treatment of *Chromolaena* does create bare ground, rehabilitation by planting grasses or indigenous trees would seem essential for effective control. Alternatively, sites with seedlings of indigenous trees or an understorey of indigenous herbs may be selected to increase the efficacy of treatment.

This study shows that the efficacy of treatment, although applied under optimal conditions in the research area, appears to be low. Modifying the treatment protocol suggested by this work will not result in local pest eradication either. Further, given the favourable conditions for control in this research area, it seems unlikely that the chemical, mechanical or combined control treatment of the plant pest would result in eradication anywhere else in the world. We therefore suggest that seeding and introducing cover plants after removal of *Chromolaena* should be tested for their ability to control the latter.

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Will water abstraction from the Table Mountain Aquifer threaten endemic species? A case study at Cape Point, Cape Town

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THE PRINCIPAL SOURCE OF CAPE TOWN'S future water needs is the Table Mountain Group aquifer. The floral characteristics of the region overlying this aquifer are unique with five endemic and one near-endemic families. Many of these endemics are restricted to areas such as wetlands and marshes that are supplied by aquifer water, making them vulnerable to groundwater abstraction. Here we report the results of a study undertaken at two sites in the Cape Point Nature Reserve using stable hydrogen isotopes to determine the water source of plants to establish dependence on a permanent water supply. The results from the Suurdam site suggest that *Erica labialis* has a more diverse rooting strategy than *Erica multumbellifera,* with two plants sourcing water close to the surface, whereas others extract water much deeper down. The results from the Anvil Hill site, however, suggest that the rare *Mimetes hirtus* uses water very close to the surface that has undergone extensive isotopic fractionation. These results indicate that this species is shallow-rooted and dependent on surface soil water for survival. As such, it would be vulnerable to an even slight lowering of the water table during the dry summer months, when the surface soil water would be replenished mainly from the permanently saturated zone of the wetland. These results have implications for other endemic plant families with the same water requirements.

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The population of the Western Cape has grown at approximately 2.7% annually between 1996 and 2001, increasing from 4 million to over 4.5 million people.[1] More than three million people currently live in the Cape Town Metropolitan Area and this rapid population growth is placing an enormous demand on already strained water resources. In the past, extra need for water was met by the construction of new dams and increased abstraction from rivers. Because the Western Cape has so few large rivers, however, it is running out of suitable new dam sites. The main source of Cape Town's future water is the Table Mountain Group (TMG) Aquifer System, a vast secondary rock (fractured) aquifer that extends from just north of Niewoudville, southwards to Cape Agulhas and stretches as far east as Port Elizabeth. An area has been selected that ranges from Kogelberg to Tulbagh, with the aim of establishing a pilot well field that, within the next three years, will deliver five million cubic metres per year.[2]

Coincidentally, one of the five principal biomes of South Africa, the Cape Floral Region, roughly overlies the TMG Aquifer System. The region boasts an estimated 9000 vascular plants, of which a remarkable 69% are endemic.[3] The floral characteristics of the Cape Region are so unusual that it has often been considered one of the world's six floral kingdoms.[3,4] The endemic families are Penaeaceae, Stilbaceae (including Retziaceae), Grubbiaceae, Roridulaceae, and Geissolomataceae. All of these families are taxonomically isolated, contributing relatively few genera and species to the flora, and are best described as palaeoendemics.[5] These families are almost without exception evergreen, sclerophyllous shrubs. They are thought to be relicts of an ancient temperate southern African flora, when considerably wetter and cooler conditions prevailed. Consequently, many of these species are restricted to areas on shady southern slopes that are permanently wet, such as wetlands, seeps or marshes.

Areas that remain permanently moist or wet throughout the dry season are most likely to be maintained by groundwater. If groundwater is abstracted on a large scale, the effects could include the drying out of groundwater-fed systems, such as wetlands, marshes and seeps, not only in the immediate vicinity of the abstraction but possibly also more distantly. Species restricted to groundwater-fed areas may therefore be particularly vulnerable to groundwater abstraction. Although it is likely that only a small area will be so affected, the loss of biodiversity is potentially great if wetlands are of disproportionate importance as a habitat to endemic species. Thus it is of critical importance to establish the degree of dependence of certain plant species and communities on groundwater prior to any abstraction. We have recently started a project to determine the ecological and environmental impacts of large-scale groundwater development in the TMG Aquifer System. One aspect of this project is to use stable water isotopes which may prove to be a useful tool to establish the dependence of vegetation on groundwater. Here we report the results of a pilot study using stable hydrogen isotopes to determine the water source of plants growing on and off wetlands.

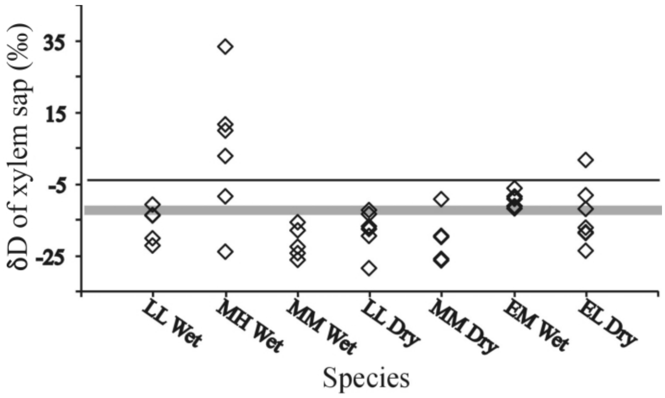

Fig. 1. The δD values of xylem sap of the five species studied. Also shown are stable hydrogen isotope values for April rainfall and range in values for five groundwater samples (indicated by the solid line and grey bar, respectively). Key to species: *Leucadendron laureolum* (LL), *Metalasia muricata* (MM), *Erica labialis* (EL), *Erica multumbellifera* (EM) and *Mimetes hirtus* (MH) growing on wet and dry sites.

Methods

Our primary hypothesis is that within the fynbos several plant species are reliant on water from the permanently saturated zone for survival. In many cases rare endemics are found in locations where groundwater is close to the surface. One such species, *Mimetes hirtus,* grows in the Cape Point Nature Reserve (34°18′S, 18°25′E) near Cape Town. This study attempted to determine the extent to which the species relies on a permanent water source fed from a deep aquifer. There are two components to the study; the first is to determine the hydrogen isotope ratio of the aquifer water at the study site, and the second is to relate that to the isotopic ratio of the water extracted from plants growing in the area.

Previous ecological work emphasized the usefulness of hydrogen and oxygen isotopes in understanding the dynamics of water in atmospheric and geochemical studies.[6,7] Recent research has shown that the hydrogen and oxygen content of both source and xylem water can be used to determine the water source of trees.[8] Within the roots and trunk and within a few centimetres of the leaves, trees do not fractionate the oxygen or hydrogen isotope during uptake due to transpiration.[9] Hydrogen and oxygen isotope analysis of water extracted from the plant should therefore reflect the water sources used by the plant. Surface soil water is isotopically enriched in the heavier isotopes of deuterium (D) and oxygen (^{18}O) because of fractionation due to evaporation. The deeper the source of the water, the more negative the isotope value is; those plants sourcing water at the surface will reflect a more positive isotope signature than those taking deeper water.[10] Moreover, water collected just below the surface in a marsh site will have stable isotope values more positive than water collected deeper down.

For our study we sampled woody species from two sites, Anvil Hill and Suurdam, within the Cape Point Nature Reserve near Cape Town in mid-April 2003. Both sites were chosen because of the presence of an anomalous wetland with perennial water supply. These wetlands are not associated with riparian systems and were deemed likely to be fed by groundwater from deep aquifers. At the first study site, Anvil Hill, seven individual twig samples of fully-suberized wood with no leaves attached were collected from three species from two locations on and off the wetland. These species included *Metalasia muricata* and *Leucadendron laureolum,* both on and off the wetland, and *Mimetes hirtus* on the wetland.

The wetland sample was collected within 20 m from where the water was welling up to the surface, whereas the sample taken off the wetland was from the top of a small hill approximately 100 m distant.

At the second site, Suurdam, an approximately 30 m by 1-km strip of slightly raised peaty soil situated on a flat plain, seven individual samples of two species were collected. These species were *Erica multumbelliferum* on the wetland and *Erica labialis* off the wetland on deep, well-drained sands. The seep area had a water table at 30 cm, whereas the adjacent area of deep pale sands <30 m away had no water table to a depth of 1.2 m (auger depth). While the peaty area supports the rare monotypic Irid, *Witsenia maura,* we could not use this species for stable-isotope analysis because of difficulties in extracting water from it that has not been fractionated.

At both sites a sample of the water welling up to the surface, representing deep groundwater, was collected at between 5 and 30 cm below the surface. An auger was used to make a hole which was allowed to fill with water. After 10–15 min a Vacutainer (a rubber-stoppered glass vial) was completely filled with this water and then resealed with its rubber stopper. This stopper was then further sealed with parafilm and the Vacutainer kept in a refrigerator prior to analysis to minimize any potential fractionation. The twig samples collected for this study were collected in Kimble glass culture (Kimax) tubes (screw-capped boron silicate containers). The twig samples were also kept in a refrigerator prior to analysis.

Stable-isotope values for rainfall were obtained from C. Harris (Department of Geological Sciences, University of Cape Town) and are based on rain samples collected at the university in April 2003. Water was extracted from the twigs we collected on a vacuum extraction line with cryogenic collection.[11] The wood sample was not removed from the Kimax tube for this purpose; rather, the tube fitted directly onto the vacuum extraction line. The water samples were analysed for $^{18}O/^{16}O$ ratios using the CO_2 equilibrium method of Socki *et al.*[12] and D/H ratios using the closed-tube method of zinc reduction of Coleman *et al.*[13] Isotopic ratios of both D/H in H_2 and $^{18}O/^{16}O$ in CO_2 were determined using a Finnegan MAT252 isotope ratio mass spectrometer. Our own independently analysed internal standards were run to calibrate our results relative to standard mean ocean water (V-SMOW) as well as to correct for drift in the reference gas. The deviation from V-SMOW is denoted by the term δ and the results are expressed as parts per thousand (‰) difference relative to V-SMOW. The analytical uncertainty was <2‰ for δD and <0.2‰ for $\delta^{18}O$.

Results

The mean δD value for rain for April was –3.0‰, whereas the water collected just below the surface in the permanently saturated zone had a δD value of –12.5 ± 1.3‰ (Fig. 1). At the Suurdam site *E. labialis* growing off the wetland had considerably more variable and more negative δD values than *E. multumbellifera* growing on the wetland. Values ranged from –5.4‰ to –22.2‰ for *E. labialis* in contrast to –6.5‰ to –11.3‰ for *E. multumbellifera.* These differences in δD values for the two species suggest that *E. multumbellifera* on the wetland has a shallow root system that taps directly into the water that is very close to the surface. As explained earlier, surface soil water is isotopically enriched in the heavier isotope because of fractionation due to evaporation; this results in more positive δD values.[10] The deeper the source of the water the more negative the isotope value. The results for *E. labialis* therefore suggest that this species has a rooting strategy that is more diverse than that of *E. multumbellifera,* with two plants sourcing water close to the soil surface while others extract water much deeper down.

At the Anvil Hill site the data suggest that both *Metalasia muricata* (from –9.5‰ to –26.1‰) and *Leucadendron laureolum* (from –10.9‰ to –28.7‰) are deep-rooted, with δD values for both species indicating use of isotopically depleted deep water (Fig. 1). However, the relatively positive values for *Mimetes hirtus* (from 33.4‰ to –24.1‰) suggest use of water very close to the surface that has undergone extensive fractionation and is isotopically enriched because of evaporation.[10]

Conclusions

The primary objective of this study was to determine whether stable hydrogen and oxygen isotopes of water could be used to establish the degree of dependence of certain plant species on a permanent water supply. The results suggest that it is feasible to use stable isotopes to distinguish between the different water sources used by plants on and off wetlands. In the Cape Point Nature Reserve most woody plants have adapted to the dry summers in such a way that active roots for water uptake are not maintained in the surface layers but occur only in the deep soil layers where moisture is more reliable. These differences are apparent in the results for *M. muricata, E. labialis* and *L. laureolum,* which are deep-rooted, and the rare endemic *M. hirtus,* which is shallow-rooted (Fig. 1). These results further suggest that *M. hirtus* growing on the wetlands at Cape Point is using neither rainwater nor groundwater directly but rather it appears to exploit a water source close to the surface. The origin of this water would be rain, directly after rainfall, and groundwater in dry periods, brought to the surface by capillary action from a shallowly located, permanently saturated zone. If this species is shallow-rooted and dependent on surface soil water for survival, it would be vulnerable to an even slight lowering of the water table during the dry summer months, when the surface soil water would be mainly replenished from the permanently saturated zone of the wetland. This would have implications for other endemic species with a similar water use strategy to *Mimetes hirtus.*

In Western Australia, one of the most significant effects of water abstraction on local vegetation was observed in the summer of 1985, when up to 80% of all *Banksia* plants died in the vicinity of the Wanneroo well field.[14] Plant mortality was directly attributed to a rapid draw down of the water table as a result of abstraction. The source of Cape Town's future water needs is the Table Mountain Group aquifer, which supplies water to many small wetlands. While we do not deny that groundwater abstraction for urban water use is necessary, planning is needed to allocate water so that rare endemics associated with these wetlands will not be prejudiced. Our goal is a conceptual and qualitative understanding of the temporal and spatial environmental water requirements of wetlands in the fynbos on an individual, population and community level, so that we may identify the dependence of certain species on available water.

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