# VEGETATION SUCCESSION AND PLANT USE IN RELATION TO ENVIRONMENTAL CHANGES ALONG THE KUISEB RIVER IN THE NAMIB DESERT

Kazuharu MIZUNO
*Graduate School of Asian and African Area Studies, Kyoto University*
Kotaro YAMAGATA
*Division of Social Studies, Joetsu University of Education*

ABSTRACT The aim of this study was to clarify the relationship between environmental change and vegetational succession in the Kuiseb River area of the Namib Desert. The results reveal the following: 1. About 5000–7000 years ago, wetter conditions prevailed in the Kuiseb River basin, forming a wider riverbed than at present. 2. About 600 years ago, a low terrace formed. The low terrace was characterized by the growth of acacia trees and other vegetation, which trapped and accreted aeolian sand. 3. About 400 years ago, the trapped and accumulated sand began to form a sand dune, eventually killing the tree population. 4. At the present time, all of the buried acacia trees have died and have been replaced by salvadora bushes, which continue to trap sand and increase the size of the dune. 5. Plants such as *Acacia erioloba*, *Faidherbia albida*, and *Acanthosicyos horridus* are very important food sources and shade plants for the local Topnaar people and their livestock. The succession of vegetation in response to environmental change has a profound impact on life in the Kuiseb River area, owing to the harsh environmental conditions and scarce plant life in the region.

Key Words: Environmental change; Sand dune; Vegetation succession; Kuiseb River; Topnaar people.

## INTRODUCTION

Desertification has been identified as a major problem in Africa in recent years. Natural environmental changes and human activities have contributed to this desertification. For instance, population increase lead to the widespread destruction of vegetation and/or excessive pasturage. Irregular movement of the Intertropical Convergence Zone (ITCZ) causes droughts.

Environmental change is also a problem in Namibia. Average temperatures in Windhoek increased by about 0.0023°C per year from 1950 to 2000 (Ministry of Environment and Tourism, Republic of Namibia, 2002). Although the average annual precipitation recorded by meteorological stations in Namibia was 272 mm from 1915 to 1997, annual precipitation exceeded this rate in only two out of sixteen years from 1981 to 1996. Because rising temperatures increase evaporation rates, the region becomes progressively drier, even while experiencing steady rates of precipitation.

Most of the rivers in Namibia are seasonal in nature, flowing only after periods of intense rainfall. The only non-seasonal rivers in Namibia are the

Orange River in the south, and the Kunene, Kavango, Kwando-Linyanti-Chobe, and Zambezi rivers in the north. The Kuiseb River defines the border between the stony desert and the sand desert, and precipitation in the upper stream area ranges from 200 mm to less than 20 mm annually; in addition, most of this surface water is absorbed by the sandy river bed. The middle and lower areas of the Kuiseb River usually remain arid, except during occasional periods of flooding. The trees on the riverside of the Kuiseb River have partially died, for a variety of reasons. The objective of this paper was to clarify the relationship between desertification, vegetational succession, and human activity.

## STUDY AREAS AND METHODS

### I. Study Area

The Namib Desert borders the Atlantic Ocean on the west coast of Namibia. Although the age of the Namib Desert has long been a topic of controversy, most agree that the climate of the narrow coastal track between the southern Atlantic Ocean and the Great Western Escarpment has varied from arid to semi-arid for at least the last 80 million years (Seely, 1992). The annual precipitation in the Namib Desert is less than 50 mm. The average rainfall varies from less than 15 mm per year on the coast to about 100 mm per year in the eastern desert. The dominant southwesterly winds carry cool air from the Benguela Current inland, creating a cool inversion layer, i.e., a layer of cooler air underlying a warmer layer. This inversion layer minimizes turbulence in the atmosphere, impeding cloud development and rain formation (Seely, 1992).

This study was performed in the Gobabeb region of the Kuiseb River during August and November of 2001 and February of 2002 (Fig. 1, 2). Although the annual rainfall in Gobabeb is only 27 mm (Fig. 3), precipitation derived from fog is 31 mm (Fig. 4, 5) (Lancaster *et al*., 1984). The fog, which can travel tens of kilometers inland on many mornings, is densest at elevations of between

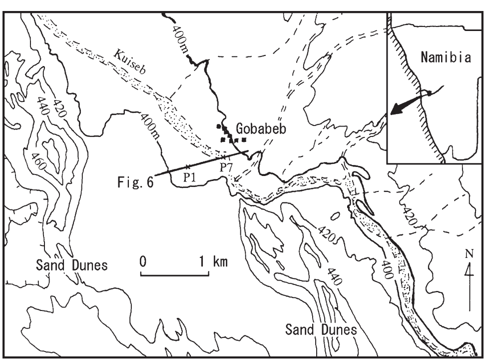


**Fig. 1.** Study area.
P1, P7: Soil profile (Fig. 14).

**Fig. 2.** Sand dune and the Kuiseb River near Gobabeb.

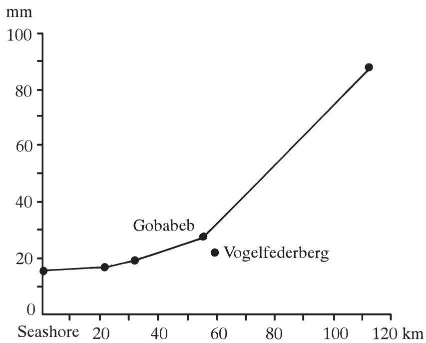


**Fig. 3.** Mean annual rainfall in the central Namib Desert plotted against distance from the coast (Lancaster *et al.*, 1984).

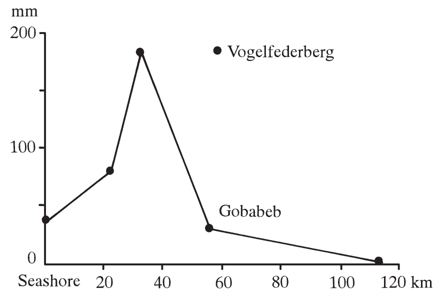


**Fig. 4.** Mean annual fog water precipitation in the central Namib Desert plotted against distance from the coast (Lancaster *et al.*, 1984).

**Fig. 5.** Fog in the morning at Gobabeb.

300 m and 600 m. Fog-water precipitation is greatest at about 40 km inland from the coast because of the gradual increase in altitude of the Namib Desert, from the coast to inland. Because fog-water condenses on inselbergs such as Vogelfederberg, the inselbergs can support plant life in the desert. The fog in Gobabeb formed and spread on an average of 37 days per year from 1976 to 1981. Fog is an important source of water for animals and plants in the Namib Desert (Lancaster *et al.*, 1984).

## II. Methods

A belt transect of 1000 m in length was taken across the Kuiseb River. The topographic profile was obtained by measuring along the transect. Vegetation and soil profiles were investigated along the transect. A pit of 1–2 m in depth was used for a soil survey and the soil profile was analyzed. The depth of the water table was measured in the well.

Soil water was measured in water content by volume using a Hydro-sense soil moisture meter made by Campbell Scientific Ltd. Radiocarbon ($^{14}C$) dating was measured by Beta Analytic Inc., in Florida. Samples 3 and 4 for dating were identified as *Acacia erioloba* and *Faidherbia albida* based on thorn morphology. Branch tips of dead trees were collected for dating samples, and were assumed to represent the site of most recent growth. Radiocarbon dates are shown as conventional $^{14}C$ ages.

## RESULTS AND DISCUSSION

### I. Environmental Change and Vegetational Succession

Figure 6 shows the topographic profile along the transect. Three terraces were classified, at altitudes of about 0 m, 2 m, and over 10 m from a base level (Fig. 6). The terrace at 0 m altitude is referred to as the low terrace; the middle terrace was at 2 m, and the high terrace was at over 10 m.

Calcretes formed on the middle terrace (Fig. 7). Calcretes are encrustations of salt where $CaCO_3$ has accumulated through the evaporation of soil water. These calcretes were dated to about 5300 ± 60 years BP and 6740 ± 50 years BP using $^{14}C$ dating (sample numbers 1, 2; Table 1). Because the calcretes are thought to have formed through the evaporation of water raised via capillary pressure from the shallow water table, the middle terrace covered by the calcrete was probably the riverbed 5000–7000 years ago. Rounded gravel is common on the land surface, and provides further evidence of the location of the former riverbed. In the period when the calcretes were made, the water table probably rose owing to much rain. In Africa, the warm period of the early Holocene (9000–8000 years ago) and the hot period of the middle Holocene (7000–5000 years ago) were both very wet periods during which much rain fell inland of the Sahara Desert. It is thought that the present desert was extensively covered by vegetation typical of a savanna or steppe, because of the rainfall at that time, and that many lakes, such as Lake Chad, extended into the desert (Kadomura, 1992). The period when middle terrace had the higher water table coincides with the wet time in the other area.

The water table underlying the forest of the low terrace is shallow, at a depth of about 13 m. The forest itself is mainly populated by tall trees such as *Faidherbia albida* (acacia), *Tamarix usuneoide*, and *Euclea pseudebenus*.

The sand dunes on the west side of the riverbed are located on the border between the low terrace and the middle terrace. Sand is carried by the southwest wind perpendicular to the river, and accumulates in the forest on the west side of the river. This process is probably the

**Fig. 7.** Calcrete ($CaCO_3$) in the middle terrace.

**Table 1.** $^{14}C$ dates of samples (conventional $^{14}C$ ages).

| Sample number | Material | $^{14}C$ data (yr BP) | $\delta\ ^{13}C$ (permil) | Laboratory code number (Beta-) |
|---|---|---|---|---|
| 1 | Carbonate | 5300±60 | –6.2 | 164939 |
| 2 | Carbonate | 6740±50 | –7.2 | 176921 |
| 3 | Wood | 300±60 | –23.8 | 165889 |
| 4 | Wood | 550±50 | –23.9 | 165888 |

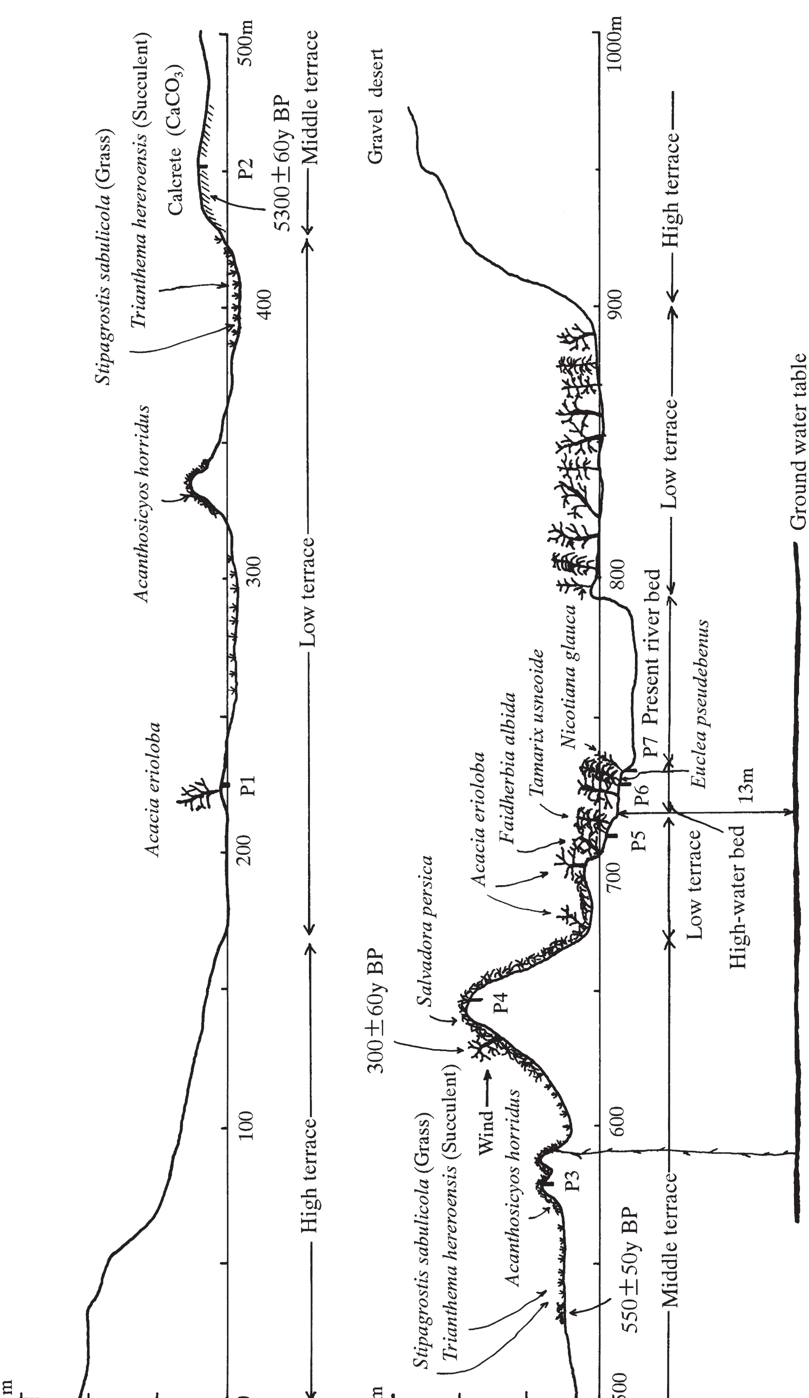


**Fig. 6.** Topographic profile and vegetation along transect (Fig.1). P1-P7: Soil profile (Fig.14).

mechanism responsible for the formation of the 10 meter high sand dune that is seen today (Fig. 8), based on the observed depth of tree burial in this area. The movement of the sand dune has been recorded as northern to northeastern, and the rate of movement ranges from 30 to 180 cm per year in Gobabeb (Ward & Brunn, 1985).

On November 29, 2002, a pole was erected on the edge of the sand dune to monitor the movement of the dune. On March 1, 2003, the pole was not buried at all and no sand dune movement was observed. By August 10, 2003, the pole was buried to a depth of 60 cm and the sand dune had advanced 100 cm horizontally. By November 30, 2003, the pole was buried to a depth of 70 cm and the sand dune had advanced 145 cm from its initial position. By August 5, 2004, the pole was buried to a depth of 130 cm and the sand dune had advanced 220 cm from its initial position. Therefore, it was concluded that the sand had advanced discontinuously, and that its rate of advance was 120–145 cm/year (November 2002–August 2004).

Acacia trees (*Acacia erioloba*, *Faidherbia* (*Acacia*) *albida*) on the middle terrace are buried in the sand (Figs. 6 & 9). Radiocarbon dating ($^{14}C$) of one buried acacia tree established an age of death at about 300 ± 60 years BP (sample 3, Table 1). Therefore, it is considered that the low terrace has been formed 500–600 years ago and formation of the sand dune may have begun approxi-

**Fig. 8.** Flying sand captured by trees along the Kuiseb River and acacia trees covered with sand.

**Fig. 9.** Growth of the sand dune and dead acacia trees.

**Fig. 10.** *Salvadora persica* covering the sand dune.

**Fig. 11.** Soil profile of plot covered by *Salvadora persica.*

mately 400 years ago. Although the exact cause of death remains unclear, it is likely that the oxygen supply to the roots decreased, and the nutritional resources in the soil became depleted. These points will be examined further in a later discussion.

In sand dunes covered by salvadora bushes (*Salvadora persica*), the trunks of salvadora bushes extend deep into the ground (Figs. 10 & 11). The bushes capture the moving sand and this contributes to the expansion of the sand dune.

The most important plant for the people of the Kuiseb River is !nara (*Acanthosicyos horridus*) (The symbol ! denotes clicks in the Nama language.). The low and middle terraces of the study area are dotted with !nara bushes of 1 m to 3 m in height (Fig. 12). The roots of the !nara plant sometimes extend more than 15 m underground, which is the approximate depth of the water table in this region, in order to reach the water supply.

Based on the soil profile, it seems that the !nara plant extends its trunk upward to escape the smothering sand (Fig. 13). Although the low and middle terraces are covered with !nara, the high terrace and sand dune are not, perhaps owing to the varying availability of groundwater. The sand dune currently dominated by salvadora growth is thought to have previously supported !nara growth but, because the groundwater supply became unreachable for the !nara plant, this population has declined.

Although two similar mounds are located on the middle terrace, one is covered with !nara and the other is characterized by fragments of carbonizing acacia trees. Acacia trees are thought to have been distributed extensively during the wet period when the middle terrace was the high-water bed of the river, but they did not survive the dry period after it. Radiocarbon dating ($^{14}C$) sets the date of this die-off period at about $550 \pm 50$ years BP (sample 4, Table 1). It is possible that acacia trees were still widely distributed as recently as about

**Fig. 12.** !Nara bush (*Acanthosicyos horridus*).

**Fig. 13.** Soil profile of plot covered by !nara (*Acanthosicyos horridus*).

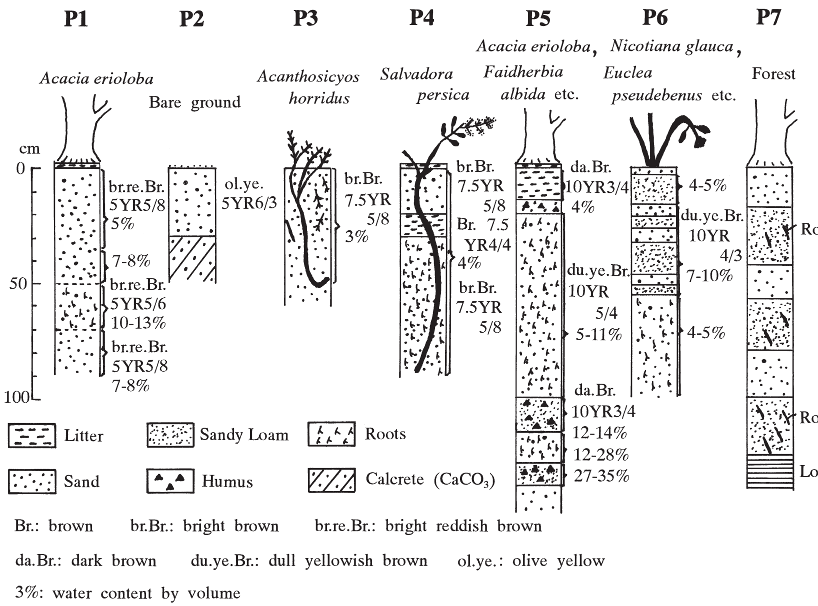


**Fig. 14.** Soil profile of plots shown in Fig. 6.
5YR5/8: Soil color.

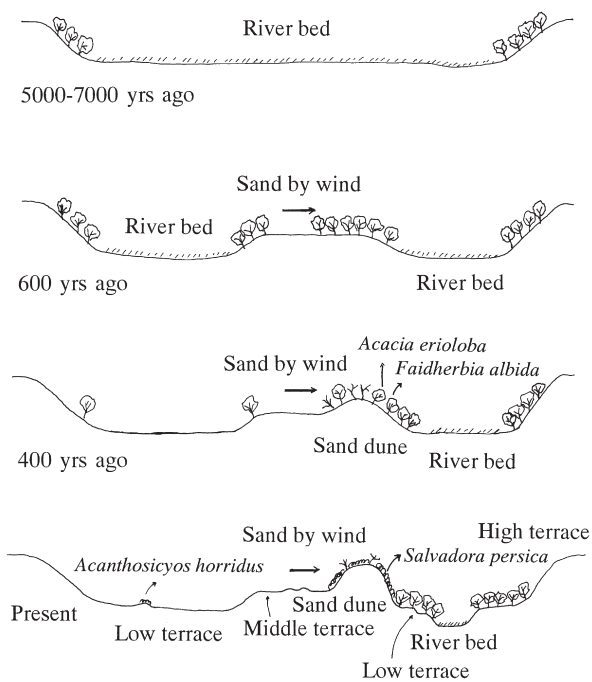


**Fig. 15.** Environmental change and vegetational succession in the study area.

600 years ago.

The low terrace is characterized by either bare land or grasses such as *Stipagrostis sabulicola* and the succulent dwarf tree *Trianthema hereroensis*. *Stipagrostis sabulicola* has a root system that can reach from 1 to 10 cm in depth and 20 m in width; it absorbs fogwater efficiently. *Trianthema hereroensis* absorbs fog-water directly through the leaves and stems (Seely *et al*., 1998).

The sandy soil that supports both !nara (P3) and salvadora (P4) has a water content by volume of only about 3 to 4% (Fig. 14). The scarcity of soil water content is another factor that encourages the roots of !nara to reach 15 m or more in depth.

Salvadora can absorb a great deal of water through its densely packed fine roots that range in length from 20 cm to more than 1 m. Although the litter 10 cm in thickness occur at depths of between 20 and 30 cm, this may record a time when sand movement was more moderate than at present. Recently, the rate of sand movement appears to have increased.

The sandy soil in the acacia-dominated forest on the low terrace (P5) has a water content by volume of 4 to 10% up to a depth of 100 cm. In depths of 100 cm to 150 cm, the sandy loam soil mixed with humus has a 12 to 35% water content by volume. Similarly, the soil from 50 cm to 70 cm depths of P1 has a water content of 10–13% by volume. The forest soil with diverse vegetation populations (P7) has deeper, finer roots. The soil of the high-water bed, which overlies trees such as *Nicotiana* and *Euclea* (P6) has similarly deep, fine roots.

The above-mentioned phenomena is summarized as Figure 15:

1. From 5000 to 7000 years ago, relatively wet conditions led to the formation of a wider riverbed than that of the present.
2. About 600 years ago, the low terrace formed. The low terrace was characterized by the growth of acacia trees and others, which trapped and accreted sand.
3. About 400 years ago, the sand dune began to form from trapped and accumulated sand, eventually killing the tree population.
4. At the present time, all acacia trees in the sand dune have died and have been replaced by salvadora bushes, which continue to trap sand and increase the size of the dune. The low terrace near the present riverbed is covered by a forest of *Acacia erioloba*, *Faidherbia* (*Acacia*) *albida*, and *Tamarix usuneoide*. The high-water bed along the riverbed is occupied by *Euclea pseudebenus* and *Nicotiana glauca*. The low terrace far from the riverbed is bare ground, dotted with some grass. !Nara partially grows on the low and middle terraces far from the riverbed.

## II. Significance of Vegetation for People Living near the Kuiseb River

The pastoral Topnaar people are part of the Nama people of Khoi Khoi in Khoisan, and live along the Kuiseb River. The most important source of food for the Topnaar is !nara, or *Acanthoicyos horridu*s. An alternative name for the

Topnaar is *!naranin,* and is derived from the word !nara, illustrating the centrality of this plant to the culture (Dentlinger, 1977; Van den Eynden *et al*., 1992).

!Nara fruits are eaten fresh and are almost the only food available during the harvest season (Ito, 2003). The fleshy portion of the ripe fruit is boiled in a drum and mixed with mealie meal to make a sweet porridge (Wyk & Gericke, 2000).

Like the watermelon, which originated in the Kalahari Desert, !nara thrives in an arid climate, accessing deep groundwater and retaining water in the fruit of the plant. !Nara seeds are sold for food or oil in the city, and are an important source of income for the Topnaar people (Ito, 2003).

!Nara grows widely in the !nara fields near the lower reaches of the Kuiseb River. Although the Topnaar people harvest wild !nara from December to March and rely on !nara as their most important source of food and income, the amount of !nara grown in this area has dramatically declined in recent years because of a lack of flood water, following a construction of a dam. Flood water is considered to be vital to the regeneration and survival of !nara.

*Acacia erioloba* (camel thorn) is a tall tree that grows in the driest regions of the Kuiseb River, and is one of the most important sources of firewood in southern Africa. An infusion of camel thorn gum is taken for coughs, colds, and tuberculosis, and a bark decoction is taken for diarrhea. A root decoction is taken for coughs and nosebleeds (Wyk & Gericke, 2000). In times of famine, the Topnaar people eat the pulp of the pods. The roasted seeds are sometimes used as a coffee substitute (Van den Eynden *et al*., 1992). One of the greatest benefits offered by the camel thorn is the shade and shelter it provides in the

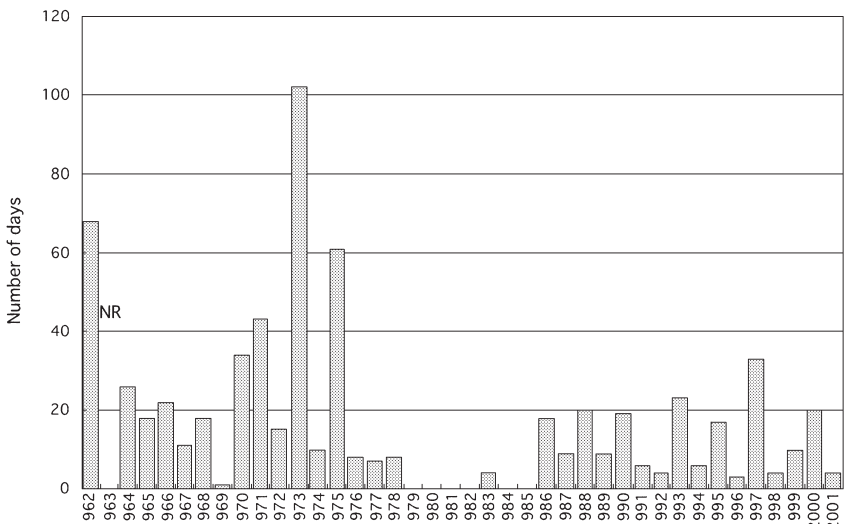


**Fig. 16.** Summary of Kuiseb River flooding at Gobabeb, 1962–2001.
1962–1984: Seely *et al.*, 1981; Ward & Brunn, 1985. 1985–2001: from data of the Desert Research Foundation of Namibia.

desert for humans and livestock (Craven & Marais, 1986). In addition, *Acacia erioloba* is an important tree for the Topnaar people because their goats eat the pods and leaves.

Goats also use the tree *Faidherbia albida* as a food source. In contrast to other trees, *Faidherbia albida* sheds its leaves at the onset of the rainy season and remains leafless until the beginning of the dry season (Craven & Marais, 1986). Thus, its leaves and pods become the most important food source for goats during a season of short supply.

Although flooding of the Kuiseb River has been recorded in Gobabeb every year from 1962 to 2001 (Seely *et al*., 1981; Ward & Brunn, 1985; data of the Desert Research Foundation of Namibia), very little water flowed during the summers of 1979 to 1985 because of dryer conditions (Fig. 16). If aridity continues to increase, the tree population will suffer, and so will the people.

## CONCLUSIONS

Environmental changes along the Kuiseb River, including changes in topography, vegetation, and soil, vary according to climatic fluctuations. It is vital, for the survival of the Topnaar people, that we better understand the relationship between environmental change and human activity.

The Topnaar people use the native vegetation in different ways. Because vegetation is very sparse along the Kuiseb River, it is very precious. Acacia trees have been buried and died, owing to expansion of sand dunes; they have been replaced by salvadora bushes capable of adapting to the changing conditions. !Nara has also disappeared as a result of environmental change. People's lives have been greatly affected by these changes in vegetation.

A slight change in temperature has strongly influenced the distribution of vegetation in the severely cold climate of the African high mountains (Mizuno, 1998, 1999, 2000, 2001, 2005; Mizuno & Nakamura, 1999). Similarly, in the severely dry environments of the desert, a slight change in precipitation produces a striking change in vegetation. The chain reaction of environmental change becomes a positive feedback loop, and the effects continue to increase. It is vital, therefore, that we investigate and understand the dynamic relationship between environment and vegetation, not only for the Topnaar people, but for all people.

ACKNOWLEDGMENTS This study was financially supported, in part, by a Grant-in-Aid for Scientific Research (Project No. 13371013 headed by Dr. Kazuharu Mizuno, Kyoto University) from the Ministry of Education, Science, Sports, Culture and Technology of Japan. I thank Dr. Joh Henschel and Ms. Inge Henschel of the Desert Research Foundation of Namibia for their support of the field survey.

REFERENCES

Craven, P. & C. Marais 1986. *Namib Flora*. Gamsberg Macmillan, Windhoek.
Dentlinger, U. 1977. An ethnobotanical study of the !Nara plant among the Topnaar Hottentots of Namibia. *Munger Africana Library Notes*, 38: 3-37.
Ito, M. 2003. The change of !nara vegetation and its influence on the people in the lower stream of the Kuiseb River, Namib Desert (in Japanese). *Proceedings of the 40th Annual Meeting of the Japanese Association for African Studies*, 90.
Kadomura, H. 1992. Changing ecotone of Sahel (in Japanese). In (H. Kadomura & M.Katsumata, *eds*.) *Sahara*, pp. 46-78. Toto Press, Tokyo.
Lancaster, J., N. Lancaster & M.K. Seely 1984. Climate of the central Namib Desert. *Madoqua*, 14: 5-61.
Ministry of Environment and Tourism, Republic of Namibia 2002. *NAMIBIA International Communication to the United Nations Framework Convention on Climate Change*. Ministry of Environment and Tourism, Windhoek, Republic of Namibia.
Mizuno, K. 1998. Succession processes of alpine vegetation in response to glacial fluctuations of Tyndall Glacier, Mt. Kenya, Kenya. *Arctic and Alpine Research*, 30: 340-348.
——— 1999. *Science of Alpine Plants and Fields* (in Japanese). Kokonshoin, Tokyo.
——— 2000. Environmental factors controlling vegetational distribution of tropical high mountains (in Japanese). In (G. Kudo, *ed*.) *Natural history of alpine plants*, pp. 99-114. Hokkaido University Press, Sapporo.
——— 2001. How do plants climb mountains as a result of global warming? (in Japanese). In (K. Mizuno, *ed*.) *Vegetation Environments*, pp. 58-70, Kokonshoin, Tokyo.
——— 2002. Nature of the Namib Desert (in Japanese). *Monthly Report of Geography*, 470: 4-5.
——— 2005. Glacial fluctuation and vegetation succession on Tyndall Glacier, Mt. Kenya. *Mountain Research and Development*, 25: 68-75.
Mizuno, K. & T. Nakamura 1999. Succession of alpine vegetation in relation to environmental changes around the Tyndall Glacier on Mt. Kenya —Discovery of a leopard's remains from the Tyndall Glacier in 1997— (in Japanese with English abstract). *Journal of Geography*, 108: 18-30.
Seely, M. 1992. *The Namib, 2nd Edition*. Shell Namibia, Windhoek.
Seely, M., W. Buskirk, W. Hamilton & J. Dixon 1981. Lower Kuiseb River perennial vegetation survey. *SWA Scientific Society*, 35: 57-86.
Seely, M., J. Henschel & M. Robertson 1998. The Ecology of Fog in Namib Desert Dunes. *Proceedings of the 1st Conference of Fog & Fog Collects*, 183-186. International Development Research Center.
Van den Eynden, V., P. Vernemmen & P. Van Damme 1992. *The Ethnobotany of the Topnaar*. Universitet Gent, Belgium.
Ward, J.D. & V. Brunn 1985. Sand Dynamics along the Lower Kuiseb River. In (B.J. Huntley, *ed*.) *The Kuiseb Environment: the Development of a Monitoring Baseline*. Pretoria: Council for Scientific and Industrial Research, 51-72.
Wyk, B.E. & N. Gericke 2000. *People's Plants*. Briza Publication, Pretoria.

——— Accepted *Janualy 22, 2005*

Author's Name and Address: Kazuharu MIZUNO, *Graduate School of Asian and African Area Studies, Kyoto University, 46 Yoshida-shimoadachi-cho, Sakyo-ku, Kyoto 606-8501, JAPAN*
*E-mail: mizuno@jambo.africa.kyoto-u.ac.jp*