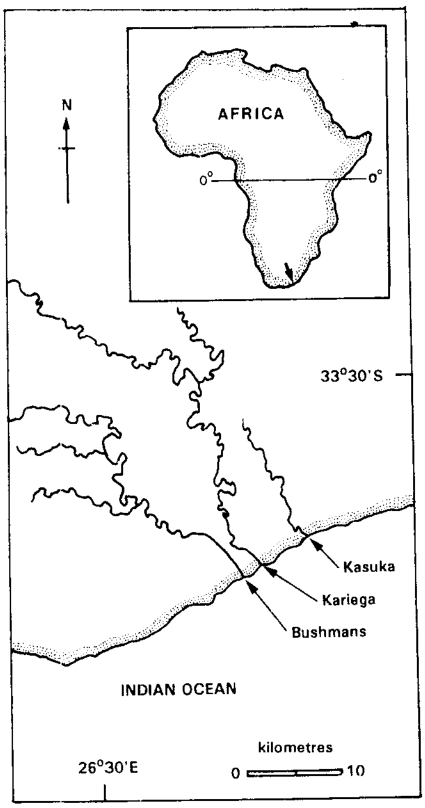

Fig. 2. Map showing the locality of the Bushmans, Kariega and Kasuka estuaries.

S. watermeyeri has already been mentioned, and is linked to the sublethal effects of freshwater deprivation on prey organisms in the Kariega and Bushmans estuaries which, in turn, increased the vulnerability of the river pipefish to natural environmental pressures.

Why did *S. acus* survive and *S. watermeyeri* become extinct? The survival of *S. acus* in the Bushmans and Kariega systems can be attributed to the fact that this species has a wide geographical distribution and is not limited to estuarine environments.[2] Consequently, recolonization by marine stocks is possible should estuarine *S. acus* populations become depleted. Although competition with *S. acus* under conditions of limited food availability may have contributed to the extinction of *S. watermeyeri*, the two pipefish species had co-existed in Eastern Cape estuaries for thousands of years prior to negative anthropogenic influences on these systems. From the available evidence, it would appear that *S. watermeyeri* was more stenotopic than *S. acus*. According to Bruton,[11] narrowly endemic, stenotopic species are especially vulnerable to extinction, possibly as a consequence of the loss of genetic variability. In addition, the river pipefish is a live bearer and evidence suggests that more specialized breeding guilds of fishes are more susceptible to extinction.[11]

The apparently irreversible loss of *S. watermeyeri* seems to be a consequence of the lack of holistic management policies for the river catchments of the Eastern Cape Province. The same is true for South Africa as a whole, despite frequent appeals for such management from the scientific community.[12] In this context the Department of Water Affairs and Forestry has reacted positively in the last decade to the freshwater requirements of both rivers and estuaries affected by new impoundments. However, the damage caused by past water allocation policies is difficult to rectify and it would appear that the river pipefish is already a casualty of the old Water Act.[13] The loss of *S. watermeyeri* is yet another event to trigger the 'environmental alarm bells' for all to hear. It is imperative therefore that adequate catchment management procedures, including freshwater allocations to estuaries where instream flow requirements have not been conducted, be implemented as soon as possible.

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Can savannas help balance the South African greenhouse gas budget?

R.J. Scholes and C.L. Bailey

In recent years considerable attention has been focused on the problem of potential changes to the world's climate resulting from anthropogenic emissions of carbon dioxide (CO_2) and other greenhous gases.[1] South Africa is a significant CO_2 emitter, especially on a per capita or per unit GDP basis.[2] This is unlikely to change in the near future, as the country is economically committed to an energy infrastructure based on coal, which produces large quantities of greenhouse gases per unit of energy derived. Furthermore, as South Africa develops, it is likely that the per capita energy use will grow, rather than decline. This country would therefore be particularly vulnerable if emission limits or penalties are adopted by the Framework Convention on Climate Change. Is there a way out of this dilemma?

The greenhouse gas budget for a country is based on net emissions. In other words, CO_2 uptake by vegetation may be balanced against our fossil fuel emissions. For instance, local plantation forests take up about 4% of the CO_2 emitted in South Africa.[3] There are climatic and environmental limits to the area of forest that can be planted in this country. Savanna ecosystems are probably the only vegetation type in the region with the potential to sequester carbon on a sufficiently large scale to make a real difference. Savannas cover 35% of the land surface in South Africa.[4] The Karoo is extensive but receives too little rain to sustain much biomass. The grasslands are largely cultivated and are thus net sources of carbon, rather than sinks.

The annual carbon assimilation by a tropical savanna is around 400 g carbon per square metre. If this increases by 15%, a medium value for plants under doubled CO_2, the extra assimilation of carbon by South African savannas would be 88 million tons of CO_2 — about a quarter of the annual fossil fuel emissions. The key questions are: to what degree is primary production in savannas enhanced by elevated atmospheric levels of CO_2; and what happens to the CO_2 taken up this way? The South African Greenhouse Experiment on Savannas (SAGES), a study initiated by the CSIR's Division of Forest Science and Technology (Forestek), aims to answer these questions.

The study focuses on the direct effects of increased levels of greenhouse gases on plants, rather than their indirect effects via climate changes. Carbon dioxide is the substrate for photosynthesis; an increased atmospheric concentration of the gas generally increases the rate of photosynthesis and hence productivity. This has been referred to as the 'CO_2 fertilization effect',[5] and is stronger in plants with a C_3 photosynthetic system (such as in trees) than C_4 plants such as tropical grasses. Under elevated CO_2 conditions, trees may grow larger and faster, increasing the storage of carbon in the ecosystem.

Elevated CO_2 levels have been widely shown to improve the efficiency with which plants use water.[6] Since plants are able to reduce the number and size of their stomata while still taking in sufficient CO_2, the molecules of carbon fixed per unit of water lost increases. Improvements in water use efficiency may lead to more water in rivers, helping to counterbalance the predicted[7] hotter, drier climate.

In contrast to these potentially beneficial effects of elevated CO_2, there may also be some detrimental impacts. The nutrient content and palatability of the plants may decrease. This effect would be more likely in nutrient-poor areas where the carbon assimilation rate may exceed the nutrient uptake. This could have two consequences: 1) a 'nutrient dilution effect', since the ratio of nutrients to carbon in the plants would decrease, resulting in a lower plant nutritional status with respect to grazers; 2) it may promote the production of secondary plant metabolites which further reduce the palatability of the plants.

The difference in the way trees and grasses are affected by elevated CO_2 conditions may lead to the trees having a competitive advantage over the grasses. This could result in a change in vegetation structure in certain ecosystems such as savannas, which are mixed tree–grass ecosystems. The biomass of trees may increase to the detriment of grass productivity, exacerbating the bush encroachment already prevalent in savanna regions. This change in vegetation structure would affect the grazing potential of the areas for farmers, and may have a negative impact on the biodiversity.

While studies of the short-term responses of high levels of CO_2 on individual species have been conducted in many parts of the world, the effects on multi-species communities in realistic growing conditions have not been widely studied, owing to the technical challenges involved. The few studies which have been completed show that it is not possible to make ecosystem-level predictions on the basis of plant-level measurements. An individual plant's positive response to elevated CO_2 does not necessarily translate into increased growth for an entire plant community, nor does increased growth necessarily mean increased carbon storage. Nor is it possible to transfer results directly from temperate to tropical ecosystems because of the very different climatic and edaphic factors which control their functioning. The only option is to conduct experiments with elevated CO_2, where possible, at an ecosystem scale and in the appropriate environment. A limited number of such experiments have been performed on tropical plants and ecosystems. None has been completed in South Africa, although some work has been done on individual species. At this stage models are being used to predict impacts at the ecosystem level using results obtained by studies on individual species. This cannot be done with any confidence owing to insufficient knowledge about the processes involved.[8]

The SAGES study, which began in November 1995, was designed to fill this need. A greenhouse facility with 20 controlled atmosphere and temperature chambers, each 3 m × 3 m × 4 m high has been constructed. Inside sixteen chambers, a model savanna ecosystem has been established, consisting of three tree, two grass and one forb species. The species have been selected to be representative of different plant functional types. The experimental design involves eight levels of CO_2, ranging from 360 ppm (present atmospheric concentration) to 900 ppm (which is predicted for the end of the next century if no measures are taken to decrease emissions), and two levels of nutrient supply. The watering regime mimics that of selected rainfall years in a typical South African savanna region. The soil in the chambers is an infertile sand 1 m deep, carefully repacked by horizon.

Due to the complexity of the study, a number of organizations are involved in the project. The CSIR's Division of Forest Science and Technology is addressing the issue at the ecosystem and plant levels, while the Institute for Soil, Climate and Water, the Range and Forage Institute, the National Botanical Institute, University of the Witwatersrand and Potchefstroom University are involved at the plant and organ level. The experiment will run for three years, at which stage it will be decided whether to continue or use the facility for other experiments.

The results of this study will not only be relevant to South Africa's carbon budget, but will also have international significance in terms of the quantification of the contribution of these ecosystems to the consumption or production of global atmospheric CO_2. SAGES has therefore been recognized as a core project of the Global Change in Terrestrial Ecosystems section of the International Geosphere-Biosphere Programme.

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