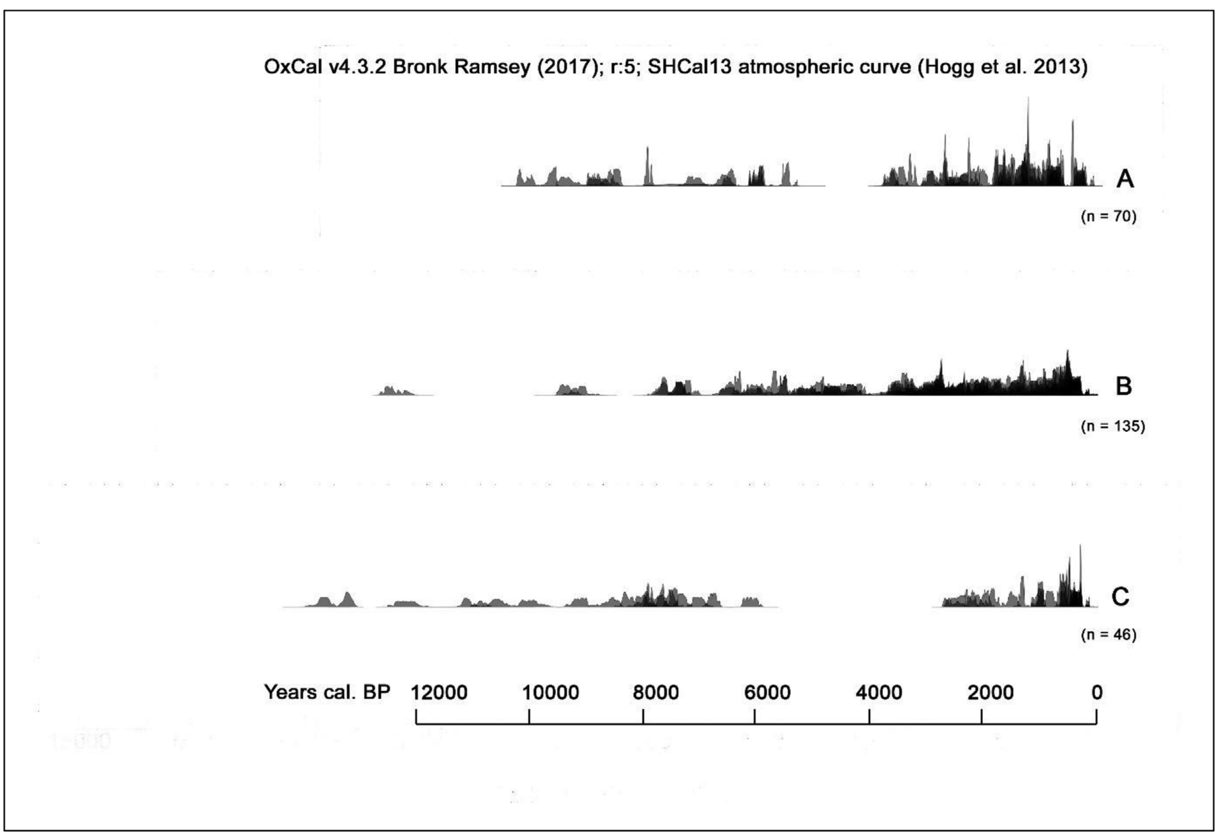

Fig. 5. Calibrated archaeological radiocarbon dates from the northern (A), central (B) and southern (C) Namib Desert.

while it is consonant with the climatic record on the millennial scale, points to a complex relationship between environmental and social responses to desert conditions. Some small peaks in the archaeological radiocarbon record correspond directly with the generalized climate record, such as in the humid pulses at 7.0 and 8.0ka (Brook et al., 2006; Vogel, 1989), and dry periods of varying length have been shown by Vogelsang and Eichhorn (2011: 201) to correspond with the northern Namib archaeological record. Likewise, the clear archaeological signal between 1.0 and 1.3ka suggests a response to climatic amelioration during the Medieval Warm Epoch.

It is axiomatic that changes over time in the landscape distribution of human activity are not solely determined by external forces such as climatic variation, even where patterns of subsistence are closely adapted to variation in rainfall, as is clearly apparent in this case. Shifts in human occupation as seen in the archaeological record also reflect so-called internal forces (Fath et al., 2015), the precedents of knowledge and custom; thus, the accumulated memory of past decisions influences human response as fundamentally as climatic variation. More important still, archaeological evidence may point to developments in which an intensification of, for example, subsistence or ritual activity, leads to a qualitative change in economic integration and social organization. Resilience theory, as conceptualized by Holling's Loop, provides a powerful means to integrate the "interweaving of behavioural adaptations … with their external environmental settings" (Bradtmöller et al., 2017: 1).

4. A Holocene adaptive cycle in the Namib Desert

In the Holocene Namib Desert archaeological sequence a single adaptive cycle would include the following four stages: a growth stage (r) commencing at about 12.0ka with the onset of Holocene climatic conditions, and terminating with the end of the mid-Holocene Optimum at about 4.8ka; an equilibrium stage (K) reached after the onset of late Holocene aridification between 4.2 and 5.6ka; a release stage (Ω) terminating with the start of the Medieval Warm Epoch at about 1.0 and 1.3ka, and a reorganization stage (α) covering the period from 1.0ka until the start of the colonial era. The growth stage terminates abruptly in the southern Namib at about 6.0ka, and the equilibrium stage commences with occupation at refugia sites after 5.0ka. A more gradual shift would most likely have preceded the release stage, followed by an abrupt response to short-term climatic amelioration in the reorganization stage.

In ecological terms, the mid-Holocene r-stage occupation of the Namib Desert is characterized by a non-equilibrial relationship of consumer and resource (cf. Vandermeer and Goldberg, 2013), in which the duration of the hunter-gatherer presence on the landscape is limited by a shortage of water in an environment with a temporary abundance of game. It is significant that this relationship shifts in the late Holocene K-stage, to an equilibrial state, in which hunter-gatherer groups cluster at more reliable water sources where the duration of their stay depends on the carrying capacity of food resources that lie within reach of occupation sites that are essentially tethered to water. This equilibrial state is only relieved by the short-term availability of water following rainfall over the desert, which enabled hunter-gatherers to disperse over the landscape. From an ecosystem perspective the K-stage represents a climax state in which biotic production and human consumption exist in precarious balance (Fath et al., 2015).

The abandonment of the southern Namib Desert at about 6.0ka indicates a threshold point in the conditions under which this environment was tolerable for mobile hunter-gatherers. The evident contrast between the southern and central Namib radiocarbon data (Fig. 5) shows that instead of moving out of the desert, hunter-gatherers began to occupy the granitic inselberg features that occur in the central parts of the desert. The inselbergs represent important resource anomalies; their extensive areas of exposed bedrock provide effective catchments for rainfall runoff which accumulates in deep fissures and below the surface sands. These sustain perennial plant communities and stable animal populations that can withstand periods of severe desiccation in the surrounding area; it is in the K-stage of the adaptive cycle in the Namib Desert that these became refugia, with densely clustered sites focussed on key resource locations.

Rock shelters in the granite inselbergs that served as refugia exhibit clear stratigraphic evidence showing the onset of arid conditions. Late Holocene occupation deposits are predominantly aeolian sediments interleaved with lenses of ash and of unburned plant material. These deposits lie on a basal layer of weathered granite, a coarse regolith weakly cemented with pedogenic calcrete. This regolith appears to represent accelerated weathering by hydrolysis of the Cretaceous granites; it's widespread occurrence with an overlying late Holocene occupation sequence marks a relatively sudden onset of dry conditions following the mid-Holocene Optimum. A further contrast is found in the archaeological preservation of organic remains under the dry conditions of late Holocene deposition, which favoured the survival of delicate materials such as vegetable twine, grass inflorescences, human hair, feathers, and leather (Kinahan, 2001).

A remarkable contrast in the behavioural adaptations that distinguish the r- and K-stages of the adaptive cycle is found in the plentiful rock art of the Namib Desert. Compared to early Holocene sites, refugia sites in the central Namib contain up to one hundred or more images in complex friezes of superimposed and juxta-positioned human and animal motifs, as well as supernatural beings. There are approximately one thousand rock art sites, with varying numbers of paintings, in the 650 km^2 Dâures Massif (Fig. 2), the largest inselberg refugium. The hunter-gatherer rock art of the Namib Desert, in common with that of southern Africa, is essentially shamanistic (Lewis-Williams, 1983). In the context of the Namib refugia, the rock art represents a response through the medium of ritual healing, to the social tensions arising from prolonged aggregation and diminishing resources of food and water (Kinahan, 2001), in delicate equilibrium.

The K-stage of the adaptive cycle is characterized by intensification both in ritual behaviour and subsistence practices. Along with the faunal evidence already noted, of systematic exploitation of small mammal populations found in the near vicinity of the sites, there is also evidence of intensification in the fabrication of bone artefacts and ostrich eggshell pendant and bead production, a practice which might point to the servicing of local exchange networks as a means to mitigate risks of isolation and food scarcity. These relationships may have played a decisive role in a local transition to nomadic pastoralism, by providing a rapid means for the introduction of stock, as well as a social network which would have served to mitigate the loss of stock when, as a pioneer population, their numbers were vulnerable to predation and other risks.

In the Ω-stage, sheep first occur at around 2.1ka and appear to be part of a social transformation involving specialist shamans as agents of interaction between hunter-gatherer and nomadic pastoralist groups (Kinahan, 2016a; b), a role similar to that played by contemporary hunter-gatherer shamans in the Kalahari (Guenther, 1975). The mountain refugia were important dry season pasture sites for livestock, although pastoral land-use lessened dependence on such highly localized resources. Resilience theory identifies the Ω-stage as a point of potential system collapse, where population, or resource consumption threatens the equilibrial state of the K-stage. To avert the collapse of pasture resources, early pastoralists in mountain refugia developed extensive transhumant grazing strategies which rested perennial mountain pastures during the growing season, saving this resource for the dry season when water was scarce elsewhere in the desert (Kinahan, 2001).

In social systems collapse is averted through the emergence of leadership which can establish "new domains of influence, opening an entirely new set of adaptive pathways" (Gunderson and Holling, 2002). Pastoral herd management based on alliances among stock owners would necessarily entail such a development. The archaeological evidence from the central Namib Desert reveals a number of additional novel subsistence practices that also represent solutions to the inherent risks of Ω-stage collapse. These include the intensive harvesting, processing and storage of wild food plants including melons and wild grass seed extracted from the underground nests of harvester ants, resources that were owned and controlled, rather than available to all (Kinahan, 2001). The systematic exploitation of marine foods also intensified during this time (Kinahan and Kinahan, 2017).

The archaeology of the last two thousand years in the Namib Desert does not permit a simple distinction of pastoralist and hunter-gatherer but points instead to a complex and changeable economic landscape in which both lifeways existed with varying reliance on livestock and hunting, while sharing a common cultural tradition: the reorganization characteristic of α-stage. Pastoral sites have evidence of hunting, and sites without livestock remains or stock enclosures nonetheless have pottery, metal artefacts and items representative of extensive exchange relationships. The evidence suggests a possible economic stratification in which livestock surplus to the management capacity of herd-owners may have been distributed among client herders who otherwise had no stock. Large centralized pastoralist camps with outlying stock posts have significant quantities of exchange items reflecting extensive links with the interior of the country. The same sites in more recent historical times have the largest concentrations of goods obtained through contact with European traders (Kinahan, 2001).

Climatic variation during the late Holocene placed limitations on the extent to which this combination of subsistence practices could expand, and relative food security may have brought the population of the Namib Desert to a new equilibrial state. The Ω-stage of the adaptive cycle is characterized by system rigidity and therefore lower resilience. It is also associated with increased social complexity and specialization (Bradtmöller et al., 2017). In the case of the complex mosaic of hunting and pastoral strategies in the Namib Desert the function of maintaining the resilience of the system was associated with specialist shamanism. Mediation between hunting and pastoralism by the shaman is evidenced by the rise of initiation rituals which reinforced gender-based roles in hunter-gatherer groups (Kinahan, 2017a). The shaman during the Ω-stage becomes an itinerant, operating among and between hunter-gatherer and nomadic pastoralist groups (Kinahan, 2017b).

The fourth and final stage of the adaptive cycle is exemplified by the behaviour of hunter-gatherer groups re-occupying the southern Namib Desert in response to climatic amelioration during the Medieval Warm Epoch. The α-stage hunter-gatherer occupation is associated with landscape-scale communal hunting of migratory oryx *Oryx gazella*. The strategy used stone hunting blinds placed in advantageous positions along the habitual routes followed by the antelope. The open terrain and near absence of natural cover making it difficult to approach the animals by stalking, the hunt was conducted by battue, using beaters to drive the herds towards the blinds. Some documented complexes of blinds would have employed as many as 150 hunters if all were in use at the same time, and probably the same number of beaters (Kinahan and Kinahan, 2006). Such activities would have required a fundamentally reorganized form of hunter-gatherer behaviour, as is consistent with the α-stage of the adaptive cycle (Fath et al., 2015).

In this model, the general characteristics of the Holocene archaeological and palaeoclimatic sequence are accommodated within a single cycle of Holling's loop, with the stages of the adaptive cycle treated as periods, as in a conventional cultural sequence. I believe this to be the most appropriate approach given the limitations of the evidence and most particularly, the relative imprecision of dating. With improved chronology this model could be based on the transitions between stages rather than the stages themselves; these would be of varying length, the transition from r to K being a likely rapid response to diminishing rainfall, and that from K to Ω being a more protracted process of increasing rigidity. Improved chronology might also make it possible to identify successive cycles within the same sequence. For example, the rise of communal hunting during the α-stage might have initiated a new and short-lived expansion or r-stage. The fact that communal hunting was not observed by early ethnographers implies that this practice may have reached a K-stage equilibrium point, before collapsing (Ω-stage). This, too, would require field evidence that is not presently available.

5. Discussion

Correspondences between palaeoclimatic and archaeological evidence have been noted throughout Africa, ranging from regional and supra-regional scales (e.g. Kuper and Kröpelin, 2006) to local and intra-site scales (Dewar and Stewart, 2016). Primarily descriptive reconstructions have been superseded by analyses incorporating large radiocarbon datasets and capable of modelling human demographic responses to climatic variation (Manning and Timson, 2014). Where social and technological systems do not show an obvious reflection of environmental shifts, a nuanced understanding may be elusive (Bradtmöller et al., 2017). To examine human behavioural responses over archaeological time-scales therefore requires in addition to detailed and well-provenanced material evidence, a conceptual framework that accommodates both climatic and cultural data, or external and internal drivers (Gunderson and Holling, 2002).

In southern Africa, the Holocene archaeological sequence is generally conceptualized as a series of developments in the form and assemblage combination of stone tools. Regional variation is thought to reflect specific ecological circumstances, forming the basis of increasingly variegated cultural identities as reflected in recent ethnography (cf. Mitchell, 2002). Namib Desert stone tool assemblages from Holocene contexts do not seem to exhibit clear developmental or regional trends (Breunig, 2003; Kinahan, 2001; Vogelsang and Eichhorn, 2011); other artefact classes using bone, wood and leather are not plentiful, and so provide few additional insights. The archaeology of Namib Desert hunter-gatherers suggests a relatively conservative cultural system, such that the adoption of pottery and livestock is conventionally thought to indicate ethnic succession rather than diffusion and social transformation (cf. Mitchell, 2002).

The model presented here, and summarized in Table 2, has a more nuanced view, combining climatic and cultural insights. The retreat from the southern Namib at the end of the mid-Holocene Optimum appears to represent a threshold point in hunter-gatherer tolerance of hyper-aridity. Yet, the late Holocene aridification of the Namib does not dictate the occupation of inselberg refugia as a response to climate as an external force. The nature of the adaptation to increasingly arid conditions reveals the operation of an internal, culturally governed response, as does each of the successive shifts in the proposed adaptive

Table 2
Namib Desert adaptive cycle, with proposed dating, climatic correlation and archaeological characteristics.

Holling stage	Occupation pattern	Dating	Climatic correlation	Archaeology
r (growth)	Expansion ephemeral	*ca* 12ka – 4.8ka	Moist early Holocene and Mid-Holocene Optimum	Dispersed hunting of migratory game Minimal rock art
K (equilibrium)	Refugia sustained	Post-4.8ka	Arid mid- to late Holocene	Aggregation Exchange networks Complex rock art
Ω (release)	Refugia with seasonal dispersion	2.0ka – 1.0ka	Variable rainfall late Holocene	Pastoralism Wealth accumulation Initiation
α (re-organization)	Expansion ephemeral	1.0ka - historic	Medieval Warm Epoch to Little Ice Age	Large scale cooperative hunting of migratory game Food storage

cycle. The archaeological evidence discussed here corroborates the general view that "while ecosystems are complex, human agency adds a …. less predictable component … [of] … dynamic preparedness … that is otherwise not found in ecological systems" (Fath et al., 2015). It is only by considering the dynamic interaction of external and internal forces that the diversity of the Namib Desert archaeological record can be understood as a chain of linked events and responses.

Correspondences between the Holocene climatic record for the Namib Desert and the combined radiocarbon record of human occupation do not in themselves provide an explanation for changes in settlement location, ritual behaviour or evidence of increasingly complex exchange networks. The adaptive cycle, on the other hand, posits a series of related (or alternative) consequences to be considered in the light of archaeological observation. This is exemplified by the proposed r-stage, with evidence of expansion and a non-equilibrial relationship between the hunter-gatherer and the unstable desert resource base, which is in contrast to the succeeding K-stage where hunter-gatherers exist in an equilibrial relationship to a resource base with limited carrying capacity. The behavioural consequences of this are evident in a shift from dispersed to aggregated settlement, and intensification of both social and ecological relations.

The adaptive cycle model has the potential to cast new light on components of the archaeological record that are currently unexplained. Two examples will serve to illustrate this, one from the rock art and another from the lithic assemblage sequence. I have pointed out that although the rock art is not dated directly, its association with early to mid-Holocene occupation sites in the southern Namib seems clear, as is its central importance in the late Holocene occupation of the central Namib refugia sites (Kinahan, 2018). Elsewhere in southern Africa recent progress in direct dating holds the prospect of improved chronological control in the association of rock art and occupation evidence (Bonneau et al., 2017).

I also drew attention to the contrast between the scarcity and relative simplicity of the earlier component when compared to the abundance and complexity of the later rock art. Ritual and rock art in the late Holocene K-stage of the adaptive cycle are associated with a process of intensification prior to the diversification of activities in the Ω-stage. In this context it is noteworthy that the late Holocene rock art shows clear evidence of technical innovation: in the painted art there are what appear to be experiments in perspective, and in the engravings there are attempts to show depth of subject by means of relief. These developments would be explicable as advanced K-stage intensification.

In the lithic assemblages, there is a marked but thus far unexplained simplification of the toolkit during the last two millennia. Holocene lithic assemblages in the Namib have a relatively limited array of formal microlithic artefacts including thumbnail scrapers, borers and backed crescentric or trapezoidal segments, designed to be mounted as the armature of a tool or as barbs in the point of a composite arrow. The latter is the centrepiece of Holocene hunting technology involving a lightweight bow and the use of stealth to approach single prey animals (Mitchell, 2002). The apparent decline of miniaturization in the Namib adaptive cycle, noted in several studies (e.g. Richter, 1991; Vogelsang and Eichhorn, 2011) may reflect a fundamental change in hunting behaviour, one which rendered the composite arrow less important. I have shown that the reorganization of hunting behaviour in the α-stage involved large-scale communal hunting, using blinds as concealment rather than stalking. This strategy, employing a large group, would have aimed to bring down multiple antelope at the place of ambush, where the animals would pass very close to the hunter. In these circumstances, the spear would have been most effective and this was probably not tipped with a microlithic point.

The dynamic nature of the adaptive cycle also provides a conceptual scheme in which to consider evidence of relatively slow or fast rates of change through the sequence (Redman, 2005). Abrupt changes such as at the end of the mid-Holocene Optimum are visible in the radiocarbon record, but the increasing intensification of behaviour during the K-stage might not be recognized if it were not as a consequence of equilibrial dynamics prevailing at that point in the cycle. The adaptive cycle accommodates the elasticity of change and the inertia that may retard the responsiveness of the system, such as in the Ω-stage, characterized by increasing specialization and rigidity. In the Namib Desert the Medieval Warm Epoch coincides with a rapid response in the archaeological record which is in agreement with the reorganization of the system associated with the α-stage. In short, the archaeological evidence from the Holocene Namib Desert is generally consistent with the theoretical properties of the adaptive cycle.

Holling's Loop provides a powerful alternative to the use of ethnographic analogy which in southern Africa is dependent on relatively recent documentary sources; it has clearly advantageous explanatory potential when compared with approaches that rely on artefact typology, for example, or the presence and absence of assemblage items such as pottery, domestic livestock or metal artefacts. The adaptive cycle approach is widely applied elsewhere in a range of archaeological contexts and at varying scales of analysis (Bradtmöller et al., 2017), and its relevance to the Holocene archaeology of the Namib Desert is an argument for its wider potential in southern Africa.

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Appendix 1

*Namib Desert Holocene archaeological radiocarbon dates (entries marked NDAS*are unpublished dates of the Namib Desert Archaeological Survey)*

Lab. number	C14 age	Age range cal. BP 2 Sigma (95.4%)		Median cal. BP	Reference
A. Northern Namib (17–21° SL)					
Pta-1624	300 ± 50	466	150	327	Vogel and Visser (1981)
KN-5286	860 ± 35	788	675	725	Vogelsang and Eichhorn (2011)
KN-4851	1407 ± 50	1359	1181	1281	Vogelsang and Eichhorn (2011)
KN-5287	1480 ± 30	1376	1294	1331	Vogelsang and Eichhorn (2011)
UtC-9881	8690 ± 50	9762	9526	9609	Vogelsang and Eichhorn (2011)
KN-5372	420 ± 35	505	324	451	Vogelsang and Eichhorn (2011)
KN-5455	535 ± 35	551	497	523	Vogelsang and Eichhorn (2011)

KN-5260	940 ± 30	906	736	799	Vogelsang and Eichhorn (2011)
KIA-22461	965 ± 35	922	760	843	Vogelsang and Eichhorn (2011)
KN-5289	985 ± 35	925	774	853	Vogelsang and Eichhorn (2011)
UtC-8103	1042 ± 33	961	803	905	Vogelsang and Eichhorn (2011)
KN-5184	1070 ± 35	1050	806	937	Vogelsang and Eichhorn (2011)
KN-5288	1145 ± 35	1064	935	1006	Vogelsang and Eichhorn (2011)
KN-5373	1275 ± 30	1266	1067	1142	Vogelsang and Eichhorn (2011)
KIA-16047	1298 ± 23	1270	1087	1199	Vogelsang and Eichhorn (2011)
KIA-11985	1442 ± 25	1351	1275	1304	Vogelsang and Eichhorn (2011)
KN-5259	1525 ± 35	1431	1301	1361	Vogelsang and Eichhorn (2011)
KN-5642	1530 ± 30	1422	1307	1364	Vogelsang and Eichhorn (2011)
KN-5465	1540 ± 35	1475	1307	1377	Vogelsang and Eichhorn (2011)
KN-5640	1565 ± 35	1517	1321	1404	Vogelsang and Eichhorn (2011)
KN-5285	1600 ± 35	1531	1370	1451	Vogelsang and Eichhorn (2011)
KIA-22463	1602 ± 29	1528	1376	1453	Vogelsang and Eichhorn (2011)
KN-5641	1705 ± 35	1700	1474	1567	Vogelsang and Eichhorn (2011)
KIA-16046	1739 ± 23	1700	1540	1603	Vogelsang and Eichhorn (2011)
KN-5639	1810 ± 35	1809	1586	1669	Vogelsang and Eichhorn (2011)
KIA-22460	1835 ± 30	1822	1611	1720	Vogelsang and Eichhorn (2011)
KIA-11982	1842 ± 25	1822	1616	1729	Vogelsang and Eichhorn (2011)
KN-5638	1890 ± 35	1875	1707	1784	Vogelsang and Eichhorn (2011)
KIA-16045	1940 ± 22	1905	1747	1849	Vogelsang and Eichhorn (2011)
KIA-16043	1956 ± 31	1985	1747	1862	Vogelsang and Eichhorn (2011)
KN-5371	2160 ± 40	2303	2002	2102	Vogelsang and Eichhorn (2011)
KIA-24949	2242 ± 23	2317	2150	2231	Vogelsang and Eichhorn (2011)
KN-5675	2345 ± 35	2424	2162	2328	Vogelsang and Eichhorn (2011)
KN-5325	2435 ± 45	2700	2337	2443	Vogelsang and Eichhorn (2011)
KN-5261	2465 ± 35	2702	2351	2468	Vogelsang and Eichhorn (2011)
KIA22462	2511 ± 37	2717	2365	2563	Vogelsang and Eichhorn (2011)
KN-5674	2600 ± 35	2759	2491	2647	Vogelsang and Eichhorn (2011)
UtC-9380	2670 ± 42	2857	2540	2756	Vogelsang and Eichhorn (2011)
KN-5326	2910 ± 40	3144	2865	2990	Vogelsang and Eichhorn (2011)
UtC-8102	2932 ± 35	3160	2886	3021	Vogelsang and Eichhorn (2011)
KIA-27702	3175 ± 25	3446	3247	3356	Vogelsang and Eichhorn (2011)
KN-5185	3330 ± 35	3613	3403	3515	Vogelsang and Eichhorn (2011)
UtC-9379	3479 ± 43	3832	3584	3696	Vogelsang and Eichhorn (2011)
KN-5677	4835 ± 40	5605	5330	5518	Vogelsang and Eichhorn (2011)
UtC-9381	5253 ± 48	6181	5892	5973	Vogelsang and Eichhorn (2011)
KIA-24948/2	5292 ± 32	6179	5922	6006	Vogelsang and Eichhorn (2011)
KN-5370	5315 ± 30	6181	5938	6060	Vogelsang and Eichhorn (2011)
KN-5676	5755 ± 40	6634	6408	6503	Vogelsang and Eichhorn (2011)
KN-5309	6280 ± 80	7408	6912	7142	Vogelsang and Eichhorn (2011)
KIA-19251	6440 ± 480	8298	6288	7259	Vogelsang and Eichhorn (2011)
KIA-17711	7155 ± 30	8009	7855	7945	Vogelsang and Eichhorn (2011)
UtC-9878	7750 ± 50	8589	8408	8491	Vogelsang and Eichhorn (2011)
KIA11981	7872 ± 56	8971	8449	8620	Vogelsang and Eichhorn (2011)
UtC-9876	7990 ± 60	8996	8610	8808	Vogelsang and Eichhorn (2011)
KIA-11984	8053 ± 36	9014	8719	8879	Vogelsang and Eichhorn (2011)
KN-5310	8415 ± 100	9539	9092	9360	Vogelsang and Eichhorn (2011)
UtC-8104	9010 ± 50	10233	9915	10101	Vogelsang and Eichhorn (2011)
Beta-85288	990 ± 60	956	740	851	NDAS*
Beta-77731	1080 ± 60	1061	801	942	NDAS*
Beta-85284	1150 ± 60	1179	921	1016	NDAS*
Pta-3929	900 ± 50	905	678	766	NDAS*
Pta-3900	1330 ± 50	1296	1088	1212	NDAS*
Pta-221	2690 ± 60	2923	2503	2773	Vogel and Visser (1981)
KN-I.469	370 ± 50	492	306	395	Freundlich et al. (1980)
Pta-2111	400 ± 40	496	323	408	Vogel and Visser (1981)
KN-I.635	910 ± 55	907	683	779	Freundlich et al. (1980)
Pta-2664	1000 ± 60	959	742	856	Vogel and Visser (1981)
KN-I.468	3450 ± 40	3828	3561	3658	Freundlich et al. (1980)
Pta-2654	5850 ± 70	6784	6440	6607	Vogel and Visser (1981)
Pta-5471	350 ± 50	491	296	388	Kinahan (1999)
B. Central Namib (21–24° SL)					
Beta-462931	4200 ± 30	4830	4571	4699	Kinahan (2018)
Pta-1577	340 ± 40	471	295	387	Vogel and Visser (1981)

Pta-3925	840 ± 50	800	655	716	Kinahan and Kinahan (1984)
Pta-3926	970 ± 50	926	741	842	Kinahan and Kinahan (1984)
Wits-1256	310 ± 50	470	152	360	Kinahan (2001)
KN-3921	310 ± 50	470	152	360	Breunig (2003)
KN-3919	350 ± 55	495	286	387	Breunig (2003)
KN-4198	350 ± 60	500	156	386	Breunig (2003)
Pta-1377	360 ± 40	486	305	392	Vogel and Visser (1981)
Pta-3896	370 ± 50	492	306	395	Kinahan (2001)
KN-4197	390 ± 60	503	304	402	Breunig (2003)
Pta-2645	420 ± 140	649	…	399	Vogel and Visser (1981)
Pta-1783	420 ± 45	506	323	438	Vogel and Visser (1981)
Pta-3794	440 ± 45	521	324	460	Kinahan (2001)
KN-3701	460 ± 50	540	325	474	Breunig (2003)
KN-3582	470 ± 50	545	327	483	Breunig (2003)
KN-4175	540 ± 60	639	339	527	Breunig (2003)
KN-3584	550 ± 50	634	487	531	Breunig (2003)
Pta-3873	570 ± 50	637	495	540	Kinahan (2001)
KN-3583	590 ± 50	646	502	552	Breunig (2003)
KN-3714	710 ± 200	1050	300	648	Breunig (2003)
Pta-1773	720 ± 45	682	555	628	Vogel and Visser (1981)
Wits-1100	730 ± 70	732	548	637	Kinahan (2001)
KN-3713	780 ± 200	1072	325	708	Breunig (2003)
KN-I.636	860 ± 55	904	658	732	Freundlich et al. (1980)
Pta-1777	910 ± 40	905	684	771	Vogel and Visser (1981)
KN-3651	910 ± 100	962	575	791	Breunig (2003)
KN-3649	1000 ± 50	956	766	856	Breunig (2003)
KN-3586	1050 ± 50	1050	792	907	Breunig (2003)
KN-3550	1080 ± 90	1175	760	942	Breunig (2003)
KN-3551	1170 ± 90	1270	818	1042	Breunig (2003)
KN-3648	1260 ± 50	1271	987	1134	Breunig (2003)
Pta-2681	1370 ± 50	1317	1093	1239	Vogel and Visser (1981)
KN-3775	1490 ± 120	1592	1073	1359	Breunig (2003)
KN-3545	1620 ± 60	1590	1321	1468	Breunig (2003)
Wits-1249	1640 ± 70	1698	1323	1488	Kinahan (2001)
KN-3704	1710 ± 110	1829	1325	1577	Breunig (2003)
Pta-2886	1840 ± 50	1836	1587	1726	Kinahan (2001)
Pta-2927	1880 ± 50	1897	1612	1776	Kinahan (2001)
KN-4174	2010 ± 60	2081	1747	1923	Breunig (2003)
Pta-2930	2040 ± 50	2083	1835	1956	Kinahan (2001)
KN-I.637	2070 ± 90	2305	1748	1999	Freundlich et al. (1980)
KN-I.639	2090 ± 45	2148	1905	2016	Freundlich et al. (1980)
KN-3549	2090 ± 55	2291	1882	2018	Breunig (2003)
Pta-2929	2100 ± 50	2288	1895	2032	Kinahan (2001)
Pta-1546	2240 ± 50	2340	2085	2217	Vogel and Visser (1981)
Pta-1551	2390 ± 50	2697	2183	2394	Vogel and Visser (1981)
KN-4065	2400 ± 55	2702	2204	2414	Breunig (2003)
KN-4428	2460 ± 45	2704	2348	2474	Breunig (2003)
KN-4429	2490 ± 60	2715	2356	2532	Breunig (2003)
Pta-1550	2590 ± 60	2768	2380	2609	Vogel and Visser (1981)
Pta-2926	2590 ± 60	2768	2380	2609	Kinahan (2001)
KN-3715	2640 ± 100	2917	2360	2671	Breunig (2003)
KN-3585	2670 ± 55	2868	2498	2755	Breunig (2003)
KN-4066	2680 ± 50	2871	2520	2764	Breunig (2003)
KN-4117	2710 ± 60	2951	2548	2790	Breunig (2003)
KN-3716	2740 ± 100	3137	2491	2824	Breunig (2003)
KN-3544	2760 ± 50	2942	2748	2822	Breunig (2003)
Pta-1776	2780 ± 60	2978	2747	2842	Vogel and Visser (1981)
KN-I.638	2820 ± 55	3030	2758	2880	Freundlich et al. (1980)
Pta-178	2890 ± 65	3160	2793	2969	Vogel and Visser (1981)
KN-3718	2940 ± 120	3346	2781	3049	Breunig (2003)
Pta-179	2950 ± 65	3237	2859	3050	Vogel and Visser (1981)
KN-3546	3110 ± 65	3444	3072	3268	Breunig (2003)
KN-3717	3180 ± 110	3631	3038	3342	Breunig (2003)
KN-4165	3348 ± 53	3686	3400	3533	Breunig (2003)
Pta-3121	3370 ± 60	3705	3399	3560	Kinahan (2001)
Pta-1263	3950 ± 60	4518	4152	4334	Vogel and Visser (1981)

Pta-1295	4080 ± 60	4820	4300	4529	Vogel and Visser (1981)
KN-3547	4290 ± 60	4967	4581	4783	Breunig (2003)
Pta-3122	4380 ± 60	5275	4729	4928	Kinahan (2001)
Pta-2917	4510 ± 70	5305	4877	5116	Kinahan (2001)
Pta-1620	4840 ± 50	5644	5328	5519	Vogel and Visser (1981)
KN-3642	5280 ± 120	6284	5741	6022	Breunig (2003)
KN-3548	5320 ± 60	6260	5918	6067	Breunig (2003)
Pta-1547	6510 ± 80	7564	7248	7376	Vogel and Visser (1981)
KN-3650	6860 ± 90	7914	7506	7666	Breunig (2003)
Pta-2230	370 ± 40	488	312	394	Vogel and Visser (1981)
KN-I.467	420 ± 60	515	314	424	Freundlich et al. (1980)
Pta-1558	1080 ± 50	1058	804	943	Vogel and Visser (1981)
Pta-4635	1240 ± 50	1265	980	1114	Kinahan (2001)
UCLA-724b	1400 ± 80	1406	1072	1263	Wendt (1972)
KN-I.465	1930 ± 50	1987	1710	1829	Freundlich et al. (1980)
KN-I.731	2150 ± 60	2307	1931	2096	Freundlich et al. (1980)
Beta-270163	2190 ± 40	2307	2016	2145	Pleurdeau et al. (2012)
KN-I.732	2190 ± 40	2307	2016	2145	Freundlich et al. (1980)
Beta-270164	2270 ± 40	2343	2151	2233	Pleurdeau et al. (2012)
Beta-236963	2430 ± 50	2702	2331	2444	Pleurdeau et al. (2012)
UCLA-724a	2550 ± 80	2748	2363	2575	Wendt (1972)
Pta-4652	2600 ± 45	2765	2472	2627	Kinahan (2001)
KN-I.730	2840 ± 55	3061	2775	2904	Freundlich et al. (1980)
KN-I.461	2910 ± 45	3156	2863	2991	Freundlich et al. (1980)
KN-I.460	2940 ± 45	3173	2879	3034	Freundlich et al. (1980)
SR-64	3080 ± 100	3458	2946	3221	Wendt (1972)
Pta-1557	3130 ± 40	3390	3173	3292	Vogel and Visser (1981)
Beta-236966	3180 ± 40	3450	3235	3357	Pleurdeau et al. (2012)
Beta-236964	3250 ± 40	3560	3356	3429	Pleurdeau et al. (2012)
C-911	3368 ± 200	4145	3064	3582	Wendt (1972)
Pta-5134	3400 ± 60	3823	3448	3597	Kinahan (2001)
Pta-4633	4160 ± 60	4830	4444	4651	Kinahan (2001)
SR-63	4590 ± 100	5569	4878	5191	Wendt (1972)
SR-88	5740 ± 110	6737	6291	6499	Wendt (1972)
Beta-217090	1510 ± 40	1430	1295	1351	NDAS*
Beta-217089	3860 ± 50	4413	4013	4218	NDAS*
Beta-238381	4180 ± 50	4831	4524	4676	NDAS*
Beta-255821	4490 ± 40	5288	4878	5082	NDAS*
Beta-235938	350 ± 50	491	296	388	NDAS*
Beta-236514	2190 ± 60	2316	2006	2149	NDAS*
CAIS-6246	5010 ± 25	5852	5605	5690	McCall et al. (2011)
Beta-258613	10530 ± 70	12647	12066	12426	NDAS*
KN-3597	350 ± 85	524	143	375	Kinahan (2001)
Pta-2554	370 ± 30	486	315	392	Vogel and Visser (1981)
Pta-1645	400 ± 50	501	316	408	Vogel and Visser (1981)
KN-3600	410 ± 50	504	319	417	Kinahan (2001)
KN-3599	620 ± 50	651	519	589	Kinahan (2001)
KN-3596	640 ± 100	732	472	595	Kinahan (2001)
KN-3598	1170 ± 50	1175	933	1025	Kinahan (2001)
Pta-4049	1470 ± 45	1406	1274	1329	Kinahan (2001)
Pta-4004	1600 ± 50	1560	1323	1450	Kinahan (2001)
Pta-2006	1720 ± 45	1708	1475	1587	Vogel and Visser (1981)
Pta-4007	1870 ± 60	1895	1594	1764	Kinahan (2001)
Pta-1344	750 ± 80	770	545	654	Vogel and Visser (1981)
Pta-1988	1210 ± 50	1258	959	1073	Vogel and Visser (1981)
Pta-1535	1550 ± 50	1515	1310	1395	Vogel and Visser (1981)
Pta-1011	5190 ± 80	6178	5664	5898	Vogel and Visser (1981)
Pta-1348	5570 ± 50	6435	6212	6331	Vogel and Visser (1981)
Pta-2075	5740 ± 60	6650	6322	6489	Vogel and Visser (1981)
Pta-1347	6330 ± 60	7413	7008	7213	Vogel and Visser (1981)
Pta-1012	6470 ± 80	7482	7174	7349	Vogel and Visser (1981)
Pta-1536	6500 ± 80	7560	7181	7369	Vogel and Visser (1981)
Pta-2077	6840 ± 70	7794	7510	7643	Vogel and Visser (1981)
Pta-1013	8200 ± 80	9409	8786	9120	Vogel and Visser (1981)
Pta-1368	8410 ± 80	9527	9137	9367	Vogel and Visser (1981)
C. Southern Namib (24–29° SL)					

Pta-1801	310 ± 20	442	291	321	Vogel and Visser (1981)
Pta-902	620 ± 40	649	521	593	Vogel and Visser (1981)
Pta-1863	710 ± 50	682	551	618	Vogel and Visser (1981)
Pta-1832	980 ± 50	930	742	847	Vogel and Visser (1981)
Pta-1824	1500 ± 40	1418	1295	1345	Vogel and Visser (1981)
Pta-1996	11900 ± 90	13946	13467	13672	Vogel and Visser (1981)
Beta-207920	310 ± 40	457	154	366	Kinahan and Kinahan (2006)
Pta-1131	330 ± 50	491	157	380	Vogel and Visser (1981)
Beta-213465	660 ± 50	664	540	603	Kinahan and Kinahan (2006)
Beta-213466	6630 ± 60	7589	7336	7489	Kinahan and Kinahan (2006)
Beta-207918	6720 ± 70	7660	7437	7546	Kinahan and Kinahan (2006)
Beta-207919	7150 ± 50	8024	7827	7936	Kinahan and Kinahan (2006)
Beta-450170	1170 ± 30	1089	956	1017	NDAS*
Pta-2295	490 ± 50	555	328	501	Vogel and Visser (1981)
Pta-2264	300 ± 50	466	150	327	Vogel and Visser (1981)
Pta-2296	400 ± 50	501	316	408	Vogel and Visser (1981)
Pta-1049	2070 ± 50	2148	1876	1988	Vogel and Visser (1981)
Pta-1927	2200 ± 50	2312	2017	2164	Vogel and Visser (1981)
Pta-2650	2300 ± 50	2355	2150	2245	Vogel and Visser (1981)
Pta-1042	2440 ± 50	2703	2339	2455	Vogel and Visser (1981)
Pta-1045	2540 ± 50	2742	2379	2578	Vogel and Visser (1981)
Pta-1186	5400 ± 70	6290	5949	6135	Vogel and Visser (1981)
Pta-1751	6940 ± 80	7928	7592	7740	Vogel and Visser (1981)
KN-I.2142	7560 ± 75	8451	8174	8326	Freundlich et al. (1980)
Pta-1185	7840 ± 90	8976	8408	8596	Vogel and Visser (1981)
KN-I.2143	8230 ± 70	9401	8999	9156	Freundlich et al. (1980)
Pta-9276	1200 ± 50	1185	938	1059	Compton (2006)
Pta-9277	6010 ± 50	6935	6673	6802	Compton (2006)
Pta-3579	330 ± 45	487	284	382	Sievers (1984)
Pta-1202	370 ± 50	492	306	395	Vogel and Visser (1981)
Pta-3521	760 ± 50	734	560	662	Sievers (1984)
Pta-2663	1160 ± 50	1173	929	1019	Vogel and Visser (1981)
KN-I.624	6910 ± 45	7825	7607	7701	Freundlich et al. (1980)
Pta-3527	8970 ± 90	10239	9706	10021	Sievers (1984)
Pta-3580	9750 ± 90	11259	10754	11086	Sievers (1984)
Pta-1009	320 ± 40	469	157	378	Vogel and Visser (1981)
KN-I.608	490 ± 45	550	334	503	Freundlich et al. (1980)
KN-I.870	1670 ± 55	1699	1378	1522	Freundlich et al. (1980)
Pta-1918	1960 ± 45	1995	1743	1865	Vogel and Visser (1981)
KN-I.609	6200 ± 65	7248	6887	7058	Freundlich et al. (1980)
Pta-1019	6480 ± 80	7500	7176	7356	Vogel and Visser (1981)
KN-I.867	7200 ± 75	8165	7840	7981	Freundlich et al. (1980)
Pta-1020	7280 ± 80	8290	7872	8065	Vogel and Visser (1981)
KN-I.610	9430 ± 90	11070	10295	10620	Freundlich et al. (1980)
KN-I.611	10420 ± 80	12550	11952	12225	Freundlich et al. (1980)
KN-I.846	11460 ± 55	13400	13124	13254	Freundlich et al. (1980)

i http://antiquity.ac.uk/projgall/kinahan325/).

References

Bonneau, A., Pearce, D., Mitchell, P., Staff, R., Arthur, C., Mallen, L., Brock, F., Higham, T., 2017. The earliest directly dated rock paintings from southern Africa: new AMS radiocarbon dates. Antiquity 91 (356), 322–333.

Bradtmöller, M., Grimm, S., Riel-Salvatore, J., 2017. Resilience theory in archaeological practice – an annotated review. Quat. Int. 446, 3–16.

Brain, C.K., Brain, V., 1977. Microfaunal remains from Mirabib: some evidence of palaeoecological changes in the Namib. Madoqua 10 (4), 285–293.

Brook, G., Srivastava, P., Marais, E., 2006. Characteristics and OSL minimum ages of relict fluvial deposits near Sossus Vlei, Tsauchab River, Namibia, and a regional climate record for the last 30ka. J. Quat. Sci. 21 (4), 347–362.

Brook, G., Marais, E., Srivastava, P., Jordan, T., 2007. Timing of lake-level changes in Etosha Pan, Namibia, since the middle Holocene from OSL ages of relict shorelines in the Okondeka region. Quat. Int. 175, 29–40.

Breunig, P., 2003. Der Brandberg—Untersuchungen zur Besiedlungsgeschichte eines Hochgebirges in Namibia. Heinrich Barth Institut, Afrika Praehistorica 17. Köln.

Bronk Ramsey, C., 2017. OxCal Program V4. 3.2. Radiocarbon Accelerator Unit. Univ. Oxford.

Burrough, S.L., Thomas, D.S.G., 2013. Central southern Africa at the time of the African Humid Period: a new analysis of Holocene palaeoenvironmental and palaeoclimatic data. Quat. Sci. Rev. 80, 29–46.

Chase, B.M., Meadows, M.E., Scott, L., Thomas, D.S.G., Marais, E., Sealy, J., Reimer, P.J., 2009. A record of rapid Holocene climate change preserved in hyrax middens from southwestern Africa. Geology 37 (8), 703–706.

Compton, J., 2006. The mid-Holocene sea-level highstand at Bogenfels Pan on the southwest coast of Namibia. Quat. Res. 66, 303–310.

Compton, J., 2007. Holocene evolution of the Anichab Pan on the south-west coast of Namibia. Sedimentology 54, 55–70.

Dewar, G., Stewart, B., 2016. Paleoenvironments, sea levels, and land use in Namaqualand, South Africa, during MIS 6-2. In: Jones, S.C., Stewart, B. (Eds.), Africa from MIS 6-2: Population Dynamics and Palaeoenvironments. Springer, New York, pp. 195–212.

Eitel, B., 2005. Environmental history of the Namib Desert. In: Smith, M., Hesse, P. (Eds.), 23 Degrees South: Archaeology and Environmental History of the Southern Deserts. National Museum of Australia Press, Canberra, pp. 45–55.

Fath, B.D., Dean, C.A., Katzmair, H., 2015. Navigating the adaptive cycle: an approach to managing the resilience of social systems. Ecol. Soc. 20 (2), 24.

Freundlich, J.C., Schwabedissen, H., Wendt, W.E., 1980. Köln radiocarbon measurements II. Radiocarbon 22 (1), 68–81.

Gil Romera, G., Scott, L., Marais, E., Brook, G., 2006. Middle- to late-Holocene moisture

changes in the desert of northwest Namibia derived from fossil hyrax dung pollen. Holocene 16 (8), 1073–1084.
Guenther, M., 1975. The trance dancer as an agent of social change among the farm Bushmen of the Ghanzi District. Botsw. Notes Rec. 7, 161–166.
Gunderson, L.H., Holling, C.S., 2002. Panarchy: Understanding Transformation in Human and Natural Systems. Island Press, Washington.
Heine, K., 2005. Holocene climate of Namibia: review based on geoarchives. Afr. Stud. Monogr. 30, 119–133 (Supplementary issue).
Holling, C.S., 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Systemat. 4, 1–23.
Jerardino, A., 1995. Late Holocene neoglacial episodes in southern South America and southern Africa: a comparison. Holocene 5 (3), 361–368.
Kinahan, J., 1999. Towards an archaeology of mimesis and rainmaking in the rock art of Namibia. In: Ucko, P., Layton, R. (Eds.), The Archaeology and Anthropology of Landscape. Routledge, London, pp. 336–357.
Kinahan, J., 2001. Pastoral Nomads of the Central Namib Desert: the People History Forgot, second ed. Namibia Archaeological Trust, Windhoek.
Kinahan, J., 2016a. Human responses to climatic variation in the Namib Desert during the last one thousand years. Afr. Archaeol. Rev. 33 (2), 183–203.
Kinahan, J., 2016b. Archaeological evidence of domestic sheep in the Namib Desert during the first millennium AD. J. Afr. Archaeol. 14 (1), 7–17.
Kinahan, J., 2017a. The dancing kudu: women's initiation in the Namib Desert during the second millennium AD. Antiquity 358, 1043–1057.
Kinahan, J., 2017b. The solitary shaman: itinerant healers and ritual seclusion in the Namib Desert during the second millennium AD. Camb. Archaeol. J. 27 (3), 553–569.
Kinahan, J., 2018. A ritual assemblage from the third millennium BC in the Namib Desert and its implications for the archaeology and rock art of shamanic performance. Azania 53, 40–62.
Kinahan, J., Kinahan, J.H.A., 1984. Holocene subsistence and settlement on the Namib coast: the example of the Ugab River Mouth. Cimbebasia B 4 (6), 59–72.
Kinahan, J., Kinahan, J.H.A., 2006. Preliminary report on the late Holocene archaeology of the Awasib – gorrasis basin complex in the southern Namib Desert. Studies in the African Past 5, 1–14.
Kinahan, J.H.A., Kinahan, J., 2009. 'A thousand fine vessels are ploughing the main…' Archaeological traces of the nineteenth century 'Guano Rage' on the south-western coast of Africa. Aust. Hist. Archaeol. 27, 43–54.
Kinahan, J., Kinahan, J.H.A., 2017. Post-Pleistocene archaeology and geomorphological processes on the Namib Desert coast of southwestern Africa. J. I. Coast Archaeol. 12 (1), 65–77.
Kirst, G.J., Schneider, R.R., Müller, P.J., von Storch, I., Wefer, G., 1999. Late quaternary temperature variability in the Benguela current system derived from alkenones. Quat. Res. 52, 92–103.
Kuper, R., Kröpelin, S., 2006. Climate-controlled Holocene occupation in the sahara: motor of Africa's evolution. Science 313, 803–807.
Lancaster, N., 1989. The Namib Sand Sea: Dune Forms, Processes and Sediments. A.A. Balkema, Rotterdam.
Lewis-Williams, J.D., 1983. The Rock Art of Southern Africa. Cambridge University Press, Cambridge.
Manning, K., Timson, A., 2014. The demographic response to Holocene climate change in the Sahara. Quat. Sci. Rev. 101, 28–35.
McCall, G., Marks, T., Thomas, J., Eller, M., Horn, S., Horowitz, R., Kettler, K., Taylor-Perryman, R., 2011. Erb tanks: a middle and later stone age rockshelter in the central Namib Desert, western Namibia. PaleoAnthropology 2011, 398–421.
Mendelsohn, J., Jarvis, A., Roberts, C., Robertson, T. (Eds.), 2002. Atlas of Namibia: a Portrait of the Land and its People. David Philip, Cape Town.
Miller, D.E., Yates, R.J., Parkington, J.E., Vogel, J.C., 1993. Radiocarbon-dated evidence relating to a mid-Holocene relative high sea-level on the southwestern Cape coast, South Africa. South Afr. J. Sci. 89, 35–44.
Mitchell, P., 2002. The Archaeology of Southern Africa. Cambridge University Press, Cambridge.
Mitchell, P., 2017. Discontinuities in hunter-gatherer prehistory in southern African drylands. J. Anthropol. Archaeol. 46, 40–52.
Nicholson, S.E., Entekhabi, D., 1986. The quasi-periodic behaviour of rainfall variability in Africa and its relationship to the Southern Oscillation. Arch. Meteorol. Geophys. Bioclimatol., A 34, 311–348.
Pleurdeau, D., Imalwa, E., Detroit, F., Lesur, J., Veldman, A., Bahain, J.-J., Marais, E., 2012. Of sheep and men: earliest direct evidence of caprine domestication in southern Africa at Leopard Cave (Erongo, Namibia). PLoS One 7 (7), e40340. http://dx.doi.org/10.1371/journal.pone.0040340.
Polis, G.A., 1991. Ecology of desert communities. In: International Congress of Ecology 1986: Syracuse, NY). University of Arizona Press.
Redman, C., 2005. Resilience theory in archaeology. Am. Anthropol. 107 (1), 70–77.
Richter, J., 1991. Studien zur Urgeschichte Namibias – Holozäne Stratigraphien im Umkreis des Brandberges. Africa Praehistorica 3, Köln. pp. 348.
Shackley, M., 1985. Palaeolithic archaeology of the central namib desert: A preliminary survey of chronology, typology and site location. Cimbebasia Mem. 6.
Seely, M., Louw, G., 1980. First approximation of the effects of rainfall on the ecology and energetics of a Namib Desert dune ecosystem. J. Arid Environ. 3, 25–54.
Sletten, H.R., Railsback, L.B., Liang, F., Brook, G., Marais, E., Hardt, B.F., Cheng, H., Edwards, L.R., 2013. A petrographic and geochemical record of climate change over the last 4600 years from a northern Namibia stalagmite, with evidence of abruptly wetter climate at the beginning of southern Africa's Iron Age. Palaeogeogr. Palaeoclimatol. Palaeoecol. 376, 149–162.
Sievers, C., 1984. Test excavations at rosh pinah shelter, southern Namibia. Cimbebasia (B) 4 (3), 29–40.
Spellman, G., 2000. The dynamic climatology of drylands. In: Barker, G., Gilbertson, D. (Eds.), The Archaeology of Drylands: Living at the Margins. Routledge, London, pp. 19–44.
Tyson, P.D., 1986. Climatic Change and Variability in Southern Africa. Oxford.
Vandermeer, J.H., Goldberg, D.E., 2013. Population Ecology: First Principles, second ed. Princeton University Press, Princeton.
Vogel, J.C., 1989. Evidence of past climatic change in the Namib Desert. Palaeogeogr. Palaeoclimatol. Palaeoecol. 70, 355–366.
Vogel, J.C., Visser, E., 1981. Pretoria radiocarbon dates II. Radiocarbon 23 (1), 43–80.
Vogelsang, R., Eichhorn, B., 2011. Under the Mopane Tree: Holocene Settlement in Northern Namibia. Afrika Praehistorica 24, Köln. .
Wendt, W.E., 1972. Preliminary report on an archaeological research programme in South West Africa. Cimbebasia (B) 2, 1–61.