An investigation into using stable water isotopes to determine the dependency of vegetation on groundwater at Cape Point Nature Reserve

Excellent piece of work.

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Abstract

We hypothesized that rainwater had a different and distinct isotopic signal to groundwater, and thus plants growing on groundwater-fed areas would have a unique and distinct isotopic composition compared to plants growing on freely-drained soils. We studied two groundwater-fed areas and adjacent freely-drained areas in the Cape Point Nature Reserve, Cape Peninsula. We sampled groundwater and analyzed the isotopic composition and compared this to the isotope composition of rainfall. We found that δ^{18}O and δD values of rainwater (δ^{18}O = 0‰ to -5.6‰ and δD = +11‰ to -22‰) overlapped the isotopic composition of groundwater (δ^{18}O = -4.2‰ to –4.5‰ and δD = -11.9‰ to -13.2‰). Thus isotopic analysis could not determine which areas were groundwater-fed and which were rain-fed. We also sampled xylem water from five species, namely *Leucadendron laureolum* and *Metalasia muricata* (both of which grew on both dry and wetland areas), *Mimetes hirtus* (wetland only), *Erica labialis* (dry area only), and *Erica multumbellifera* (wet area only). Our results suggest that both of *L. laureolum* and *Metalasia muricata* had access to groundwater on both groundwater-fed sites and the free-drained site. *E. multumbellifera* at a groundwater-fed marsh was likely also using groundwater, however on the adjacent freely drained site *E. labialis* was likely using rainwater. *M. hirtus* had a much more positive isotopic composition (δ^{18}O = -1.5 ±1.2‰ and δD = 5.1 ± 18.0‰) than either groundwater or rainwater, indicating that it was using evaporated water, which suggests the species were very shallow rooted. Thus *M. hirtus* would be very sensitive to drying out of the soil. This study has demonstrated that stable water isotopes cannot clearly distinguish rainwater and groundwater and we may have to use other methods such as thermal imagery, chemical analysis, and xylem pressure potentials to determine the degree of dependency of vegetation on groundwater.

INTRODUCTION

The Western Cape's population has grown at approximately 2.7% annually from 1996 to 2001, increasing from 4 million to over 4.5 million people (2001 census data). Currently approximately 3 million of these people live in the Cape Town Metropolitan Area and this rapid population expansion is placing an enormous demand on already strained water resources. Water resources in the Cape Town are limited largely because of low rainfall (515 mm mean annual rainfall) and the Mediterranean climate that prevails over Cape Town and most of the Western Cape Province. The climate consists of cool, low rainfall winters and hot, dry summers, a combination that causes a shortage of water in the dry summer months. In fact over a century ago Cape Town ran out of water within its boundaries and 98% of Cape Town's water comes from river systems well outside its boundaries (Davies and Day, 1997). In the past increased demand for water was simply met by the construction of new dams and increased abstraction from rivers. However because the Western Cape has so few large rivers, it is running out of suitable new dam sites. The Skuifraam Dam is currently being constructed and will likely be one of the last large dams built in the Western Cape. Water shortages in Cape Town have become particularly apparent with water restrictions being enforced over the past few years and with the present prevailing climate, restrictions will likely continue to be enforced. It is clear that with Cape Town's current growth and water use patterns, serious water shortages will become a reality unless suitable alternative water supplies are found. Groundwater is perceived to offer large volumes of water that can be abstracted at a low impact to the environment. Thus groundwater is considered to be a suitable alternative water source to supplement Cape Town's current water supply.

The focus of future groundwater abstraction for Cape Town is from 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 stretching as far east as Port Elizabeth. The TMG Aquifers constitute the second largest aquifer system in South Africa, with a staggering estimated water storage of between 66 000 km^3 (Weaver & Talma, 2000) and 100 000 km^3 (Brown *et al.*, 2003). Water in the TMG Aquifer is stored and moves through cracks and fractures in the TMG quartzites. The great thickness of the TMG, the existence of large outcrop areas and their high permeability and exposure in faulted and high rainfall areas, and the generally excellent water quality has lead to a feasibility study (Brown *et al.*, 2003) to determine the possible impact(s) of abstracting groundwater from the TMG Aquifer to supplement Cape Town's current water supply. Currently a study area has been selected from Kogelberg to Tulbagh, with the aim of establishing a pilot well field delivering 5 million m^3 per year in the study area, within the next three years. (See Appendix 1 for a basic introduction to groundwater and aquifers as well as further information on the TMG Aquifer).

The Cape Floristic Region (CFR) is an area of land about 90 000 km^2 (Goldblatt, 1978), which roughly overlies the TMG Aquifer System. The region boasts an estimated 9000 vascular plants of which a remarkable 69% are endemic (Goldblatt & Manning, 2000). The floral characteristics of the Cape Region are so unusual that it has often been considered as one of the World's six floral kingdoms (Goldblatt, 1978). There are no generally accepted criteria for distinguishing 'floral kingdoms' and notion of the Cape Floral Kingdom does not receive universal recognition (Goldblatt & Manning, 2000). There are a number of floristic peculiarities of the CFR that lend support to the idea that the region forms one of the six 'Floral Kingdoms'. These include its unusual floristic composition, the notable absence of many large trees, the dominance of sclerophyllous (leathery leaf consistency) shrubs, a remarkably high number of geophytes, and most importantly remarkably high endemism, including several families (Goldblatt, 1997; Goldblatt and Manning, 2000). The endemic families of the CFR are Penaeaceae, Stilbaceae (including Retziaceae), Grubbiaceae, Roridulaceae, Geissolomataceae and the near-endemic family, Bruniaceae (three species occur outside of the CFR). All of the endemic and near-endemic families are taxonomically isolated, contributing relatively few genera and species to the flora, and are best described as palaeoendemics (Goldblatt, 1997). These families are almost without exception evergreen, sclerophyllous shrubs. It appears as though they are relics of an ancient temperate southern African flora, when considerably wetter and cooler conditions prevailed. Consequently many of these palaeoendemic species are restricted to areas on shady south slopes that are permanently wet, such as wetlands, seeps or marshes. Areas that remain permanently moist or wet throughout the dry season are mostly likely to be maintained by groundwater. There are also many other species that are not in these endemic families that may be dependent on groundwater. The ability of any vegetation to access groundwater depends on the depth of the water table, the penetrability of the profile and the inherent physiology of the plant that allows it to develop deep roots (Scott & Le Maitre, 1998). If large-scale abstraction of groundwater occurs the impacts could include the drying out of groundwater-fed systems, such as wetlands, marshes and seeps, not only in the immediate vicinity of abstraction but possibly also far from the source of abstraction. Therefore species restricted to groundwater-fed areas may be particularly vulnerable to groundwater abstraction. Although it is likely that only a small area will be affected by the abstraction of water, the loss of biodiversity is potentially large if wetlands are of disproportional importance as a habitat to endemics families and species. Thus it is of critical importance to establish the degree of dependency of certain plant species and communities on groundwater prior to any abstraction of groundwater. Stable water isotopes may prove to be a useful tool to establish the dependency of vegetation on groundwater.

Stable isotopes of water, namely oxygen (^{16}O and ^{18}O) and hydrogen (^{1}H and ^{2}H or deuterium), can be used to determine the zone of active water uptake of plant roots (Ehleringer *et al.*, 1991; Ehleringer & Dawson, 1992; Dawson, 1996). Water close to the soil surface undergoes more evaporation than deeper soil water (or groundwater), and is thus enriched with heavy isotopes (more positive isotope composition) relative to water in deeper soil layers (because of preferential evaporation of the lighter isotopes) (Allison *et al.*, 1983). Therefore analysis of isotope ratios of xylem sap of a plant should reveal the depth of water source used by that particular plant.

We wondered if rainfall would have a unique and different isotope signal to groundwater, and therefore whether plants growing on groundwater-fed areas would have different and distinct xylem water isotope ratios to individuals growing on freely drained soil. We hypothesized that plants growing on groundwater-fed areas were mainly utilizing groundwater and would therefore have a different isotopic signal to individuals growing on freely-drained soils that were putatively using rainwater. We also hypothesized that some species only occurred on groundwater-fed areas because of a lower tolerance to seasonal drought. We anticipated that groundwater would have a more negative isotopic composition compared to rainwater (more evaporated), and thus we expected plants growing on groundwater-fed systems would have more negative isotope ratios compared to plants growing on freely-drained soils, that would likely be rain-fed. Thus we analysed stable water isotopes of rainwater and groundwater to investigate if there was any isotopic difference between them. We also analyzed the isotopic composition of twig samples from species growing on groundwater-fed areas and freely-drained soils to investigate if plants on the two habitats had different and distinct isotopic signals.

METHODS

Study Area

The Cape Point Nature Reserve (34°17' S 18°25' E, 0-370 m elevation) is situated in the Cape Peninsula, 60 km south of Cape Town, South Africa, and forms part of the Cape Peninsula National Park. The reserve, like most the Western Cape, falls within a Mediterranean climatic region, and is characterized by cool, wet winters and hot, dry summers. The annual rainfall for the reserve is 630 mm with the most rain falling in June and July (Davidge, 1978) (Figure 1).

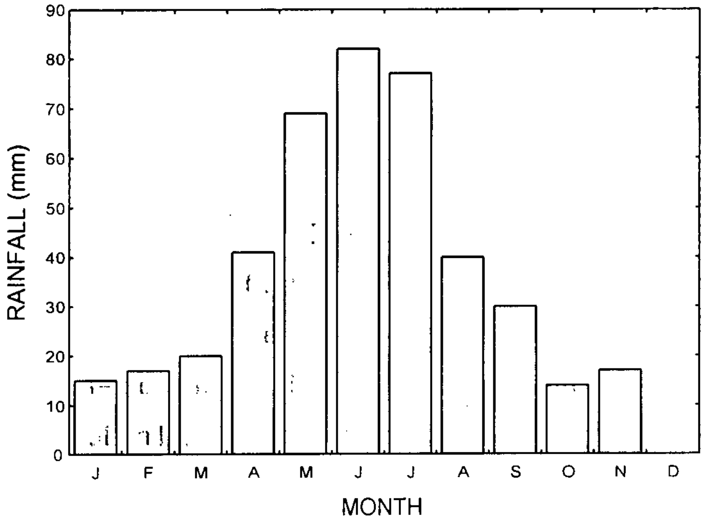

Figure 1: Mean monthly rainfall over the period 1961-1990 (source: South African Weather Bureau) for Cape Town (33°59' S 18°36' E, elevation 42 m) about 60 km north of Cape Point.

Our sampling was conducted in mid-April, which is the end of the dry season for the Cape Peninsula. Several types of fynbos cover the Cape Point Nature Reserve, with the most common types being wet restoid fynbos and mesic mesotrophic proteoid fynbos. The exposed geology of the Cape Point Nature Reserve is almost entirely Peninsula Formation and thus rain can contribute directly to the groundwater system. Wetland and marshy areas are common within the reserve throughout the year. Many of these wetland and marshy areas are best described as 'moustache-shaped', usually being less than 50m wide but stretching for a kilometer or more. There is often no apparent geological or physical reason for their existence.

Two study areas, each with two study sites, were selected in the reserve (Figure 2). The first study area, hereafter referred to as the Anvil Hill study area, included a shrubby wetland site (Plate 1) and an adjacent dry hill slope site (Anvil Hill). This study area was selected because of presence of *Mimetes hirtus* (Red Data Book status of vulnerable) at the wetland site. The soil substrate over the study area was quartzitic sand, being derived from sandstone. The wetland site was of approximately the same slope and soil type as the hill slope site, however the species composition of each site was different (Appendix 2, table A).

Plate 1: Anvil Hill wetland study site. A shallow pond (10 meters wide and 40 meters long) was surrounded by gently inward-sloping banks. Vegetation grew on top of these banks where the water table was 1.0 to 1.5 m from the soil surface.

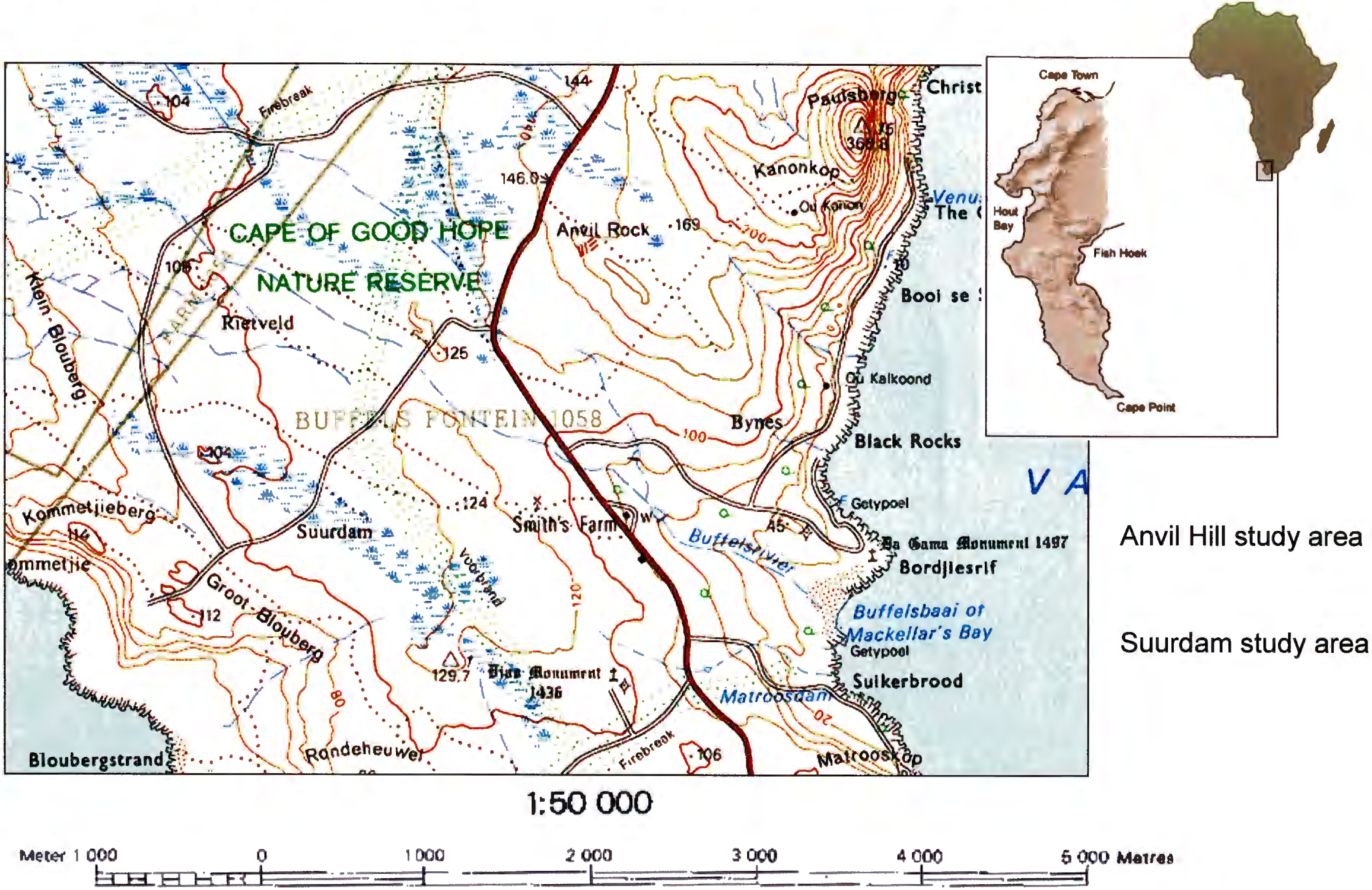

Figure 2: Map of Cape Point Nature Reserve indicating the Anvil Hill study area and the Suurdam study area (Source: Paul Taylor, City of Cape Town). Inset is map of the Cape Peninsula.

The second study area, hereafter referred to as Suurdam study area, was much more ericoid and restoid in nature (Appendix 1, table B). This study area included a marsh study site on a "moustache-shaped" marsh and also an adjacent dry site. This study area was selected because of the presence of the rare and endemic *Witsenia maura* on the marshy study site. The soil types between the two study sites were different. Underlying the marsh site was a peaty layer approximately 300mm deep, beneath which sandy soil occurred, similar to the soil at the Anvil Hill study area. On the adjacent dry site the soil was uniformly sandy, similar to the Anvil Hill study sites.

Plate 2: Suurdam study area showing the clearly differentiated vegetation between the marsh (taller vegetation on the right) and the adjacent freely-drained soil (shorter vegetation of the left). The marsh was approximately 40 meters wide and extended for at least a kilometer in both north-west and south-east directions. The water table at the marsh site was approximately 20 cm from the surface, although some small standing pools of standing water occurred. The water table at the dry site was deeper than 1.5m (the depth limit of the soil auger).

Study Species

At the Anvil Hill study area *Leucadendron laureolum*, *Metalasia muricata* and *Mimetes hirtus* were the selected study species. *L. laureolum* is a large, yellowish shrub growing up to 2 m tall. This species grew on both the wetland and hill slope sites and was selected as a study species because it was hypothesized to have a deep root system able to access groundwater. *M. muricata* is a small round shrub often found growing in relatively dry conditions. *M. muricata* grew on both sites and it was suspected that *M. muricata* had a shallow root system that was only able to access rainwater and shallow soil water. *M. hirtus* is an erect shrub growing 1 - 2.5 m tall. It is restricted to marshes, seeps, wetlands and stream banks in the Cape Peninsula, Kogelberg, Kleinmond Mountains, Klein River Mountains and Elim Flats (Rebelo, 1995). *M. hirtus* has a Red Data Book status of 'vulnerable' because of its reliance on moist conditions as well as settlement expansion onto its habitat. This species only occurred at the wetland study site and was hypothesized to be dependent on groundwater because of its wetland habitat preference.

At the Suurdam study area *Erica multumbellifera* and *Erica labialis* were the selected study species. The same species did not occur on both the dry site and the marsh site, and thus these two Erica species were selected as the study species because they were the two most similar plant species. *E. multumbellifera* is a small, bushy plant that bears many round, almost bead-like, purplish-red flowers. It is a common inhabitant of lower moist areas (Schumann *et al.* 1992) and was only found on the marsh site. *E. labialis* is also a small, bushy plant that bears many small white bell-like flowers and was only found on the dry site.

Isotope Sampling

Isotopes are variations of an element that have different numbers of neutrons, and therefore different atomic weights. The difference in mass, which tends to be more pronounced in the lighter elements such as oxygen and hydrogen (Redwine & Howell, 2002), leads to a process called isotopic fractionation, which is the change in isotopic ratios of a material owing to different rates at which various isotopes undergo chemical or kinetic reactions (Dansgaard, 1964). Plants do not fractionate oxygen or hydrogen isotopes during water uptake (White *et al.*, 1985; Dawson & Ehleringer, 1991), therefore the stable oxygen and hydrogen isotope ratios (δ^2H and $\delta^{18}O$) of xylem water should reflect the isotopic ratio of the water source used by a plant. Evaporation of water from the upper soil layers can lead to a large gradient in isotopic composition within the soil profile, with water in the upper soil layers typically tending to have more positive δD and $\delta^{18}O$ values than water deeper in the soil profile (Ehleringer *et al.*, 1991; Ehleringer & Dawson, 1992; Dawson, 1996).

We collected seven twig samples, each from a separate plant, from each study species. Only non-photosynthetic, suberised twigs were sampled because transpiration or evaporation can alter the isotope ratio (Dawson & Ehleringer, 1991). Once cut twig samples were quickly sealed in a Kimax® tube and the lid sealed with Parafilm®. Two samples of surface water were taken at the Anvil Hill wetland site and one sample of surface water was taken from the Suurdam marsh site. At the Anvil Hill wetland site two soil augers were drilled and at the marsh site one auger was drilled, until the water table was hit. Water samples (groundwater) were then taken from the augered holes. All water samples were collected in small screw-top plastic bottles and sealed using Parafilm®. All twig and water samples were collected between 0800 and 1000 hours, 18 April 2003. After collection all twig samples were frozen in a deep-freeze and water samples were stored in a cool cupboard.

Laboratory Methods

Water was extracted from twig samples using cryogenic vacuum distillation (Dawson, 1996). Oxygen isotopes were extracted using the CO_2 equilibrium method (Socki *et al.*, 1992). This involved injecting about 1.0 to 1.5 ml of extracted sample water involved into Vacutainers® (7 ml airtight glass vials) prefilled with about 500 mbars CO_2. The filled Vacutainers® were placed for between 12 and 18 hours in a gently rocking apparatus in a water bath with the temperature set at 25°C. An equilibrium exchange process occurs (1) and the oxygen isotope signal becomes reflected in the oxygen of the carbon dioxide gas. The carbon dioxide was then extracted from the sample using a cryogenic process involving a system of U-tubes.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow CO_2 + H_2O \qquad (1)$$

A variation of the zinc closed tube reduction method (Coleman *et al.*, 1982) was used to measure hydrogen isotopes. This method involves introducing approximately 2 µl of water into a tube containing 105-120mg of zinc turnings. The tube was attached to the vacuum line, frozen in liquid nitrogen, evacuated to eliminate non-condensable gases (such as nitrogen and oxygen) and then sealed using an acetylene torch. Samples were placed for 2 hours in a furnace set at 500°C to reduce the water to H_2 and oxygen. The oxygen readily combines with zinc to form zinc oxide (2), leaving behind hydrogen gas.

$$Zn + H_2O \rightarrow ZnO + H_2 \qquad (2)$$

Both oxygen and hydrogen isotope ratios were measured using a Finnegan MAT252 isotope ratio mass spectrometer. Once hydrogen samples were burnt in the furnace the samples were run on the mass spectrometer within 12 hours. Isotopic composition for hydrogen or oxygen is expressed in delta notation (δ) as:

$$\delta = (R_{sample}/R_{Standard} - 1) \times 1000 \qquad (1)$$

where R_{sample} and $R_{Standard}$ are the molar ratios of either D/H (for δD) or $^{18}O/^{16}O$ (for $\delta^{18}O$) of the sample and standard respectively. The international standard for δD and $\delta^{18}O$ is Vienna-Standard Mean Ocean Water (V-SMOW) and isotope values as reported the deviation from V-SMOW in parts per thousand or per mil (‰). The equations of Coplen (1993) were used to convert raw data to the V-SMOW scale. We ran our own internal standards (CTMP and DML ICE for hydrogen, and DISTILLED STANDARD for oxygen), which have been calibrated against V-SMOW, and independently analyzed, to correct for drift in the reference gas.

Size and reproductive measurements

At the Anvil Hill study area species that occurred on both the wetland site and the hill slope site, i.e. *L. laureolum* and *M. muricata*, were measured in terms of their volume and reproductive output. The volume was calculated by measuring the height, longest diameter and the diameter perpendicular to this, and then multiplying these together. *L. laureolum* is dioecious and thus male and female plants were dealt with separately. For female *L. laureolum* plants reproductive output was measured as the estimated number of cones and the reproductive output of males was measured as the estimated number of inflorescences. The reproductive output of *M. muricata* was also measured as the estimated number of inflorescences.

Groundwater Dependent Species from Endemic Families

A list of species from endemic and near-endemic families of the Cape Flora which may depend on groundwater was generated from plant habitat descriptions from "*Cape Plants: A conspectus of the Cape flora of South Africa*" by Goldblatt & Manning (2000) (Appendix 3). Species that were considered to be dependent on groundwater had habitats listed in "*Cape Plants*" as stream banks, wetlands, damp slopes, swampy areas, marshes and seeps. This list will need to be validated by field studies.

Data Analysis

Data were statistically analyzed using the computer package STATISTICA 6. We used t-tests for independent variables to test the hypothesis that $\delta^{18}O$ and δD xylem water values of plants growing on groundwater-fed areas were significantly different to $\delta^{18}O$ and δD xylem water values of plants growing on rain-fed areas. We also used t-tests to determine if plants growing on the wetland site were significantly larger and had significantly higher reproductive output compared to plants growing on the freely drained hill slope site.

Results

Rainfall

The isotopic composition of precipitation was quite variable during February, March and April (Unpublished data, Stable Isotope Laboratory, Department of Geological Sciences, UCT). Most of this isotopic variation can be explained by the amount of rainfall. During the abnormally heavy rainfall month of March (52 mm) approximately 36 mm fell over the course of two days. March's rainfall was much more depleted in oxygen and hydrogen isotope ratios ($\delta^{18}O$ = -5.6‰ and δD = -22‰) than the lighter rainfall months of February (7 mm, $\delta^{18}O$ = 0‰ and δD = +11‰) and April (10 mm, $\delta^{18}O$ = -2.3‰ and δD = -3‰). Oxygen and hydrogen isotope ratios for April are for the entire month's rainfall (10 mm), however only 3 mm of rain fell in April prior to sampling.

Anvil Hill

Oxygen Isotope Ratios

Groundwater collected from soil augers had a mean $\delta^{18}O$ value of -4.2 ± 0.3‰ and surface water at the wetland had a nearly identical δO^{18} value of -4.5‰ (Figure 3). Both groundwater and surface water had more negative $\delta^{18}O$ values than either February or April rainfall but more positive $\delta^{18}O$ values than March rainwater. $\delta^{18}O$ values of water extracted from *L. laureolum* twig samples showed no significant difference between individuals growing on the hill slope site (-4.5 ± 0.5 ‰) and wetland site (-3.9 ± 0.7‰) ($t = 1.50$, d.f. = 10, $P = 0.165$). Most *L. laureolum* individuals growing at both sites appeared to have similar $\delta^{18}O$ values to that of groundwater suggesting that they were mainly using groundwater at the time of the study. Although some *L. laureolum* individuals on the hill slope seemed to be more shifted towards the $\delta^{18}O$ of March rainwater, possibly indicating a greater reliance on rainwater. Although there was no significant difference in δO^{18} values of xylem water of *M. muricata* individuals on the hill slope site (-5.0 ±0.7‰) and wetland (-4.5 ± 0.3‰) ($t = 1.40$, d.f. = 9, $P = 0.194$), some individuals on the hill slope had a similar $\delta^{18}O$ value to March rainfall, suggesting that they were utilizing mostly rainwater. Other *M. muricata* individuals growing on the hill slope site and the wetland site had similar values to groundwater, suggesting that they were more reliant on groundwater during the period of the study. The $\delta^{18}O$ value of xylem water of *M. hirtus* individuals at the wetland (-1.5 ±1.2‰) was clearly very different (unexpectedly more positive) to both groundwater and March rainwater (Figure 3). The xylem water $\delta^{18}O$ value of *M. hirtus* was also significantly different to xylem water $\delta^{18}O$ values of both *L. laureolum* wetland individuals ($t = 4.48$, d.f. = 11, $P = 0.001$) and *M. muricata* wetland individuals ($t = 5.57$, d.f. = 10, $P = 0.000$).

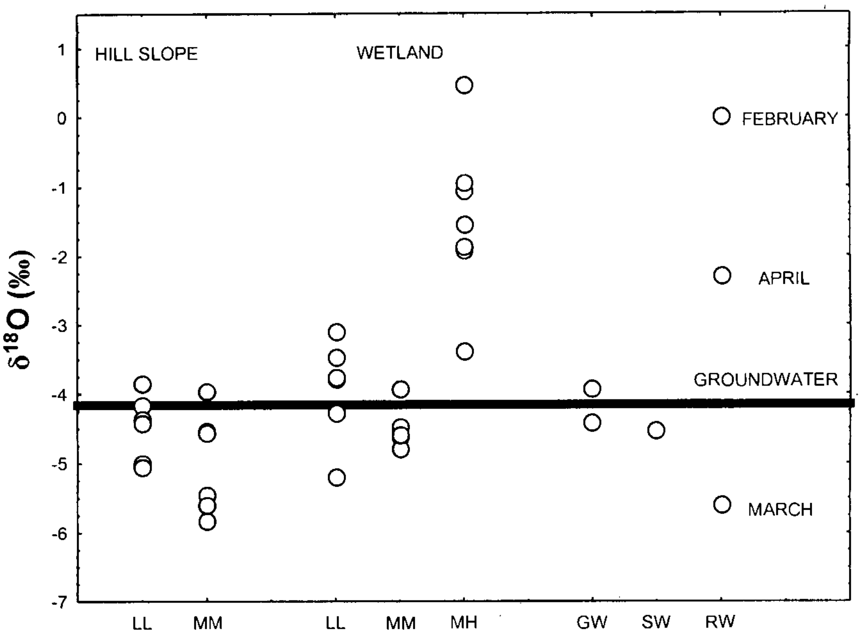

Figure 3: The oxygen isotope ratio for xylem sap during mid-April for species at the Anvil Hill wetland site and hill slope sites. The solid line represents the oxygen isotope ratio of groundwater. Oxygen isotope ratios of rainwater are recorded for February, March and April and are based on rainfall collected at UCT (Source: unpublished data, Stable Isotope Laboratory, Department of Geological Sciences, UCT). (LL = *Leucadendron laureolum*, MM = *Metalasia muricata*, MH = *Mimetes hirtus*, GW = Groundwater, SW = Surface water, RW = Rainwater).

Hydrogen Isotope Ratios

Hydrogen isotope ratios shown very similar results to the oxygen isotope ratios. Groundwater at the wetland site had a δD value of -13.2 ± 0.5‰ and surface water was similar with a δD value of -13.8‰ (Figure 4). The δD value of groundwater fell in between the δD values of April rainwater and March rainwater. We found no significant difference in the xylem water δD values of *L. laureolum* individuals growing on the wetland site (-15.2 ± 4.8‰) and the hill slope site (-18.0 ± 5.9‰) (t = 0.90, d.f. = 10, P = 0.390). Many of the *L. laureolum* individuals at both sites had δD values slightly more negative than that of groundwater, possibly indicating some utilization of rainfall from March. δD values of water extracted from *M. muricata* were indistinguishable for individuals growing at the wetland site (-20.9 ± 4.1‰) and hill slope site (-20.2 ± 6.1‰) (t = -0.25, d.f. = 10, P = 0.806). Although, the δD values of *M. muricata* were closer to that of March's rainfall than *L. laureolum*, possibly indicating more use of March rainwater by *M. muricata*. In contrast the δD value water extracted from *M. hirtus* (5.1 ± 18.0‰) was very different to groundwater and March rainwater (Figure 4) as well as being significantly different to xylem water δD values of both *L. laureolum* (t = 2.67, d.f. = 11, P = 0.022) and *M. muricata* (t = 3.45, d.f = 11, 0.005) individuals growing at the wetland site.

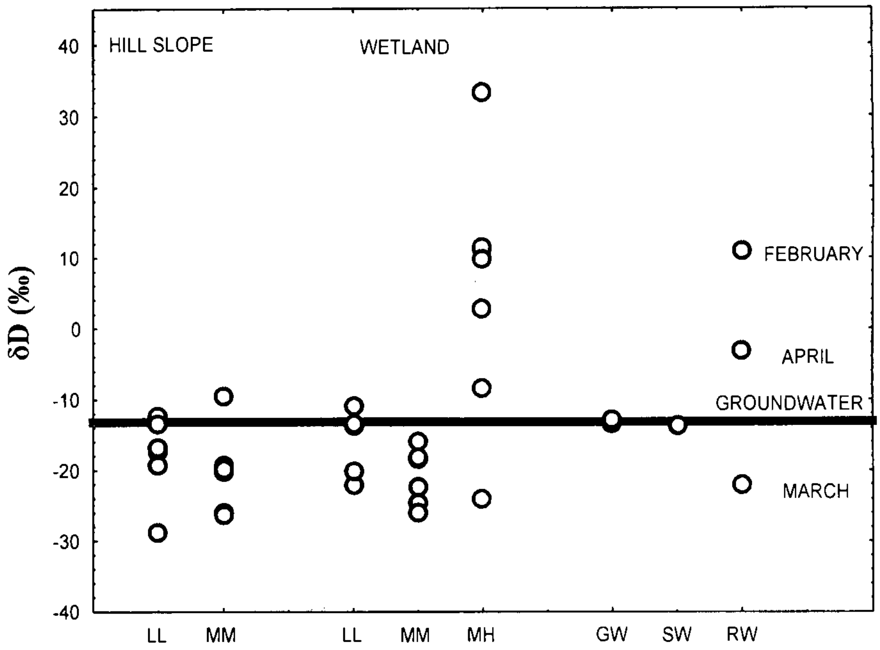

Figure 4: The hydrogen isotope ratio for xylem sap during mid-April for the study species at the Anvil Hill study area. The solid line represents the hydrogen isotope ratio of groundwater at the study area. Hydrogen isotope ratios of rainwater are recorded for February, March and April and are based on rainfall collected at UCT (Source: unpublished data, Stable Isotope Laboratory, Department of Geological Sciences, UCT). (LL. *Leucadendron laureolum*, MM = *Metalasia muricata*, MH = *Mimetes hirtus*, GW = Groundwater, SW = Surface water, RW = Rainwater).

Suurdam

Oxygen Isotope Ratios

Groundwater at the marsh site had a $\delta^{18}O$ value of -4.4‰ and surface water had a very close $\delta^{18}O$ value of -4.2‰ (Figure 5). The $\delta^{18}O$ value of groundwater is similar to that of the Anvil Hill wetland site, suggesting that the water is of the same origin. Again the $\delta^{18}O$ value of groundwater fell in between the $\delta^{18}O$ values of April rainwater and March rainwater. Although there was no significant difference between the $\delta^{18}O$ values of water extracted from *E. multumbellifera* (only growing on the marsh, -3.5 ± 0.8‰) and *E. labialis* (only growing off the marsh, -3.2 ± 1.1‰) (t = 0.53, d.f. = 11, P = 0.606), *E. labialis* showed a considerably wider range of $\delta^{18}O$ values (Figure 5). Most $\delta^{18}O$ values of xylem water for both *E. multumbellifera* and *E. labialis* were slightly more positive than groundwater, indicating some evaporative enrichment.

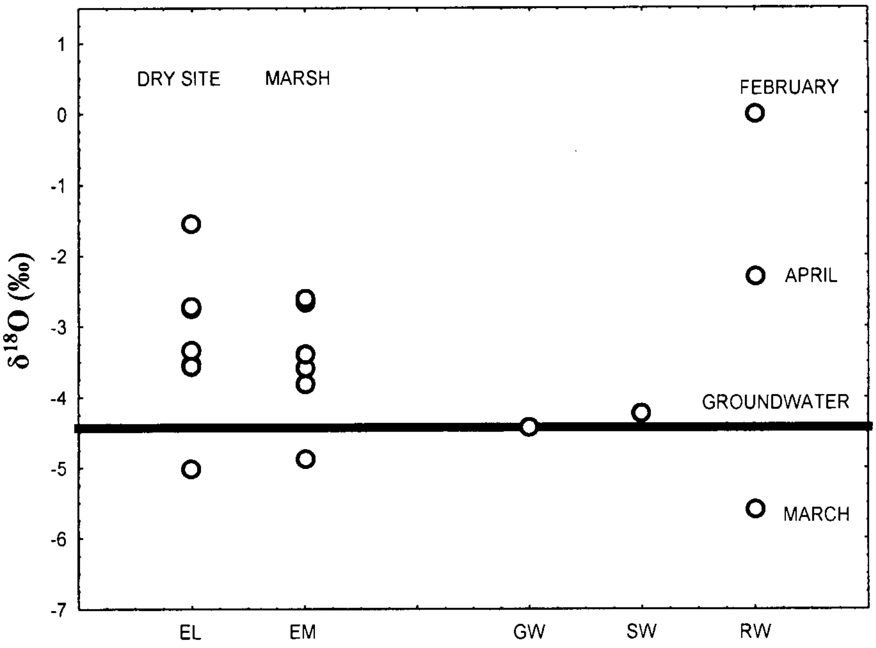

Figure 5: The oxygen isotope ratio for xylem sap during mid-April for *E.multumbellifera* and *E. labialis* at the Suurdam study sites. The solid line represents the hydrogen isotope ratio of groundwater at the marsh. (EL = *Erica labialis* (dry site), EM = *Erica multumbellifera* (marsh site), GW = Groundwater, SW = Surface water, RW = Rainwater). Oxygen isotope ratios of rainwater are recorded for February, March and April and are based on rainfall collected at UCT (Source: unpublished data, Stable Isotope Laboratory, Department of Geological Sciences, UCT).

Hydrogen Isotope Ratios

At the marsh site groundwater had a δD value of -11.9‰ and surface water had a similar δD value of -10.7‰ (Figure 6). The δD value of groundwater again fell in between δD values of March and April rainwater. Although there was no distinguishable difference between the δD values of *E. multumbellifera* (growing on marsh site) (-8.9 ± 2.4‰) and *E. Labialis* (growing on dry site) (-13.8 ± 8.4‰) (t = 1.38, d.f. = 11, P = 0.195), *E. labialis* had considerably more variable δD values. *E. labialis* also had δD values that were mostly more negative than those of *E. multumbellifera*, whose δD values were clustered around the δD value of groundwater.

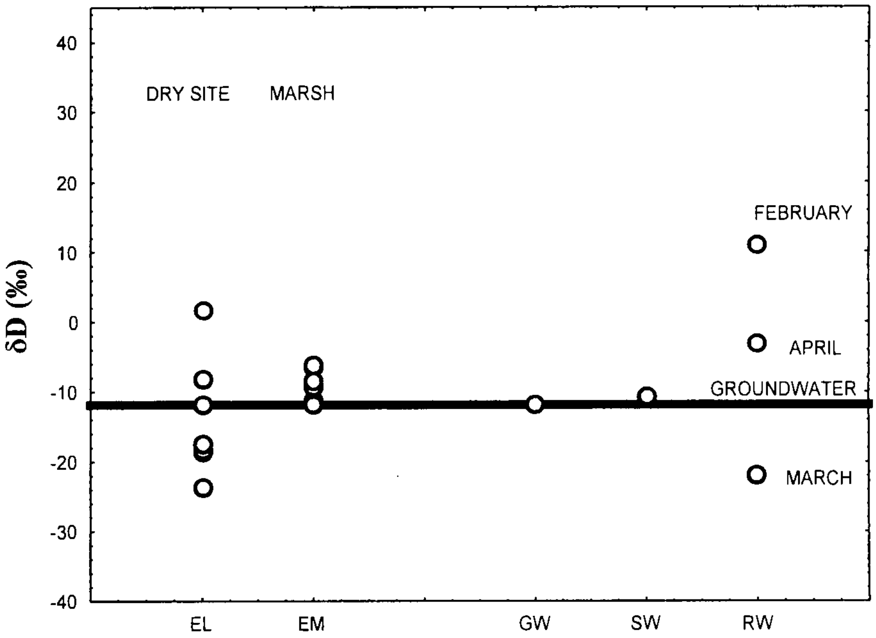

Figure 6: The hydrogen isotope ratio for xylem sap during mid-April for *E.multumbellifera* and *E. labialis* at the Suurdam study sites. The solid line represents the hydrogen isotope ratio of groundwater at the study area. (EL = *Erica Labialis*, EM = *Erica multumbellifera*, GW = Groundwater, SW = Surface water, RW = Rainwater). Hydrogen isotope ratios of rainwater are recorded for February, March and April and are based on rainfall collected at UCT (Source: unpublished data, Stable Isotope Laboratory, Department of Geological Sciences, UCT).

Species characteristics

Table 1: Mean (± standard deviation) volume (m^3) and number of inflorescences (*M. muricata* and male *L. laureolum*) or cones (female *L. laureolum*) of individuals growing on the wetland and hill slope study sites. The vegetation on the wetland and hill slope sites was estimated to be the same age. (See Appendix 4 for complete dataset)

	L. laureolum				***M. muricata***	
	Male		Female			
	Wetland	Hill	Wetland	Hill	Wetland	Hill
Volume (m^3)	14.9 ± 7.1	1.3 ± 1.3	3.8 ± 3.1	1.0 ± 0.9	1.1 ± 0.9	0.7 ± 0.8
No. reprod.	271.7 ± 168.5	23.7 ± 22.1	61.2 ± 49.5	10.5 ± 8.8	266.7 ± 283.2	195.8 ± 232.3

As expected male *L. laureolum* plants growing on the wetland site were significantly larger than male individuals on the hill slope site (t = 4.61, d.f. = 10, P = 0.001). Male *L. laureolum* individuals at the wetland site also had significantly more inflorescences than male individuals at the hill slope site (t = 3.58, d.f. = 10, P = 0.005). Although female *L. laureolum* individuals growing at the wetland site also had significantly more cones compared to female plants growing at the hill slope site (t = 2.47, d.f. = 10, P = 0.033), female *L. laureolum* individuals at the two sites showed no significant difference in volume (t = 2.13, d.f. = 10, P = 0.059). Unexpectedly, *M. muricata* individuals growing on the hill slope and wetland sites showed no significant difference in either volume (t = 0.79, d.f = 10, P = 0.449) or number of inflorescences (t = 0.47, d.f. = 10, P = 0.646).

Discussion

We found that the isotopic composition of rainfall varied considerably over the three months prior to sampling. The δD and $\delta^{18}O$ values were more positive during the lighter rainfall months of February and April than the δD and $\delta^{18}O$ from the heavier rainfall month of March. This isotopic variation is likely to be an amount effect because it is widely accepted that larger amounts of rainfall lead to lower oxygen and hydrogen isotope ratios (Dansgaard, 1964). This is because during periods of heavy rainfall there is usually less opportunity for evaporation prior to reaching the ground.

We found the isotopic composition of rainfall ($\delta^{18}O$ = 0‰ to -5.6‰ and δD = +11‰ to -22‰) overlapped the isotopic composition of groundwater ($\delta^{18}O$ = -4.2‰ to –4.5‰ and δD = -11.9‰ to -13.2‰), and thus there was no different and distinct isotopic signal between rainwater and groundwater. A similar overlap of δD and $\delta^{18}O$ values for groundwater and rainwater was reported by Diamond & Harris (1999) on the slopes of Table Mountain (Cape Town). At Cape Point there is only a slight difference between δD and $\delta^{18}O$ values of groundwater and surface water, suggesting that surface water at the marsh and wetland sites is likely maintained by groundwater.

Water is a fundamental requirement all plants and plants can obtain water from two sources; precipitation and groundwater. There are two main rooting strategies that plants follow to gain the water necessary to assimilate carbon (Stock *et al.*, 1992). The first strategy is to have deep roots that are able to access the groundwater. Large proteoid shrubs are thought to be deep-rooted having direct access groundwater because they are able to maintain relatively high and constant xylem pressure potentials (XPP) throughout the year (Van der Heyden & Lewis, 1989). The second rooting strategy that plants can adopt is to be shallow-rooted, thus having no direct access to groundwater. The high concentration of root biomass close to the surface allows the plant to rapidly take up water as soon as it becomes available, thereby maximizing carbon dioxide uptake during the time when water is freely available (Stock *et al.*, 1992). Many restoids and ericoids employ this strategy together with water-saving features (such as decreased leaf size and reduced number of stomata) and thus when water is scare, such as in summer, they exhibit greater declines in XPP values than deeper-rooted plant species (Miller, 1985). However Stock *et al.* (1992) missed the possibility of the existence of another group of species that are shallow-rooted but are "water spenders" having few adaptations to cope with drought. Species using this strategy would be unlikely to be able to survive drought periods between rainfall events and would thus be best suited to areas that are permanently wet such as wetlands, seeps and marshes.

good point

L. laureolum individuals growing at the wetland site should be able to develop a deep root system that can access groundwater. The similar isotopic composition of groundwater and *L. laureolum* individuals growing at the wetland suggests that they were utilizing groundwater at the time of sampling. This however did not preclude *L. laureolum* from using rainwater when it is available. And many individuals growing on the wetland were using some rainwater from March, observable by the shift in δD and $\delta^{18}O$ values towards those of March's rainfall. *L. laureolum* individuals growing on the hill slope site had a similar isotopic composition to *L. laureolum* plants growing on the wetland and this suggests that hill slope individuals are also able to access groundwater. This is consistent with the findings of Miller (1985) that many large proteoid species are able to access groundwater. However since the water table is likely to be lower on the hill slope, plants on the hill slope will have to develop deeper root structures to obtain groundwater, making it more difficult for individuals on the hill slope to obtain enough water to keep CO_2 uptake at its maximum. This has observable impacts for *L. laureolum* individuals on the hill slope with both male and female reproductive output reduced on the hill slope and as well as a significant reduction in the size of males on the hill slope. It is hypothesized that if plants do not have access to enough water, carbon dioxide uptake would be reduced, and thus there would be less carbon compounds available for growth and reproduction.

M. muricata also showed no significant difference in isotopic ratios of oxygen and hydrogen for individuals growing on the wetland and those growing on the hill slope. The similarity in isotopic composition between *M. muricata* individuals growing on the wetland site and groundwater suggests that they were sourcing some groundwater. Although *M. muricata* individuals growing on the wetland site may have also been sourcing some of March's rainfall. It appears that some hill slope individuals are utilizing water almost entirely from March's rainfall, whilst other hill slope individuals have an isotopic composition closer to groundwater, indicating that they may possibly be sourcing some groundwater. This suggests that *M. muricata* more deeply rooted than originally hypothesized, and this allows the species to have some access to groundwater. There was no difference in either the reproductive output or size of *M. muricata* individuals growing on the hill slope and wetland sites. This likely indicates a lesser ability of both wetland and hill slope individuals to tap into groundwater and thus either wetland individuals probably did not have superior access to water compared to hill slope individuals, or the growth of *M. muricata* is not limited by water.

M. hirtus only occurred at the wetland site and not at the hill slope site. Like most of the species in the Mimetes genus, *M. hirtus* only occurs in areas that are permanently moist and has Red Data Book status. Unexpectedly, we found *M. hirtus* individuals growing at the wetland site had a more positive isotopic composition than either groundwater or March's rainwater. *M. hirtus* may be sourcing April's rainwater but this is unlikely because only 3 mm of rain fell in April prior to sampling. Thus it is likely that *M. hirtus* was sourcing rainwater from March or groundwater, both of which must have undergone evaporation. This suggests that *M. hirtus* has a very shallow root system, which lies close to the soil surface (Figure 7). Thus *M. hirtus* is unable to utilize groundwater directly, but is able to use soil water in the upper soil layers that has undergone extensive evaporation. This shallow root system and a general intolerance of dry conditions explain this species' inability to grow away from permanently moist areas. A shallow root system would also make this species unsuited to cope with drought conditions and particularly vulnerable to a drop in the water table.

There was no significant difference in the isotopic composition of *E. multumbellifera* (marsh) and *E. labialis* (dry site). With the water table only some 20 cm below the soil surface at the marsh site it seems likely that E. multumbellifera would be able to develop a root structure to utilize groundwater. Although the $\delta^{18}O$ values do not show this association to groundwater very well, δD values of *E. multumbellifera* are very similar to the δD value of groundwater, indicating that *E. multumbellifera* was probably utilizing groundwater. Bearing in mind that ericoids are generally shallow-rooted it is unlikely that *E. labialis* was able to develop roots deep enough to be able to reach the water table (>1.5 m) at the dry site. Hydrogen isotopes of *E. labialis* individuals indicate that the species was probably sourcing rainwater from March, but one is unable to differentiate whether the species is using groundwater or rainwater.

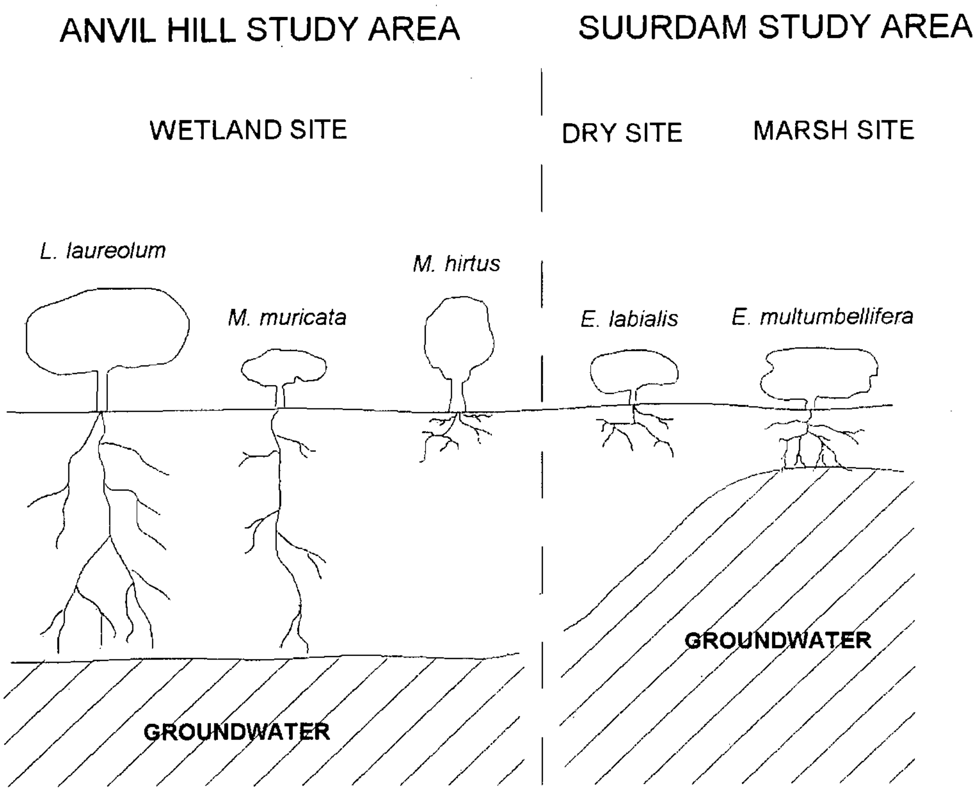

Figure 7: Schematic showing the likely rooting strategies of *L. laureolum* (deep-rooted), *M. Metalasia* (possibly deep-rooted in some areas), *M. hirtus* (shallow-rooted), *E. multumbellifera* (marsh site) and *E. labialis* (dry site) (both shallow-rooted).

Many species in the Cape's endemic and near-endemic families occur on damp slopes, wetlands, seeps, marshes and stream banks and thus may be dependent on groundwater (Table 2). All of endemic families and near-endemic families of the Cape Flora had species that were possibly dependent on groundwater (table 2), and in the case of some families (Grubbiaceae, Roridulaceae and Geissolomataceae) the whole family may be entirely dependent on groundwater.

Table 2: The endemic and near-endemic families of the Cape Flora, their number of genera and species (Source: Goldblatt & Manning, 2000), and the percentage of species in the family that are found in wetlands, seeps, marshes, stream banks, and damp slopes, and thus may have a possible dependence on groundwater (See Appendix 3 for a complete list of possible groundwater dependent species).

Family	Genera	Species	% possibly dependent on groundwater
Penaeaceae	7	23	35%
Stilbaceae	6	14	7%
Grubbiaceae	1	3	100%
Roridulaceae	1	2	100%
Geissolomataceae	1	1	100%
Bruniaceae	11	64 (3 extend outside of CFR)	25%

Abstraction of groundwater could have large implications for species dependent on groundwater. Many endemic families and species depend on groundwater-fed habitats, such as seeps, marshes and wetlands, and thus large-scale abstraction of water could result in the loss of these endemic families and species as groundwater-fed areas dry out. It would be tragic and a great loss to lose these taxonomically isolated, endemic families and even more devastating for the status of the CFR as floral kingdom. One of the key features that contributes greatly to the notion of the CFR as a floral kingdom is the high endemism, particularly of endemic families. If one or more of these endemic families was to go extinct there is a risk that the CFR will lose all claims to be a floral kingdom. This loss of kingdom status could have serious economic implications as a result of loss of revenue from environmental tourists and less funding from important international sources. It would have been useful to be able to use stable isotopes of hydrogen and oxygen to identify whether particular species or communities are sourcing groundwater therefore vulnerable and sensitive to groundwater abstraction. However this study has demonstrated that the unfortunate overlap of rainfall and groundwater oxygen and hydrogen isotope values in the Western Cape means that stable water isotope analysis cannot conclusively determine whether plants are relying exclusively on groundwater or rain water. Hence we may have to use other methods to determine whether species are depending on groundwater.

Long

Isotopes may still offer a partial solution to this problem as our results suggest that plants that were sourcing rainwater had a more variable isotopic composition than plants that were sourcing groundwater. However at least three ~~of~~ four samples would need to be taken over the course of a year to establish the variability of xylem water isotope ratios. If the isotope ratios of the plants are relatively constant over the course of a year then the vegetation is likely sourcing groundwater (which is likely to have a stable isotopic composition). This would not be an attractive option because isotopic analysis is expensive, its time consuming analysis, and only a limited number of samples which can be analyzed at once. Thus we may have to look at other suitable alternatives of determining whether a system is groundwater-fed. A basic method of doing this is to observe if an area is wet through the year, particularly through the dry season. If this is the case then it is likely that the system is maintained by groundwater and not rainwater. This would likely need to be backed up by other studies such as ones using thermal imagery. Thermal imagery may prove to be a particularly useful method for identifying areas where groundwater may be an important water source to plants (Morton & Franszen, 2000). Thermal scans can detect deep groundwater because it is much colder than surface water, such as rain-fed wetlands. Thermal imagery typically has a resolution of 2 to 3 m (if taken at 1000 m altitude) (Morton & Franszen, 2000) and the advantage of thermal imagery is the ability to scan for groundwater-fed systems over large areas of land as well as inaccessible terrain. Another possibility of determining if plants are using groundwater may be xylem water potentials (XPP). If plants are sourcing groundwater then it is expected that XPP should be higher and less variable through the dry summer months than vegetation sourcing rainwater, which would exhibit greater summer declines in XPP. Another method could involve chemical analysis. Rainwater may contain chemical compounds such as trace elements, heavy metals, or pollutants which do not occur in deep groundwater and thus chemical analysis may allow rain-fed systems to be differentiated from deep groundwater-fed systems.

As observed with *L. laureolum* at Cape Point Nature Reserve, lowering of the water table can cause subtle differences such as species composition, size and reproductive ability and these in turn can cause major changes to ecosystem structure and functioning. More importantly these types of changes can be very difficult to detect over the short term. Whilst the TMG Aquifer is confined by a shale layer and thus access by plants to water this aquifer is largely restricted, it is possible that extensive fracturing of the shale layer can have compromised the continuity of this layer. Ironically it is often these highly fractured areas that are most sought after for abstraction projects because they yield superior quantities of water. It is obvious that we are just beginning to understand aquifers and how they work and we need to be careful with how we manage abstraction of water from them.

Conclusion

The overlap of isotopic composition of rainwater and groundwater means that stable isotopes of water extracted from xylem sap will not provide conclusive evidence of whether a wetland, seep or marsh is groundwater-fed or rain-fed. Hence we may have to resort to other methods such as thermal imagery, chemical analysis, and xylem pressure potentials to investigate the dependency of vegetation on groundwater.

I have made a first attempt at developing a list of plant species from the endemic and near-endemic families of the Cape Flora that grow on wetlands, marshes, stream banks, damp slopes, and seeps, and thus may be dependent on groundwater. To the best of my knowledge no such list currently exists. The report also has reaffirmed the idea that many plants, not just those restricted to moist areas, may be reliant on groundwater. Thus a drop in the water table may affect all plant communities, but may be particularly harsh on species that are entirely dependent on groundwater, such as species from endemic and near-endemic families. This study has also shown that changes to a community can be subtle, such as smaller plant size (which can affect dispersal) and lower reproductive output, and these changes can be very difficult to track over the short term.

With Cape Town's current growth and water use patterns it is clear that the city will require an alternative source of water. There will be a point where Cape Town will need further water sources to supplement the current water supply and we will have to proceed with an experimental abstraction. However any large-scale water abstraction needs to be carefully monitored for any negative impacts to plant communities.

Appendix 1

Nearly all rocks and soils in the upper part the Earth's crust are capable of retaining water in pores or voids (Price, 1996). Close to the Earth's surface only some or part of these pores are filled with water and this layer is called the unsaturated zone. Deeper in the soil profile the pores gradually become filled until all the pores are filled with water, and this is referred to as the saturated zone. The upper limit of the saturated zone forms what is commonly called the water table. Technically any water that occurs naturally in the saturated zone (or below the water table) is called groundwater, and any water that occurs in the soil above the water table is called soil water. Not surprisingly the depth of the water table is usually not uniform but tends to fluctuate with the topography, but in a much-subdued fashion, so that the water table is usually deeper beneath mountains and shallower beneath valleys. Groundwater is recharged by precipitation and where the water table intersects the land surface groundwater may emerge as springs, wetlands, seeps or as baseflow into rivers or the sea.

An aquifer refers to any geological formation that contains enough groundwater to yield significant quantities of water to wells and springs. Aquifers are divided into two main types, primary aquifers and secondary aquifers. In primary aquifers water collects and moves through pores and spaces that were created at the time the geological formation was formed. A good example of this type of aquifer is the sandy aquifer under the Cape Flats in Cape Town where water is stored between sand grains. In secondary aquifers the primary porosity has usually been destroyed (e.g. by the cementation process during the formation of sandstones) and thus water collects and moves in spaces that were created after the geological formation formed. Secondary rock aquifers are extremely common in South Africa and are estimated to underlie more than 80% of the country (Van der Voort & Van Tonder, 2000; Brown *et al.*, 2003).

The Table Mountain Group (TMG) is a geological formation of the Cape Supergroup, which can be divided into three conformable series (of the same dip and strike). The Table Mountain Group at the base and the Witteberg Group at the top are composed mainly of quartzitic sandstones. Lying in between these two series is the Bokkeveld Group, which has a much higher shale composition and is thus more clayey in nature than either the TMG or the Witteberg Group (Weaver & Talma, 2000). During the Cape

Orogeny[1] these layers of rock underwent immense pressure causing deformation and fracturing of in the layers. Shales, which usually have a high clay content, tend to be flexible and resistant to fracturing, and thus the Cape Orogeny resulted in the extensive folding of shale layers (Weaver & Talma, 2000). The more brittle sandstone layers fractured and faulted under this immense pressure, particularly the purer sandstones of the TMG (Weaver & Talma, 2000).

The TMG Aquifer System is composed of two main aquifers, namely the Nardouw Aquifer and the Peninsula Aquifer. These two aquifers are separated from each other by the largely impermeable Cedarberg shale formation. Springs often emerge where the contact between Cedarberg shale and TMG sandstone is exposed at the surface, because recharging water cannot easily penetrate the shale layer. Many of these types of springs are referred to as 'perched' because they are primarily maintained by rainwater and not groundwater.

Abstraction is planned from the Peninsula formation typically from where it is confined by the overlying Cedarberg shale. There is already abstraction of significant quantities of groundwater from the TMG Aquifers, mainly by farmers from the Nardouw Aquifer; Hex River (20 mill m^3/yr, Rosewarne, 2002), Oliphants-Doring (12 mill m^3/yr, Hartnady and Hay 2000). However there is currently little abstraction from the Peninsula Aquifer; Kammanassie (1 mill m^3/yr, Cleaver *et al.*, 2003).

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[1] A period of mountain building caused by continental drift resulting in the Cape Fold Belt

Appendix 2

Table A: Species composition of wetland study site and the hill slope study site at the Anvil Hill study area.

Species	% Cover wetland	% Cover hill slope
Lecaudendron laureolum	30%	20%
Metalasia muricata	20%	<1%
Watsonia meriana	10%	
Berzelia abrotanoides	5%	
Mimetes hirtus	<5%	
Elegia cuspidata	<5%	
Elegia stipularis		10%
Erica labialis	<5%	50%
Erica tristis	<5%	
Erica paniculata		10%
Osmitopsis asteriscoides	<1%	
Rhus lucida	<1%	
Diastella divaricata		<1%

Table B: Species composition of marsh study site and the dry study site at the Suurdam study area

Species	% Cover marsh	% Cover dry site
Berzelia abrotanoides	30%	
Restio ambiguus	30%	15%
Erica multumbellifera	30%	
Witsenia maura	<1%	
Erica labialis		60%
Elegia filacea		15%
Diastella divaricata		<5%
Serruria glomerata		<5%

Appendix 3

Table 7: List of species from endemic and near-endemic families of the Cape Flora that may have a possible dependence on groundwater (Source: Goldblatt & Manning, 2000)

Family	**Genus**	**Species**	**Distribution**
Penaeaceae	*Endonema*	*lateriflora*	Rocky sandstone slopes along stream banks
	Glischrocolla	*formosa*	Wetlands and rocky cliffs
	Penaea	*acutifolia*	Damp sandstone slopes
	Penaea	*cneorum*	Damp sandstone slopes
	Penaea	*dahlgrenii*	Sandstone slopes along stream banks
	Stylapterus	*barbatus*	Damp slopes
	Stylapterus	*ericoides*	Stream banks
	Stylapterus	*micranthus*	Stream banks
Stilbaceae	*Kogelbergia*	*verticillata*	Moist slopes
Grubbiaceae	*Grubbia*	*rosmariniflora*	Damp sandstone slopes
	Grubbia	*rourkei*	Damp sandstone slopes
	Grubbia	*tomentosa*	Damp sandstone slopes
Roridulaceae	*Roridula*	*dentata*	Swampy sandstone slopes
	Roridula	*gorgonias*	Swampy sandstone slopes
Geissolomataceae	*Geissoloma*	*marginata*	Langeberg mountains
Bruniaceae	*Berzelia*	*lanuginosa*	Damp sanstone slopes, seeps and stream banks
	Berzelia	*ecklonii*	Marshy sandstone slopes
	Brunia	*albiflora*	Marshy on peaty sandstone
	Lonchostoma	*esterhuyseniae*	Wet sandstone rocks
	Lonchostoma	*monogynum*	Sandstone slopes in seeps and marshes
	Lonchostoma	*myrtoides*	Sandstones slopes in seeps and marshes
	Lonchostoma	*pentandrum*	Montane marshes
	Lonchostoma	*purpureum*	Marshy montane slopes
	Mniothamnea	*bullata*	Damp sandstone rocks
	Mniothamnea	*callunoides*	Damp sandstone rocks
	Pseudobaeckia	*africana*	Stream banks on sandstone slopes
	Pseudobaeckia	*cordata*	Montane marshes, seeps and streams
	Pseudobaeckia	*stokoei*	Sandstone slopes near streams
	Raspalia	*virgata*	Moist rocky slopes and stream banks
	Raspalia	*sacculata*	Damp sandstone and clay slopes
	Raspalia	*villosa*	Rocky, damp to marshy sandstone slopes

Appendix 4

Table C: Volume (m^3) and number of reproductive structures of for six *L. laureolum* (male and female) and *M. muricata* individuals growing on the wetland study site.

	Leucadendron laureolum						***Metalasia muricata***		
	Male			Female					
	Ht (cm)	Vol (m3)	No. reprod.	Ht (cm)	Vol (m3)	No. reprod.	Ht (cm)	Vol (m3)	No. reprod.
1	150	20.5	530	160	9.2	100	105	0.68	350
2	150	18.2	350	150	2.7	80	110	0.39	100
3	145	12.2	280	160	5.1	130	65	0.82	120
4	240	22.5	200	120	0.7	5	110	2.30	800
5	130	2.9	20	150	1.6	27	55	0.25	30
6	170	13.3	250	160	3.5	25	90	2.00	200

Table D: Volume (m^3) and number of reproductive structures of for six *L. laureolum* (male and female) and *M. muricata* individuals growing on the hill slope study site.

	Leucadendron laureolum						***Metalasia muricata***		
	Male			Female					
	Ht (cm)	Vol (m3)	No. reprod.	Ht (cm)	Vol (m3)	No. reprod.	Ht (cm)	Vol (m3)	No. reprod.
1	110	3.8	10	105	2.3	25	75	2.14	600
2	86	1.4	50	110	2.0	17	30	0.23	100
3	64	0.2	0	100	0.6	9	20	0.01	15
4	75	0.1	2	100	0.4	3	60	1.01	350
5	100	1.1	40	80	0.8	6	66	0.66	30
6	95	1.1	40	90	0.1	3	50	0.12	80

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