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Long-term ecological research from an arid, variable, drought-prone environment

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Abstract

Long-term ecological research (LTER) is invaluable for understanding environmental processes, particularly variability and drought, in arid countries and as support for effective natural resource management in the drylands. The Gobabeb Training and Research Centre undertakes various long-term monitoring focused on, inter alia, climate and the biophysical environment. Examples are given of the results of this LTER and how they could be used to serve social and environmental functions in the drylands.

Key words: arid zone, climate, drought, environmental monitoring, indicators, Namibia

Résumé

La recherche écologique à long terme dans un environnement aride, variable, enclin à la sécheresse

La recherche écologique à long terme (LTER) a une valeur inestimable pour la compréhension des processus environnementaux, particulièrement la variabilité et la sécheresse, dans les pays arides et comme soutien à la gestion efficace des ressources naturelles dans les terres sèches. Le centre de formation et de recherche Gobabeb entreprend diverses activités de surveillance à long terme focalisées, entre autres, sur le climat et l'environnement biophysique. Des exemples de résultats du LTER sont présentés et leur utilisation pour assurer des fonctions sociales et environnementales dans les terres sèches est discuté.

Mots clés : climat, indicateur, Namibie, sécheresse, surveillance environnementale, zone aride

The Gobabeb Training and Research Centre, situated in central Namibia, has set itself the goal of increasing understanding of this hyperarid environment, especially its variability, so that it can be applied to other variable environments to help reduce the latter's vulnerability to loss of sustainable livelihoods. One of the major means of increasing understanding is through long-term ecological research (LTER), continuous or periodic monitoring, combined with short-term studies of diverse environmental aspects. This contributes to understanding the effects of extreme hydrological variability and to potential appropriate application of this knowledge.

Understanding natural environmental variability, which includes frequent and often prolonged periods of drought, is important for environmental management [1]. Arid and semiarid regions, like those characterising much of Namibia, experience extreme temporal and spatial varia-

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tion of rainfall [2, 3]. In arid regions, brief episodic events interspersed with longer dry periods affect long-term processes [4]. In particular, heavy rainfall events cause dramatic responses [5, 6], have effects lasting for decades [7, 8], and are prominent ecosystem drivers. Furthermore, there is a high spatial variability of rainfall in the drylands [9]. Biotic responses to temporal and spatial variability may depend either on pulses and sources, *i.e.* irruption, or on tolerance of reserve and sink conditions, *i.e.* persistence during dry periods including drought. These responses influence and are influenced by management processes, and it is therefore important to understand natural variability in order to facilitate appropriate environmental management [1].

LTER enables recognition and understanding of natural variability patterns and changes in such patterns [10]. It provides context and increases the power of interpreting short, experimental or observational studies by integration with results of continuous or periodically repeated environmental monitoring. LTER covers time spans longer than funding cycles of projects, legislative periods of governments, and generations and lifetimes of people. It can thus provide researchers, resource managers, and policy-makers with data needed to detect, quantify, locate, understand, and respond to changes in terrestrial ecosystems to support sustainable development [11]. Seely [12] and Seely *et al.* [13] outline how the connection between science and development serves creative problem-solving in Namibia.

In this paper we describe examples of results from the LTER programme at Gobabeb. Forty-five years of research in the Namib (since 1962) have enabled the Gobabeb Training and Research Centre to gain knowledge on environmental processes under arid conditions [14]. Since Namibian Independence in 1990, this knowledge is being used throughout the country to further awareness and to promote capacity to appropriately manage the environment.

Study areas and general method

LTER of the Gobabeb Training and Research Centre (23°33′ S; 15°02′ E) *(figure 1)* encompasses sites in the central Namib Desert and transects ranging through the drylands of Namibia. Study sites in the Namib are located in the three major habitats characterising the central Namib: on the gravel plains, in the Kuiseb riverbed, and in the dunefield of the sand sea. The general climatic, geological, geomorphological and ecological conditions

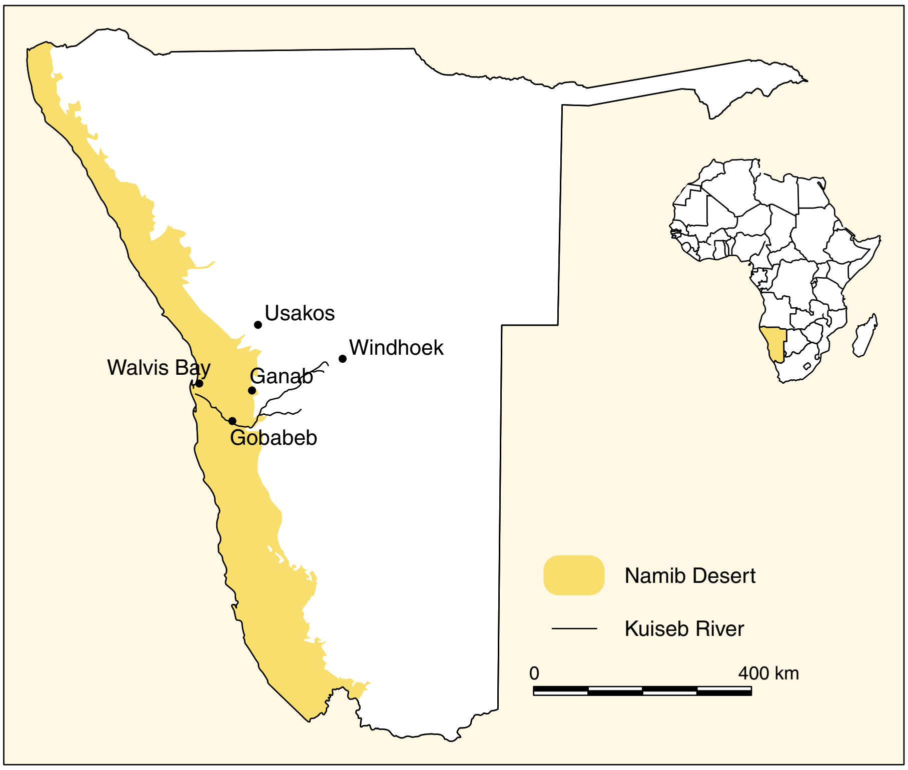

Figure 1. Map showing the Namib Desert, the Kuiseb River and Gobabeb, as well as the long-term rainfall sites (see *figure 2*).
These sites support a wide network of LTER observatories in western, central Namibia.

have been described, for example by, *inter alia*, Besler [15], Lancaster *et al.* [16], and Robinson and Seely [17]. Study sites are monitored at regular intervals, varying from daily to annually, or at intervals of several years.

The projects

Climate

Long-term weather data are fundamental to the understanding of a highly variable, arid environment such as the Namib. Gobabeb operates a network of autographic weather stations covering 10,000 km^2 with a main transect ranging from 10 km inland of the Atlantic coastline at an altitude of 40 m above mean sea level in the west, 300 km inland to an altitude of 1,800 m above mean sea level in the east. The amount of, and variability in, rainfall differs across the Namib *(figure 2)*, and this is very important for understanding the composition of biotic communities, the distribution of organisms and their life history patterns [6, 7, 18-21].

As an important climatic feature of the Namib, fog has been studied for over 60 years [16, 22, 23] using autographic recording stations, continuously measuring the water content of the air. In the last 10 years, this monitoring has been complemented by large fog harvesting nets (50 m^2), and more broadly-distributed standard fog collectors (1 m^2) with the aim of assessing the feasibility of collecting this water source for domestic use in the western Namib Desert [24]. LTER data series are invaluable for planning these applications.

Biophysical environment

Long-term research has covered, *inter alia*, dune movements, weathering, soils, ephemeral rivers, and the impact of off-road vehicles (ORV) [25]. Plant studies and long-term monitoring include the Welwitschia and the !Nara plants. *Welwitschia mirabilis* is a long-lived plant affected by long-term processes and it requires long-term study. It is a widespread endemic of the central and northern Namib [26] surviving many years of no rain. A monthly monitoring programme of the growth of *Welwitschias* was initiated in 1985, indicating that seasonal patterns are correlated with air humidity, while annual differences are affected by rainfall, or lack thereof, but not fog [27] *(figure 3)*. The ongoing study elucidates not only the growth rate, but also the reproductive output, seed dispersal, recruitment, water availability, age structure, ecological

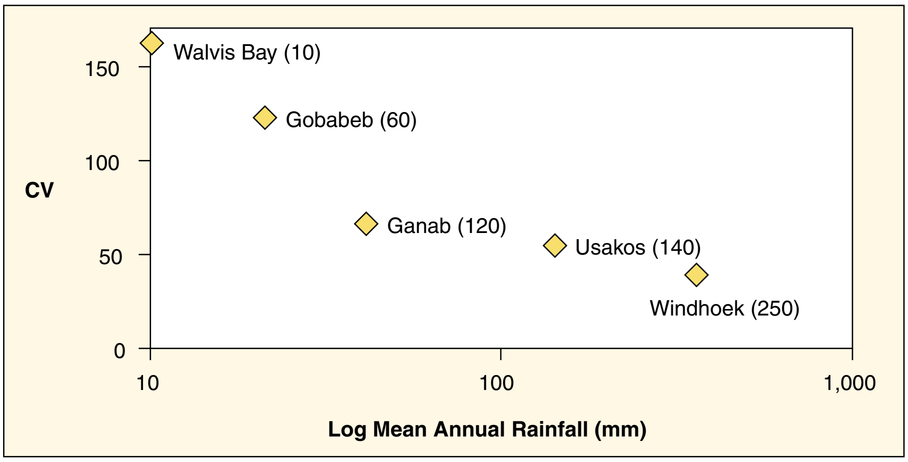

Figure 2. Coefficient of variation (CV) versus mean annual rainfall (mm) at five places across the Namib Desert and eastwards (see map).
As distance from the coast increases (km in brackets), so does the amount of rainfall while variation in rainfall decreases. Data are from Meteorological Services of Namibia (n=20–108 years) [14].

differences between the sexes, and long-term, life-history strategies.
Several separate short-term studies of !Nara – another long-lived plant, *Acanthosicyos horridus* -, conducted in the same study areas as those where the *Welwitschias* were monitored, have yielded a data series that allows long-term tracking of populations [28]. !Nara appears, from monthly observation and intermittent study, to be affected by various environmental factors, such as climate, groundwater availability, herbivory and fruit harvesting, while plant condition may affect numerous invertebrates and vertebrates that feed on or shelter in it. !Nara fruits are used by the local Topnaar people as food, fodder, for medical purposes, and as a cash crop under a unique form of tenure [29].
In the central Namib, grass is a major source of primary productivity and detritus, and forms the basis of a major food web. Here ephemeral grasses germinate and can complete their life cycle after a minimum rainfall event of 10-12 mm [19, 30, 31]; biomass increases with increasing rainfall. Since 1988, the annual distribution of ephemeral grass biomass has been monitored at specific GPS-referenced sites across the central Namib [30], and was found to be highly variable due to patchy rainfall [18, 32] *(figure 4)*.

Animals

• *Invertebrates and small vertebrates*

A major contribution to the long-term account of Namib Desert animal populations is an intensive pit-trapping programme. The repeated monitoring technique is being used, *inter alia*, for the lizard *Meroles anchietae* [33] and golden mole

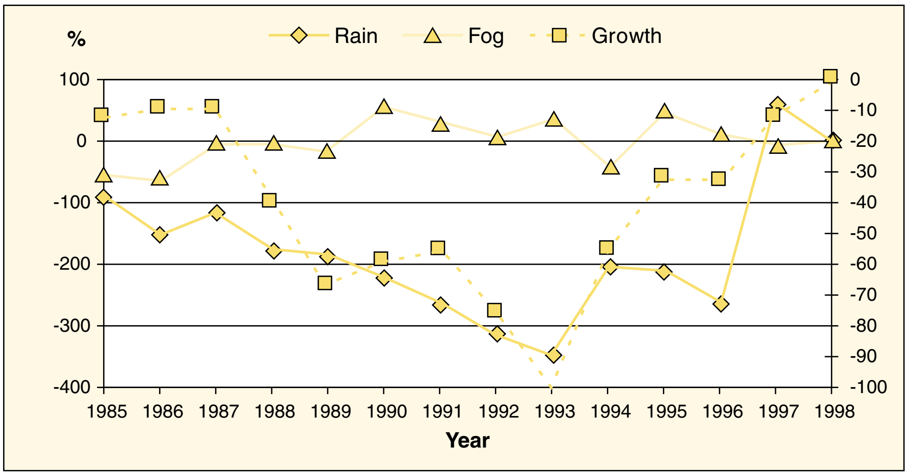

Figure 3. Cumulative percent deviation from the mean of rainfall, fog and of annual growth of *Welwitschia mirabilis*.
These data indicate the influence of rainfall on growth while fog makes no contribution [27].

Eremitalpa granti [34, 35]. Annual monitoring of three spider species since 1987 [36-39] is revealing how their populations relate to different aspects of the environment, namely food (mainly tenebrionids and ants) and substrate instability due, for example, to sand storms or trampling by ungulates. Long-term monitoring and modelling demonstrate how these factors affect clusters of spiders and how clusters develop, shift, and decline over generations [36-39].

• *Tenebrionid beetles*

Tenebrionids (Coleoptera) are good indicators of environmental conditions because their populations integrate multiple environmental factors - namely detritus, leaves, and dung, on which they feed -, vegetation cover under which they shelter, the hardness, moisture, and stability of the soil, and the availability of water from rain, fog, and runoff. Furthermore, tenebrionids are abundant, conspicuous, diverse, flightless, and easy to capture and identify. Taxonomic, ecological, behavioural, and ecophysiological studies have devoted much attention to Namib Tenebrionidae [25]. These factors make beetles excellent subjects for further in-depth research and for environmental education.
In an ongoing study initiated in 1968, we are investigating the long-term population dynamics and the species composition of tenebrionid beetles in six habitats near Gobabeb. Different population trends (*i.e.* population increasing or decreasing rapidly or slowly) characterise changes in species composition and diversity. The extraordinary high diversity of Namib tenebrionids (more than 200 species) has attracted much attention [40, 41]. Most of the 82 species found near Gobabeb are endemic to the Namib. We have found that abundance is highest in those habitats where detritus is richest (riverbed and slipface) while diversity is relatively high in the habitat where food resources fluctuates most strongly (gravel plains). The time series for various species at first appear to be chaotic (e.g. *figure 5*) and difficult to interpret [42], but some patterns emerge upon closer examination [43, 44]. Many of these patterns seem to be related to water availability or absence. Rainfall, fog, and river floods appear to be important for population growth of most (but not all) Namib tenebrionid species, but the species differ in the type of water source to which they respond, as well as the rate at which they respond *(figure 5)*, "response" being defined as an annual increase in population. Population decline after growth also differs between species [45]. These differences may explain the coexistence of so many species that use a common food source.

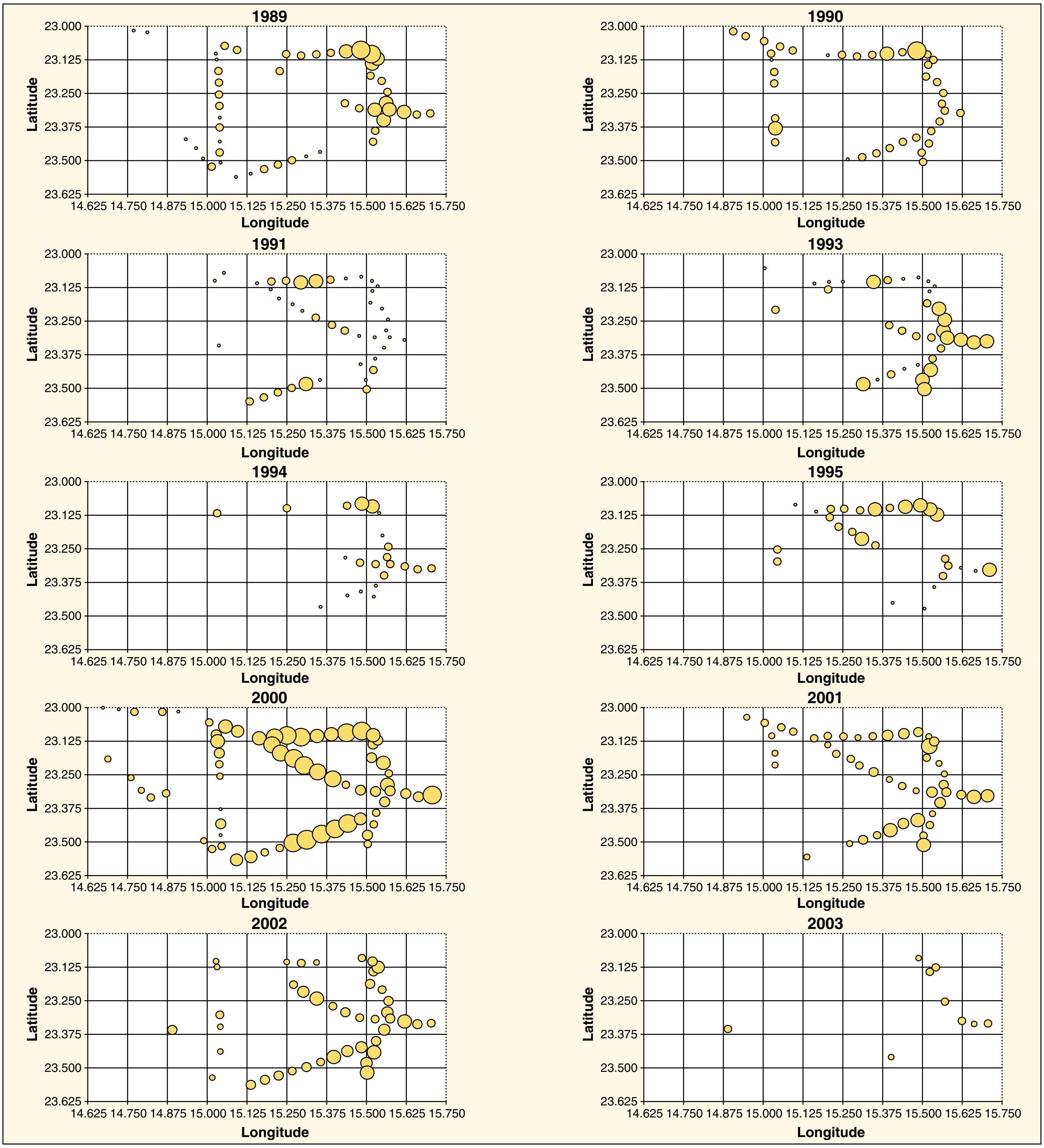

Figure 4. Grass biomass mapped on the gravel plains north of the Kuiseb River in the central Namib Desert (1989–2003).
Size of each point is scaled to biomass ranging from 1 to 30 g/m^2. The distribution of grass biomass varied across the study area and between years, depending on where rain had fallen (after [32]).

We have found that during the dry years between effective rainfalls (enough to enable plants to germinate and to produce seeds) at Gobabeb, Namib tenebrionid populations undergo substantial decline *(figure 5)*. Only few small areas appear to remain relatively rich in species and biomass. By placing pit traps in and next to these rich patches, we are gaining knowledge of their dynamics (for example, which factors affect their richness), and how these areas relate to other rich areas (meta-populations) and to poor areas between the rich patches. By examining the variety of population changes by

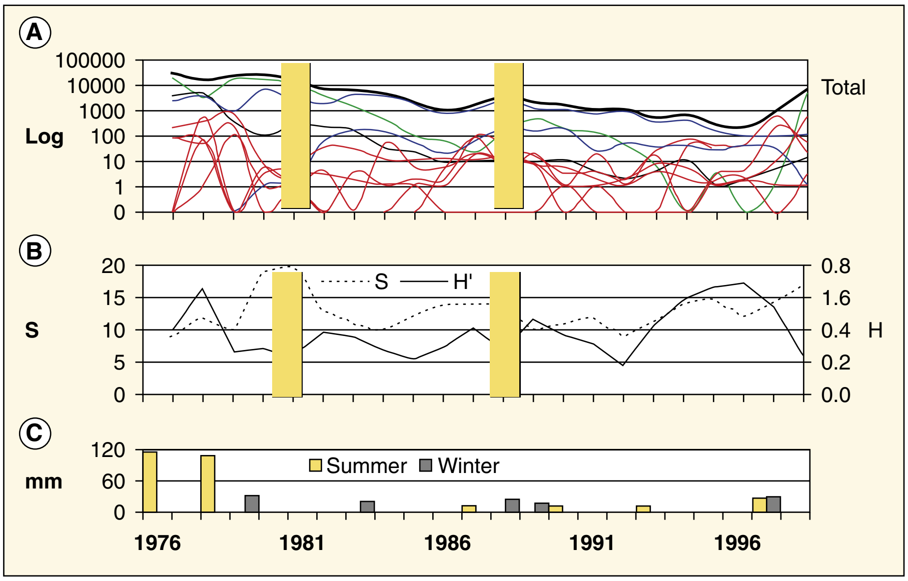

Figure 5. Data series at an interdune LTER site in the Namib dunes.

A) log abundance of the ten most common tenebrionid beetles; B) species richness S (left axis) and Shannon-Wiener diversity index H' (right axis) of all tenebrionid species in the habitat; C)) effective rainfall (>10 mm per week) during summer or winter (axis: mm rainfall).

Compare data from the shaded areas (two short periods within the long-term measurements when abundance and diversity data were very different) as examples of short-term studies within long-term trends [14].

different species in response to changes in different environmental factors, such as rainfall over long periods of time (30 years), we are gaining insights into underlying ecological processes. This, in turn, can improve our understanding of processes that affect biodiversity and can inform appropriate management approaches.

Using and applying LTER data

Many short-term research results, particularly those that feature aspects of biodiversity in arid environments, can be interpreted against the background of long-term aridity and drought trends. To this end, sharing of data is of fundamental importance. Indeed, because of their long-term nature, the data have proved to be useful in the compilation of wider scale, national [46, 47] and international studies [48]. The characterisation of natural variability through LTER is crucial for distinguishing apparent from real environmental changes [49-51]. Furthermore, LTER provides details of mechanisms underlying long-term changes identified, in archaeological studies [52-54] and palaeoclimatology [55, 56] and can contribute significantly to climate change studies. In this way, LTER effectively complements other research fields concerned with characterising environmental changes.

General discussion

The Gobabeb and other LTER sites described here are part of a larger network of LTER sites on arid lands where continuity and consistency in methods are required. However, LTER should be more than generating and interpreting data, and it must involve human communities. The Gobabeb LTER projects demonstrate that baseline information and understanding derived from an undisturbed, arid environment is useful to the interpretation of shorter-term data [3, 6, 47, 49, 54].

Biophysical and socio-economic LTER projects are extremely important for the Namibian environment. However, today it becomes more and more difficult to maintain long-term sites. There appear to be several reasons. First, the maintenance of long-term environmental research is costly; it also demands dedication. Second, the value of long-term data collection is often not fully recognised. This may partly be because LTER data and conclusions are sometimes not published appropriately and timely, nor made accessible. The current paper underlines the value of published LTER data for many social and environmental fields in Namibia.

The ultimate value depends on the alliance between basic and applied research that underlines the importance of both. Basic research is vital because it provides first-hand knowledge that can be translated and applied into relevant information to relevant target groups. Basic research often comes up with novel insights that were not initially predicted. It is the fruitful interaction between basic and applied research that increases the value of both. Well-tested conclusions and honed skills can be transferred from basic to applied research and *vice versa*, while applied questions form a guiding framework for basic research. LTER embraces both.

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