TMGA Ecological and Hydrogeological Monitoring (2010 – 2013)

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FINAL

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GLOSSARY, ACRONYMS AND ABBREVIATIONS

Glossary

Alluvial aquifer: an aquifer formed of unconsolidated sediments deposited by flowing water (river or stream); typically occurring beneath or alongside a current channel, or in a buried old or palaeo-channel of the river (from Colvin *et al.,* 2007).

Alluvial: a deposit formed by flowing water, often in the valleys of large rivers.

Aquiclude: A geologic formation, group of formations, or part of formation through which virtually no water moves, hence it is essentially impervious to water.

Aquifer: a geological formation, which has structures or textures that hold water or permit appreciable water (sufficient to supply a well or borehole) movement through them (from National Water Act (Act No. 36 of 1998)).

Aquifer-dependent ecosystems (ADE): ecosystems that depend on groundwater in or discharging from an aquifer (Colvin *et al.,* 2007). They are distinctive because of their connection to the aquifer and would be fundamentally altered in terms of their structure and functions if groundwater was no longer available.

Aquitard: a saturated body of poorly permeable rock that is capable of slowly absorbing water from and releasing it to an aquifer. It does not transmit water rapidly enough, by itself, to directly supply a borehole or spring (McGraw-Hill, 1978).

Arenaceous: composed of sand or sandstone.

Argillaceous: composed of very fine-grained material, such as clay, shale, etc.

Artesian borehole: A borehole that penetrates a confined aquifer in which the piezometric surface is above ground level, so that the borehole spontaneously discharges water without being pumped.

Base flow: that part of the stream discharge that is not attributable to direct runoff from precipitation; not necessarily all contributed by groundwater; includes contributions from interflow and groundwater discharge. Base flow is not a measure of the volume of groundwater discharged into a river or wetland, but it is recognised that groundwater makes a contribution to the base flow component of river flow. The term groundwater contribution to base flow should be used.

Baseflow recession curve: a recession curve of streamflow so adjusted that the slope of the curve is meant to represent the runoff depletion rate of the base flow.

Borehole: includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer (from National Water Act (Act No. 36 of 1998)).

Cape Fold Belt: folded sedimentary sequence of rocks in the south-western Cape, comprising shales in the valleys and erosion-resistant sandstone forming the mountain ranges.

Capillary fringe: the subsurface layer in which groundwater seeps up from a water table by capillary action to fill pores. Pores at the base of the capillary fringe are filled with water due to tension saturation.

Channel: an open conduit with clearly defined margins that (i) continuously or periodically contains flowing water, or (ii) forms a connecting link between two waterbodies.

Channelled valley-bottom wetland: a mostly flat valley-bottom wetland dissected by and typically elevated above a channel. Dominant water inputs to these areas are typically from the channel, either as surface flow resulting from overtopping of the channel bank/s or as interflow, or from adjacent valley-side slopes (as overland flow or interflow). Water generally moves through the wetland as diffuse surface flow, although occasional, short-lived concentrated flows are possible during flooding events. Small depressional areas within a channelled valley-bottom wetland can result in the temporary containment and storage of water within the wetland. Water generally exits in the form of diffuse surface flow and interflow, with the infiltration and evaporation of water from these wetlands also being potentially significant (particularly from depressional areas). The hydrodynamic nature of channelled valley-bottom wetlands is characterised by bidirectional horizontal flow, with limited vertical fluctuations in depressional areas.

Colluvial: material deposited through gravity.

Confined aquifer: A confined aquifer has its upper and lower boundaries marked by aquicludes (confining beds), confined groundwater is generally subject to pressure greater than atmospheric. This pressure causes water in a borehole to rise above the top of the aquifer layer . If the pressure causes the water to rise above ground level, the well overflows and is called an artesian well.

Conglomerate: this is a rock consisting of individual clasts within a finer-grained matrix that have become cemented together. Conglomerates are sedimentary rocks consisting of rounded fragments.

Discharge area: an area in which subsurface water, including water in the unsaturated and saturated zones, is discharged at the land surface; may be associated with a wetland or a stream (from Colvin *et al.*, 2007).

Drawdown: the difference between the water level observed during abstraction and the rest water level when no abstraction is taking place, measured in the abstraction and or observation borehole (McGraw-Hill, 1978).

Ductile: refers to the ability of a material to deform elastically without fracture, i.e. whether the material can be stretched into a wire.

Ecochannels: TMGA ecological monitoring river channel sites.

Ecoseeps: TMGA ecological monitoring wetland (both seeps and valley-bottom wetlands) sites.

Edaphic: of or relating to the physical and chemical conditions of the soil, especially in relation to the plant and/or animal life it supports.

Flora: the plant species occurring in a particular area; usually recorded as present or absent.

Fractured aquifer: an aquifer that owes its water-bearing properties to water storage and flows through fractures in the rock caused by folding and faulting (from Colvin *et al.*, 2007).

Granitic plutons: a pluton in geology is an intrusive igneous rock (called a plutonic rock) body that crystallized from magma slowly cooling below the surface of the Earth. Plutons include batholiths, dikes, sills, laccoliths, lopoliths, and other igneous bodies. In practice, "pluton" usually refers to a distinctive mass of igneous rock, typically kilometres in dimension, without a tabular shape like those of dikes and sills. Batholiths commonly are aggregations of plutons. The most common rock types in plutons are granite, granodiorite, tonalite, monzonite, and quartz diorite. The term originated from Pluto, the ancient Roman god of the underworld. Outcrop of plutonic granite on the earth's surface requires some kind of erosion to expose the buried granite. Granites may take the form of batholiths; sills and sheets; swarms of plutonic intrusions or migmatite complexes. They form the major part of surface exposure of continental crust.

Greywacke: this is a variety of sandstone generally characterized by its hardness, dark colour, and poorly-sorted, angular grains of quartz, feldspar, and small rock fragments or lithic fragments set in a compact, clay-fine matrix. It is a texturally immature sedimentary rock. The larger grains can be sand- to gravel-sized, and matrix materials generally constitute more than 15% of the rock by volume. The term 'Greywacke' can be confusing, since it can refer to either the immature (rock fragment) aspect of the rock or the fine-grained (clay) component of the rock.

Groundwater: water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.

Groundwater-dependent ecosystems (GDEs): ecosystems that must have access to groundwater to maintain their ecological structure and function (from Murray, 2006, cited in Colvin *et al.*, 2009).

Habitat: the natural home of species of plants or animals.

Hillslope seep: a wetland area located on (gently to steeply) sloping land, which is dominated by the colluvial (i.e. gravity-driven), unidirectional movement of material down-slope. Water inputs are primarily from groundwater or precipitation that that enters the wetland from an up-slope direction in the form of subsurface flow. Water movement through the wetland is mainly in the form of interflow, with diffuse overland flow (sheetwash) often being significant during and after rainfall events. Water leaves a hillslope seep with channelled outflow mostly by means of concentrated surface flow, whereas water leaves a hillslope seep without channelled outflow by means of a combination of diffuse surface flow, interflow, evaporation and infiltration.

Hornfels: this is the group designation for a series of contact metamorphic rocks that have been baked by the heat of intrusive igneous masses and have been rendered massive, hard, splintery, and in some cases exceedingly tough and durable. Most hornfels are fine-grained, and while the original rocks (such as sandstone, shale and slate, limestone and diabase) may have been more or less fissile owing to the presence of bedding or cleavage planes, this structure removed in the hornfels.

Hydraulic conductivity: measure of the ease with which water will pass through earth material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (in m/d)

Hydraulic gradient: the slope of the water table or piezometric surface; is a ratio of the change of hydraulic head divided by the distances between the two points of measurement.

Hydraulic lift: the process whereby deep rooting plants take up groundwater during the day, and release it at night at shallower depths.

Interflow: lateral movement of water that occurs in the upper part of the unsaturated zone, or vadose zone, that **directly** enters a stream channel or wetland without having occurred first as surface runoff (from www.physicalgeography.net, January 2010).

Intermittently inundated: holding surface water irregularly for changeable time periods of less than one season's duration (but generally for periods of less than 3 to 4 weeks), at intervals varying from less than a year to several years.

Lower foothill River: lower-gradient, mixed-bed alluvial channel with sand and gravel dominating the bed and may be locally bedrock controlled; reach types typically include pool-riffle or pool-rapid, with sand bars common in pools; pools are of significantly greater extent than rapids or riffles. Characteristic gradient is 0.001–0.005.

Mountain stream: steep-gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools; reach types include cascades, bedrock fall, step-pool; approximately equal distribution of vertical and horizontal flow components. Characteristic gradient is 0.04–0.99.

Never inundated: never covered by water for more than a few days at a time (up to one week at most), but saturated with water at least intermittently for one week or more at a time.

Non-perennial: does not flow or hold water continuously throughout the year.

Peat: a dark brown or black organic soil layer, composed of partly decomposed plant matter, and formed under permanently saturated conditions.

Pelitic: of sedimentary rock made up of fine material, such as clay or mud (see also argillaceous).

Perched water table: the surface of a local zone of saturation held above the main body of groundwater by an impermeable layer or stratum, usually clay, and separated from the main body of groundwater by an unsaturated zone.

Perennial: flows or holds water continuously throughout the year.

Permanently inundated: with surface water present throughout the year.

Permanently saturated: where all the pores between the soil particles are permanently filled with water.

Petrography: study dealing with microscopic details of rock, looking at the mineral content and textural relationships.

Phreatic zone = saturated zone: The saturated zone is that part of the earth's crust beneath the regional water table or piezometric surface in which all voids, large and small, are filled with water under pressure greater than atmospheric.

Phyllite: a type of foliated metamorphic rock primarily composed of quartz, sericite mica, and chlorite. The rock represents a gradation in the degree of metamorphism between slate and mica schist. Minute crystals of graphite, sericite, or chlorite impart a silky, sometimes golden sheen to the surfaces of cleavage (or schistosity). Phyllite is formed from the continued metamorphism of slate, under low grade metamorphic conditions. They are usually black or gray, and the foliation is commonly crinkled or wavy in appearance.

Piezometer: narrow diameter piping that is installed through a means of water jetting, auguring or drilling to enable measurement of the depth of the groundwater level and also sampling of groundwater if required for analysis purposes.

Piezometric surface: An imaginary or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi-confined aquifer; analogous to the water table of an unconfined aquifer.

Quartzite: this is a hard metamorphic rock which was originally sandstone. Sandstone is converted into quartzite through heating and pressure usually related to tectonic compression within orogenic belts. Pure quartzite is usually white to grey. When sandstone is metamorphosed to quartzite, the individual quartz grains recrystallize along with the former cementing material to form an interlocking mosaic of quartz crystals. Most or all of the original texture and sedimentary structures of the sandstone are erased by the metamorphism.

Recharge: a hydrologic process where water moves downward from the earth's surface to groundwater (i.e. the saturated zone). This process usually occurs through the vadose zone below plant roots and is often expressed as a flux to the water table surface.

Seasonal: with water present for extended periods during the wet season but not during the rest of the year.

Seasonally inundated: with surface water present for extended periods (usually more than three to four weeks duration) during the wet season but drying up annually, either to complete dryness or to saturation during the dry season.

Seasonally saturated: with all the spaces between the soil particles filled with water for extended periods (3 – 10 months of the year), usually during the wet season, but dry for the rest of the year (during the dry season).

Semi-confined aquifer: an aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur, also referred to as a leaky aquifer (from Colvin *et al.*, 2007).

Shale: This is a fine-grained, clastic sedimentary rock composed of mud, which is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable. Shale is characterized by breaks along thin laminae or parallel layering or bedding less than one centimetre in thickness, called fissility. (Mudstones, on the other hand, are similar in composition but do not show the fissility).

Slate: this is a fine-grained, foliated, homogeneous metamorphic rock derived from an original shale-type sedimentary rock composed of clay or volcanic ash through low grade regional metamorphism. The result is a foliated rock in which the foliation may not correspond to the original sedimentary layering. Slate is frequently grey in colour especially when seen en masse covering roofs. However, slate occurs in a variety of colours even from a single locality. Slate is not to be confused with shale, from which it may be formed.

Slope: an inclined stretch of ground that is not part of a valley floor, which is typically located on the side of a mountain, hill or valley (includes scarp slopes, mid-slopes and footslopes). Slopes are considered to be those areas where the gradient is steeper than 0.001 (i.e. 1:1000).

Soil profile: a vertical section of the soil through all its horizons and extending to the underlying material.

Soil water: water held in the soil pores (gaps between the particles), in both liquid and vapour phases (McGraw-Hill, 1978) - may be saturated or unsaturated (wet or dry). Measured as **volumetric soil moisture content**, as a percentage of the soil dry weight (% by weight) but sometimes as the volume of water as a percentage of the soil volume (% by volume) or as the depth of water per metre depth of soil (m/m). **Soil saturation** is the water content of a soil when all the pores (total porosity) are filled with water, while the **degree of soil saturation** is the water content of a soil expressed as a percentage of the total porosity (saturated water content).

Spring: a distinct point where groundwater emerges at the surface, usually as a result of topographical, lithological or structural controls.

Standard Light Antarctic Precipitation (SLAP): a water standard defining the isotopic composition of precipitation.

Standard Mean Ocean Water (SMOW): a water standard defining the isotopic composition of freshwater.

Sub-greywacke: texturally and mineralogically immature sandstones that contain more than 15% clay minerals, however the fragments of quartz and feldspar are sub-rounded (not angular). The matrix comprises clay minerals, chlorite and carbonate

Subsurface water: all water which occurs beneath the surface of the earth, including soil moisture, liquid water in the vadose zone and groundwater (from Colvin *et al.,* 2007).

Terrane: a fragment of crustal material formed on, or broken off from, one tectonic plate and accreted — "sutured" — to crust lying on another plate. The crustal block or fragment preserves its own distinctive geologic history, which is different from that of the surrounding areas (hence the term "exotic" terrane). The suture zone between a terrane and the crust it attaches to is usually identifiable as a fault.

Throughflow: lateral movement of water that occurs in the upper part of the unsaturated zone, or vadose zone, which emerges first as surface runoff before entering a waterbody (from www.physicalgeography.net, January 2010).

Transitional river: moderately steep stream dominated by bedrock and boulders; reach types include plain-bed, pool-riffle or pool-rapid; usually in confined or semi-confined valley. Characteristic gradient is 0.02–0.039.

Transmissivity: the rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d); product of the thickness and average hydraulic conductivity of an aquifer.

Unconfined aquifer: these are sometimes also called water table or phreatic aquifers, because their upper boundary is the water table or phreatic surface. It is an aquifer without an upper confining layer of impermeable or low permeability soil or rock material. The water table is exposed to the atmosphere through a series of interconnected openings in the overlying soil and/or rock layers and is in equilibrium with atmospheric pressure.

Unconformably: where a series of younger strata do not succeed the underlying older rocks in age or in parallel position, as a result of a long period of erosion or non-deposition.

Upper foothill river: moderately steep, cobble-bed or mixed bedrock-cobble bed channels, with plain-bed, pool-riffle or pool-rapid reach types; length of pools and riffles/rapids is similar. Characteristic gradient is 0.005–0.019.

Vadose zone: the unsaturated zone above the water table and below the ground surface.

Valley floor: the typically gently sloping, lowest surface of a valley – i.e. an elongated, relatively narrow region of low land between ranges of mountains, hills, or other high areas (such as sand dunes), often having a river or stream running along the bottom. For the purposes of the classification system, valley floors exclude areas situated between two valley side-slopes with a gradient of 0.1 or more (i.e. ≥ 1:10). The valley floor typically has a gradient of between 0.001 and 0.1 (i.e. 1:1000 to 1:10).

Vegetation: the structure and floristics of the plant life of a given area, which is distinct due to its broad habitat. Unlike flora (presence and absence), this includes dominance/abundance of plant species.

Water table: the upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.

Wetland: land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports or would support vegetation typically adapted to life in saturated soil (National Water Act).

Acronyms and abbreviations

^{18}O	Oxygen-18
BH_ID	borehole identity number
CGS	Council for Geoscience
cm	centimetre
CMWL	Cape meteoric water line
D	deuterium (^{2}H)
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EPM	Exploratory Phase Monitoring
FCG	Freshwater Consulting Group
GEOSS	Geohydrological and Spatial Solutions International (Pty) Ltd;
GMWL	global meteoric water line
H	height
H_Spr	hot spring
km	kilometre
LMWL	local meteoric water lines
m	metre
m/s	metres per second
m^3/d	cubic metres per day
m^3/s	cubic metres per second
Ma	Million years
ma.logger	metres above data logger
mbch	metres below collar height
mbgl	metres below ground level
mm	millimetres
mm/a	millimetres per annum (year)
mm/month	millimetres per month
$10^6m^3/m$	million cubic metres per month
MOD	moderate
MONAREA	monitoring area
mS/m	milliSiemens per metre
^{o}C	degrees Celsius
OD	outer diameter
ORP	Oxygen Reduction Potential
Pal	Palmiet River
PIEZO_ID	piezometer identity number
R^2	correlation coefficient
RSE	Riviersonderend River
SANBI	South African National Biodiversity Institute
SLAP	Standard Light Antarctic Precipitation
SMOW	Standard Mean Ocean Water
SPR	spring
SRTM	Shuttle Radar Topography Mission

STR	stream
T	Temperature
TDS	Total Dissolved Solids
Temp	temperature
TMG	Table Mountain Group
TMGA	Table Mountain Group Aquifer
TMGAA	Table Mountain Group Aquifer Alliance
TMGA-EMA	Table Mountain Group Aquifer - Ecohydrological Monitoring Alliance
TMGID	Table Mountain Group identity number
TSA	Target Site Areas
UCT	University of Cape Town
V	velocity
W	width
W_G	weir gauge
WL	water level
WL	water level
WQ-F	water quality - field measurements
WQ-I	water quality – isotope measurements
WQ-L	water quality – laboratory measurements
WRC	Water Research Commission

1 INTRODUCTION

1.1 Background to the project

The Table Mountain Group Aquifer (TMGA) Feasibility Study and Pilot Project commenced in May 2002 with the appointment of the TMGA Alliance (the 'TMGAA') by the Resource and Infrastructure Planning Branch of the Bulk Water Department of the City of Cape Town (the 'Client'). The TMGAA was tasked with investigating the viability of the TMGA, as a bulk water resource for the City, and with assessing the risks associated with its use. While the TMGA system extends from just north of Nieuwoudtville southwards to Cape Agulhas and eastwards to Port Elizabeth, the TMGA project focuses on the confined portions of the Peninsula Aquifer located throughout the study area (Figure 1.1), and where the development of well-fields for bulk water supply to the City may be feasible in terms of existing reticulation infrastructure.

The TMGAA adopted a phased approach to the TMGA project, as follows:

- The Inception Phase (May 2002 – October 2002) involved the finalisation of the Terms of Reference for the Feasibility Study as a whole.
- The Preliminary Phase (May 2002 – August 2004) included the following main activities:
    - The development of a preliminary regional and local-scale conceptual flow model (City of Cape Town, 2004a);
    - The collation of datasets and database design and management;
    - The identification of six broad geographical locations, or Target Zones, for potential well-fields and exploratory drilling, and within these a number of Target Site Areas (TSAs), within which Exploration Boreholes could be located;
    - The spatial overlay of the TSAs with important conservation areas for aquatic and terrestrial biodiversity to produce a first level refinement of a short-list of eleven TSAs to be taken forward to the Exploration Phase;
    - A hydrocensus to identify relevant seep and spring zones - Groundwater Dependent Ecosystems (GDEs) - in the TSAs; and
    - The identification of the need and importance of a monitoring programme, and the development of a Monitoring Framework (City of Cape Town, 2004b; 2005).
- The Exploratory Phase (September 2004 - ongoing) includes the following:
    - The drilling of ten Exploratory Boreholes, in three of the short-listed TSAs, H8, T4 and W7. Monitoring and testing were initiated, with the aim of verifying the predicted aquifer characteristics, refining the location of the target well-fields and evaluating the risks associated with these;
    - The continuation of broader regional hydrogeological, hydrological and climate monitoring, but rationalised after evaluation of monitoring data; and
    - The use of the Monitoring Framework developed in the Preliminary Phase by the TMGAA Monitoring Task Team to develop an Ecological and Hydrogeological Monitoring Protocol, which was adopted for the Exploratory Phase Monitoring (EPM) project.
- The final Pilot Testing Phase (still to be initiated) will comprise the drilling of a number of Pilot Boreholes in order to develop at least one well-field with a target yield of 3 to 5 million m^3/a. Monitoring will continue.

In 2007 the Table Mountain Group Aquifer - Ecohydrological Monitoring Alliance (TMGA-EMA), a joint venture between GEOSS and the Freshwater Consulting Group, was contracted to undertake the

Exploratory Phase Ecological and Hydrogeological Monitoring project, or EPM project, which comprised the collection of baseline data from 2007 to 2010. Data were collected from *c*. 40 ecological monitoring sites, spanning ten of the 11 TSAs shortlisted in the Preliminary Phase[1], and a final data report was submitted in July 2010. The Monitoring Protocol developed by the TMGAA Monitoring Task Team for the EPM project was refined based on the results of the 2010 report. On the 2nd July 2010, the City of Cape Town issued a tender document (Contract Number 1C/2010/11) inviting proposals for the 2010 – 2013 TMGA Ecological and Hydrogeological Monitoring project. The Freshwater Consulting Group (FCG), in association with a number of sub-contractors, was subsequently appointed on the 31st December 2010 to undertake this work.

Due to the fact that the Pilot Phase has not yet commenced, the 2010 – 2013 TMGA Ecological and Hydrogeological Monitoring project is a continuation of the EPM project, focusing on the establishment of baseline information from the TMGA study area. This contract is thus referred to as EPM2, to distinguish it from the 2007 - 2010 monitoring, which is now referred to as EPM1.

1.2 Aims and objectives of the EPM2 project

The Exploratory Phase Monitoring as a whole was designed to establish baseline information on the nature of representative aquatic ecosystems within the TMGA study area that are expected to be hydraulically linked with the Peninsula Aquifer, against which future monitoring of potential impacts associated with abstraction from the Aquifer (during pilot and later phases) will be evaluated. A range of physical parameters will be used to detect changes related to a possible decline in water supply as a result of abstraction from the Peninsula Aquifer, while the measurement of a number of biological parameters will be used to assess the significance of these changes for aquatic and terrestrial biota.

Under the auspices of the TMGAA Monitoring Task Team, the EPM1 project tested a number of monitoring techniques, and collected baseline data from a number of monitoring sites. During EPM2, FCG continued to collect, analyse, transform, interpret and store baseline data from a reduced number of monitoring sites (see Figure 1.1) using the fine-tuned Monitoring Protocol. The focus in EPM2 was to ensure that a viable comparable baseline data set is established prior to abstraction of water from the TMGA.

The activities in EPM2 are divided into a number of tasks, as follows:

TASK 1: Site setup and installation;

TASK 2: Datasheets and database design;

TASK 3: Ecological site monitoring;

TASK 4: Routine data collection and collation for regional monitoring;

TASK 5: Aerial photography and remote sensing analysis;

TASK 6: Data processing and storage;

TASK 7: Data analysis; and

TASK 8: Reporting.

EPM3 is expected to follow EPM2, and so on until the commencement of the Pilot Phase Monitoring (PPM). The establishment of a Pilot Phase well-field will signal the end of EPM and commencement of PPM.

[1] *Sites located in TSA T2 were all rejected at the Inception Phase of the EPM1 project as this TSA is not being considered as a potential Pilot well-field, and the sites there were either forested with or recently cleared of invasive alien plants (TMGA-EMA, 2008).*

1.3 Structure and objectives of the EPM2 Monitoring Report

The Final EPM2 Monitoring Report is divided into four volumes:

Volume 1 is the Monitoring Framework and Protocol, providing the regional conceptual model of the Table Mountain Group Aquifer as background to an explanation of the monitoring framework, a summary description of the network of monitoring sites and detailed descriptions and maps of the monitoring sites.

Volume 2 is a Method Statement, containing a summary description of the network of monitoring sites (as in Volume 1) and the methods used during EPM2 for the implementation of the Monitoring Protocol detailed in Volume 1. This volume refers back to the Tender Document for EPM2, and how and why methods have changed through EPM2.

Volume 3 is a Data Report, which contains a summary of the data collected and collated from April 2011 till April 2013, including data from EPM1 and before, where possible.

Volume 4 (this report) is a Data Analysis Report documenting and interpreting the analyses done on all project datasets.

The **TMGA Database** is a collation of all the data collected and collated throughout EPM1 and EPM2, and includes automated data files for the upload and quality control of new data.

1.4 Network of monitoring sites

The monitoring sites fall into two broad categories –regional monitoring sites and ecological monitoring sites (see Figure 1.1). The sites are described in detail in Volume 1 of the Monitoring Report 2013, and summarised in Table 1.1. Briefly, the **regional monitoring sites** comprise a network of boreholes, rainfall gauges, weather stations and gauging weirs, from which baseline data regarding regional hydrogeology, hydrology and climate are provided. These comprise:

- 14 cumulative rainfall gauges and 13 weather stations;
- 10 exploration boreholes drilled specifically for the TMGA project;
- 10 WRC monitoring boreholes;
- 18 DWA monitoring boreholes drilled in Wemmershoek and Nuweberg, and
- Four DWA streamflow gauging stations.

The **ecological monitoring sites** or ‘ecosites’ comprise 9 seeps and 8 rivers.

Table 1.1. List of monitoring sites referred to in this report, with altitudes, and distances to other sites.

TSA	Site	Type of site	Altitude (mamsl)		Closest TMG borehole	Distance to closest borehole (m)	Closest CRG	Distance closest to CRG (m)	Closest weather station	Distance to closest weather station (m)
SOS	B1_1	seep	P1	356	TMG461	6954	CRG 14	25	Rustfontein (0006332_9) (SAWS)	3300
			P2	354						
	CRG14	cumulative rainfall gauge	360		TMG461	6980				
Steenbras	H8_3a	channel	384		H8A1	898	CRG8	4430	Steenbras IV (0005760_3) (SAWS)	2461
	H8_3b	seep	P1	395	H8A1	827	CRG8	4480	Steenbras IV (0005760_3) (SAWS)	2522
			P2	392						
			P3	390						
	CRG8	cumulative rainfall gauge	396		H8A3	3700				
	CRG9	cumulative rainfall gauge	?		H8A3	5200				
	CRG10	cumulative rainfall gauge	869		H8A1	2929				
	H8A1	TMGA expl & monitoring borehole	427				CRG10	2930	Steenbras IV (0005760_3) (SAWS)	3334
	H8A3	TMGA expl & monitoring borehole	415				CRG10	3105	Steenbras IV (0005760_3) (SAWS)	3521
Kogelberg	K_1	seep	P1	115	TMG544	62	CRG 11	840	Kogelberg WS then Oudebosch (0005829_9) (SAWS)	640
			P2	105						
	K_2a	channel	78		TMG544	317	CRG 11	570	Kogelberg WS	720
	K_2b	seep	P1	87	TMG544	368	CRG 11	440	Kogelberg WS	890
			P2	82						
	K_5a	channel	62		TMG485	4662	CRG 11	4710	Kogelberg WS	4489
	K_5b	seep	P1	76	TMG485	4914	CRG 11	4920	Kogelberg WS	4748
			P2	72						

TSA	Site	Type of site	Altitude (mamsl)	Closest TMG borehole	Distance to closest borehole (m)	Closest CRG	Distance closest to CRG (m)	Closest weather station	Distance to closest weather station (m)
	K_6	seep	P1 86 P2 82	TMG544	213	CRG 11	620	Kogelberg WS	732
	Kogelberg weather station	TMGA	48	TMG485	378	CRG 11	1260		
	CRG 11	cumulative rainfall gauge	120	TMG544	828			Kogelberg WS	1260
	TMG456	TMGA regional borehole	43			CRG 11	1595	Kogelberg WS	470
	TMG457	TMGA regional borehole	43			CRG 11	2045	Kogelberg WS	480
	TMG458	TMGA regional borehole	80			CRG 11	915	Kogelberg WS	462
	TMG466	TMGA regional borehole	33			CRG 11	2670	Kogelberg WS	2929
	TMG485	TMGA regional borehole	65			CRG 11	940	Kogelberg WS	378
	TMG544	TMGA regional borehole	94			CRG 11	830	Kogelberg WS	575
Nuweberg	T3_Pal4	seep	P1 770 P2 757	T4D1	627	CRG 1	2050	Nuweberg (0006065_1) (SAWS)	1640
	T4_Pal1	channel	614	T4B1	357	CRG 2	260	Nuweberg (0006065_1) (SAWS)	2827
	T4_Pal3	channel	620	T4D1	222	CRG 1	1920	Nuweberg (0006065_1) (SAWS)	1424
	CRG 1	cumulative rainfall gauge	509	T4D1	1730			Nuweberg (0006065_1) (SAWS)	560
	CRG 2	cumulative rainfall gauge	642	T4B1	605			Nuweberg (0006065_1) (SAWS)	3085
	CRG 3	cumulative rainfall gauge	1058	T4B1	3270			Nuweberg (0006065_1) (SAWS)	5060
	CRG 4	cumulative rainfall gauge	-	T4E2	1885			Nuweberg (0006065_1) (SAWS)	1120

TSA	Site	Type of site	Altitude (mamsl)	Closest TMG borehole	Distance to closest borehole (m)	Closest CRG	Distance closest to CRG (m)	Closest weather station	Distance to closest weather station (m)
	T4B1	TMGA expl & monitoring borehole	610			CRG2	618	Nuweberg (0006065_1) (SAWS)	2486
	T4C2	TMGA expl & monitoring borehole	604			CRG2	894	Nuweberg (0006065_1) (SAWS)	2243
	T4C3	TMGA expl & monitoring borehole	629			CRG2	1054	Nuweberg (0006065_1) (SAWS)	2348
	T4D1	TMGA expl & monitoring borehole	626			CRG1	1736	Nuweberg (0006065_1) (SAWS)	1224
	T4E2	TMGA expl & monitoring borehole	587			CRG4	1887	Nuweberg (0006065_1) (SAWS)	1669
	T4-1 (BE00040)	DWA borehole	523			CRG4	955	Nuweberg (0006065_1) (SAWS)	1276
	T4-2 (BE00045)	DWA borehole	333			CRG4	2289	Nuweberg (0006065_1) (SAWS)	2870
	T4-3 (BE00044)	DWA borehole	550			CRG1	2285	Nuweberg (0006065_1) (SAWS)	2333
	T4-5 (BE00041)	DWA borehole	491			CRG1	4046	Nuweberg (0006065_1) (SAWS)	4620
	T4-6 (BE00043)	DWA borehole	512			CRG4	5458	Nuweberg (0006065_1) (SAWS)	6162
	T4-7 (BE00047)	DWA borehole	340			CRG12	2409	Robertsvlei (0022148_3) (SAWS)	4633
	T4-8 (BE00046)	DWA borehole	373			CRG4	8568	Chiltern Dam Wall (20079)	4885
	T4-9 (BE00048)	DWA borehole	346			CRG4	2307	Nuweberg (0006065_1) (SAWS)	2919
	T4-10 (BE00049)	DWA borehole	380			CRG1	2167	Nuweberg (0006065_1) (SAWS)	2240
	T4-11 (BE00050)	DWA borehole	340			CRG12	2414	Robertsvlei (0022148_3) (SAWS)	4613
Boesmanskloof	T6_1a	channel	350	T4C3	7658	CRG 12	221	Chiltern Dam Wall (20079)	5690
	T6_1b	seep	P1 370 P2 366	T4C3	7515	CRG 12	307	Chiltern Dam Wall (20079)	5735
	T6_2a	channel	385	TMG461	7830	CRG 12	610	Chiltern Dam Wall (20079)	5600
	T6_4	seep	P1 380	TMG461	8000	CRG 12	455	Chiltern Dam Wall (20079)	5670

TSA	Site	Type of site	Altitude (mamsl)	Closest TMG borehole	Distance to closest borehole (m)	Closest CRG	Distance closest to CRG (m)	Closest weather station	Distance to closest weather station (m)
			P2 370						
	CRG 12	cumulative rainfall gauge	360	T4C3	7725			Chiltern Dam Wall (20079)	5645
	20079 (Chiltern Dam Wall)	ARC	308	T4C3	8785	CRG12	5645		
Purgatory	T8_2a	channel	386	TMG459	346	CRG 13	300	Purgatory WS	60
	T8_2b	seep	P1 440 P2 436	TMG459	646	CRG 13	300	Purgatory	360
	Purgatory weather station	TMGA	385	TMG459	311	CRG 13	380		
	CRG 13	cumulative rainfall gauge	431	TMG459	695			Purgatory WS	
	20139 (High Noon)	ARC	606	TMG459	11000	CRG13	10600		
	TMG459	TMGA regional borehole	360			CRG13	697	Purgatory WS	311
	TMG460	TMGA regional borehole	350			CRG13	744	Purgatory WS	371
	TMG461	TMGA regional borehole	351			CRG13	1253	Purgatory WS	866
	TMG462	TMGA regional borehole	346			CRG13	1250	Purgatory WS	862
Wemmershoek	W7_4	channel	315	W7D1	43	CRG 6	2350	La Motte (30453)	7335
	CRG 5	cumulative rainfall gauge	797	W7K1	2320			La Motte (30453)	9300
	CRG 6	cumulative rainfall gauge	290	W7F2	800			La Motte (30453)	8175
	CRG 7	cumulative rainfall gauge	496	W7K1	1750			La Motte (30453)	7350
	30453 (La Motte)	ARC	207	W7K1	6980	CRG6			
	W7D1	TMGA expl & monitoring	325			CRG6	2339	La Motte (30453)	7280

TSA	Site	Type of site	Altitude (mamsl)	Closest TMG borehole	Distance to closest borehole (m)	Closest CRG	Distance closest to CRG (m)	Closest weather station	Distance to closest weather station (m)
		borehole							
	W7F2	TMGA expl & monitoring borehole	324			CRG6	727	La Motte (30453)	7469
	W7K1	TMGA expl & monitoring borehole	274			CRG7	1752	La Motte (30453)	7000
	W7-1 (BG00091)	DWA borehole	251			CRG5	4171	La Motte (30453)	13442
	W7-3 (BG00093)	DWA borehole	392			CRG5	1301	La Motte (30453)	9987
	W7-4 (BG00094)	DWA borehole	191			CRG7	1416	La Motte (30453)	8152
	W7-5 (BG00095)	DWA borehole	200			CRG7	3069	La Motte (30453)	4365
	W7-6 (BG00096)	DWA borehole	305			CRG6	8676	La Motte (30453)	2886
	W7-7 (BG00097)	DWA borehole	752			CRG13	4867	Purgatory WS	5190
	W7-9 (BG00099)	DWA borehole	318			CRG6	478	La Motte (30453)	7947
	W7-10 (BG00100)	DWA borehole	328			CRG6	8828	La Motte (30453)	3629

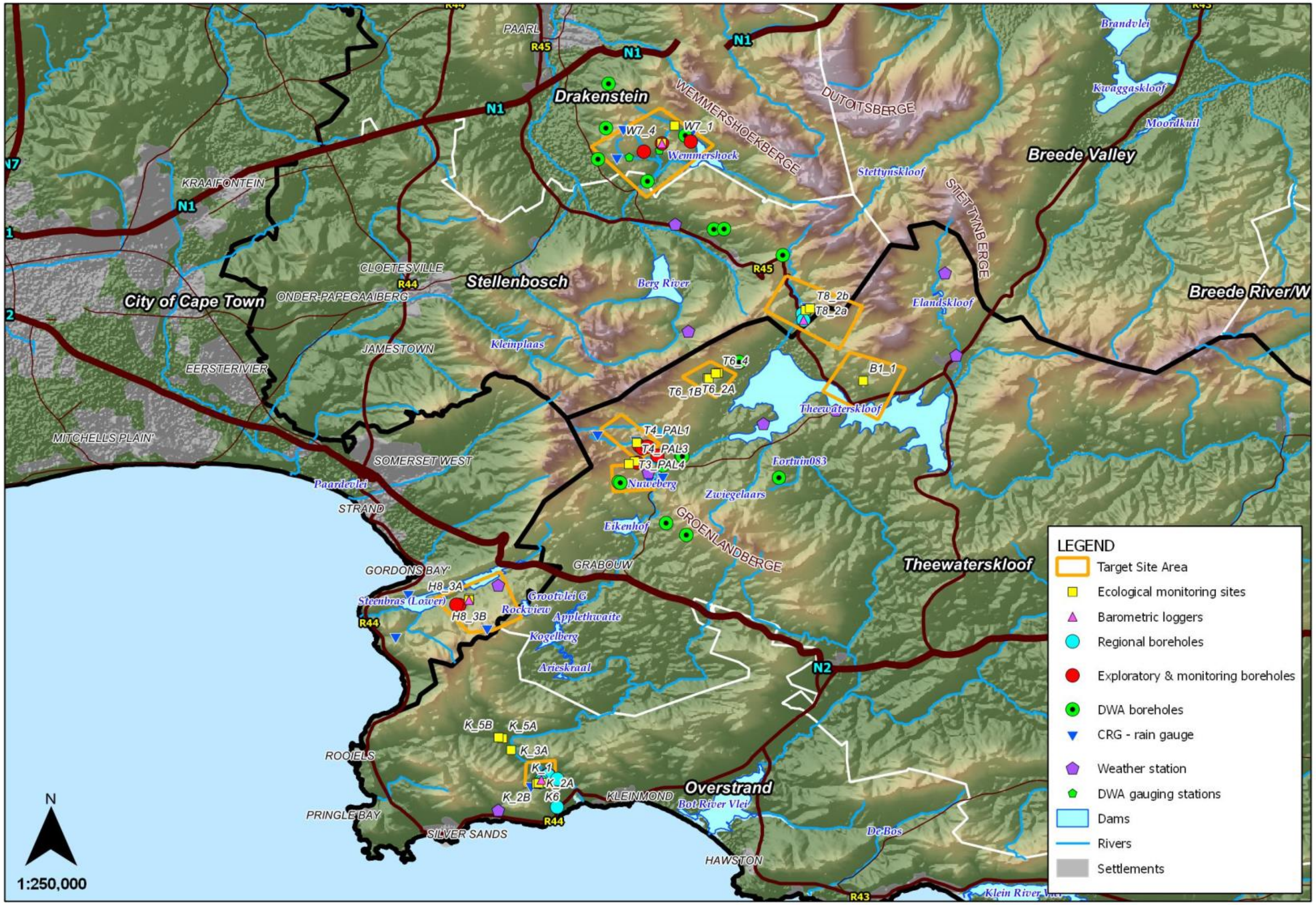


Figure 1.1 A map of the TMGA project study area, showing the EPM2 network of ecological and regional monitoring sites located in eight Target Site Areas (TSAs).

2 CLIMATE

2.1 Introduction

The monitoring objectives for the collection of climatic data in EPM2 were to document spatial and temporal variability in rainfall and air temperature across the study areas and close to the ecosites being monitored for biological data. These data were used to interpret monitoring data in other disciplines.

Four datasets were collected, as follows:

- Time series of daily rainfall at 14 cumulative rainfall gauges (CRGs) located close to the ecosites;
- Time series of daily rainfall[2] at two TMGA weather stations located at Kogelberg and Purgatory, and 11 SAWS and ARC weather stations located across the broader study area;
- Time series of other climatic parameters from the weather stations, which were collated and stored in the project database; and
- Time series of hourly air temperature at 13 air temperature loggers located close to the ecosites.

The following sections discuss the analysis of the rainfall and air temperature data collected during EPM1 and EPM2. The methods used for the analysis are presented in Volume 2: Method Statements.

2.2 Cumulative rainfall gauges

Monthly rainfall is presented in Figure 2.1 for the CRGs. The CRGs generally showed similar rainfall patterns, with lowest rainfall occurring from January to March each year, and the highest from May to September. The highest rainfall months were May/June from 2009 – 2011, with lower peaks again in August/September and October/November. However, in 2012 the highest rainfall was in July/August, with lesser peaks earlier in the year in April and June 2012, and later in November 2012 (Figure 2.1). The annual total was highest in 2012.

CRG2 and CRG3 at Nuweberg regularly recorded the highest rainfall over the winter months, and this could be seen in the mean monthly rainfall per TSA shown in Figure 2.2. CRG6 at Wemmershoek recorded the single highest monthly rainfall during the monitoring period, in May 2010.

2.3 Weather stations

Figure 2.3 gives monthly rainfall data for the two TMGA (at Purgatory and Kogelberg), three ARC (Chiltern, La Motte and High Noon) and eight SAWS weather stations (at Franschhoek, Grabouw, Harold Porter, Nuweberg, Kogelberg (Oudebosch), Rustfontein (Theewaterskloof Dam), and Steenbras). The TMGA datasets contain frequent and lengthy gaps (see Volume 3: Data Report for details on data gaps), whereas the ARC datasets have no data gaps, and provide good data for comparison with the CRGs. The longest datasets were from the ARC station at Chiltern (on the south-western edge of Theewaterskloof Dam) and at La Motte (near Franschhoek). These data matched the CRG data, showing the three main rainfall peaks in 2009, 2010 and 2011 (compare with Figure 2.1 and Figure 2.2). The highest monthly rainfall in a year was recorded at different locations in different years. For instance, in 2008 the highest monthly rainfall was recorded at La Motte; in 2009 and 2011 at Purgatory; and, in 2010 at Chiltern. All stations showed less overall rainfall in 2010 than in 2009 or 2011.

[2] A number of other climatic variables are recorded at the weather stations, however only rainfall data are analysed for EPM2. All other variables are collated and stored on the project database.

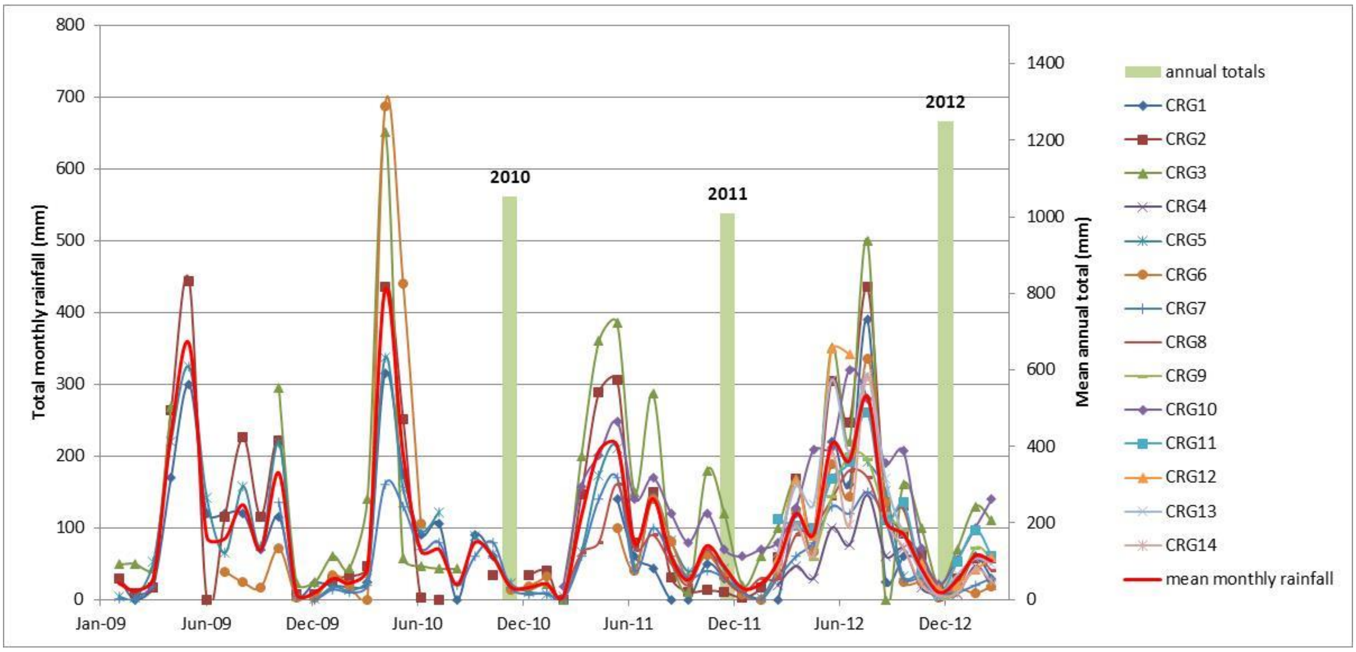


Figure 2.1 Total monthly rainfall at the CRGs. Mean monthly rainfall across all CRGs is shown as a red line, and annual totals as green columns. No annual total is provided for 2009, as the record only commenced in February 2009.

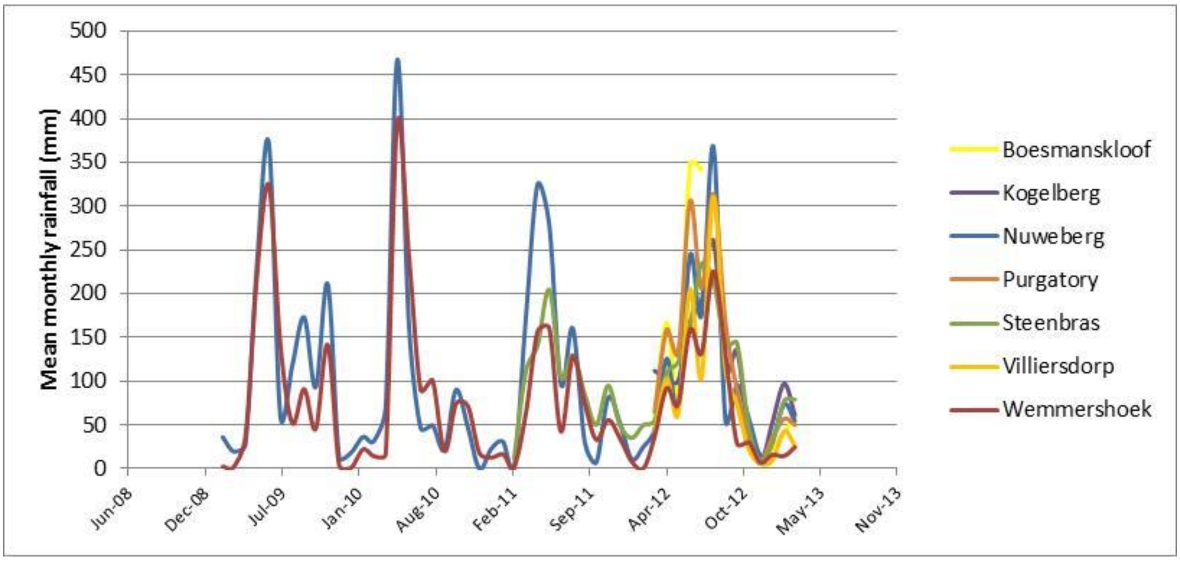


Figure 2.2 Mean monthly rainfall per TSA recorded at the CRGs.

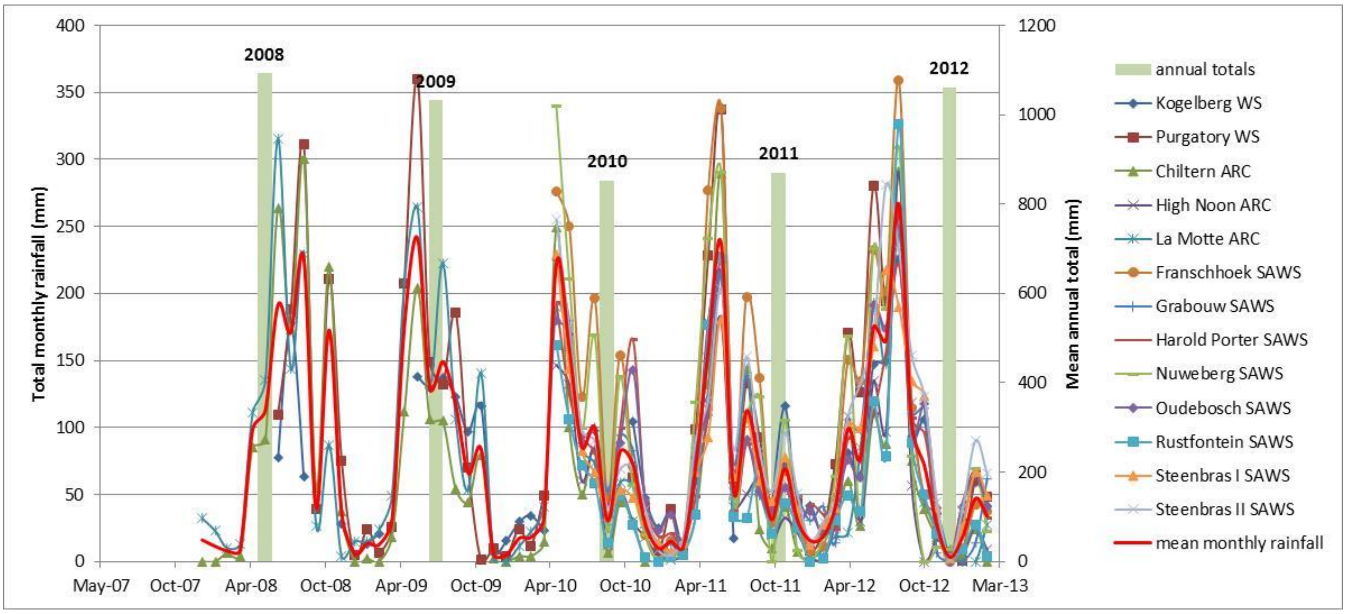


Figure 2.3 **Total monthly rainfall at the two TMGA weather stations, three ARC and eight SAWS weather stations being monitored during EPM2. Mean monthly rainfall across all weather stations is shown as a red line, and annual totals as green columns.**

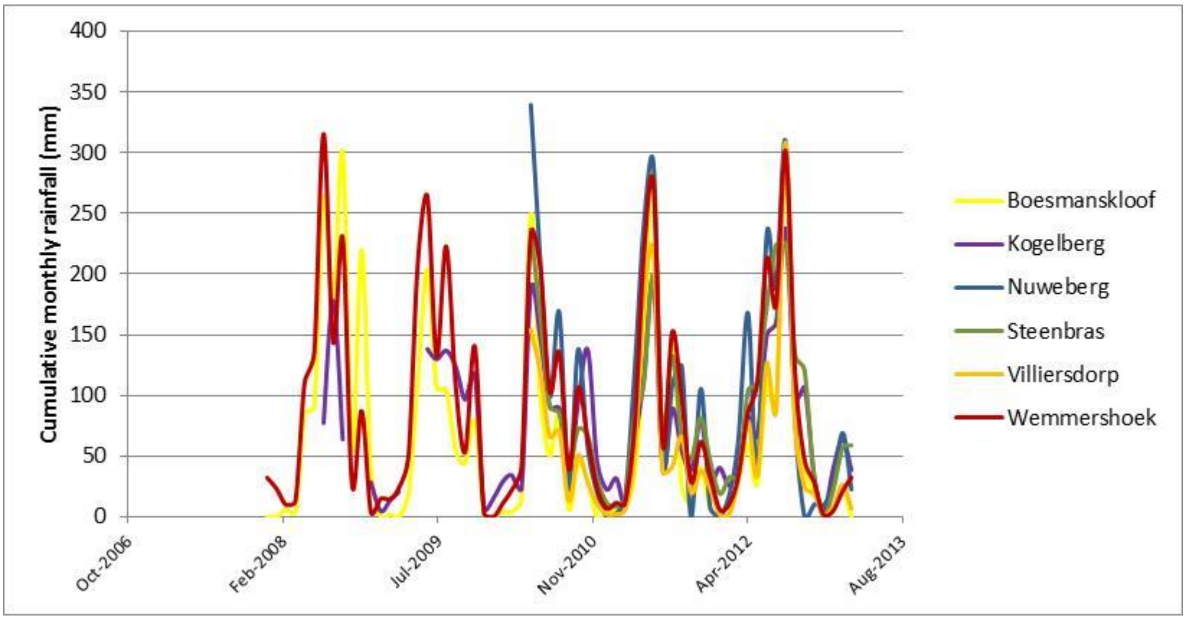


Figure 2.4 **Mean monthly rainfall per TSA recorded at the weather stations.**

2.4 Air temperature loggers

Mean monthly air temperatures are presented for all ecosites in Figure 2.5. Air temperatures were generally higher at the Kogelberg sites K_2a and K_2b, K_5a and K_5b, and K_6 (see also Figure 2.6). This TSA is close to the coast and at the lowest altitude. The high altitude T3_Pal4 and T4_Pal3 sites at Nuweberg were the coolest sites overall (see Figure 2.5 and Figure 2.6).

Temperatures peaked in January/February 2012 and 2013, with a second peak in March of both years. Air temperatures were at their lowest in June 2011, and in August 2012. The later dip in temperature in 2012 matched the later peak in rainfall in this year (see Figure 2.1 and Figure 2.3).

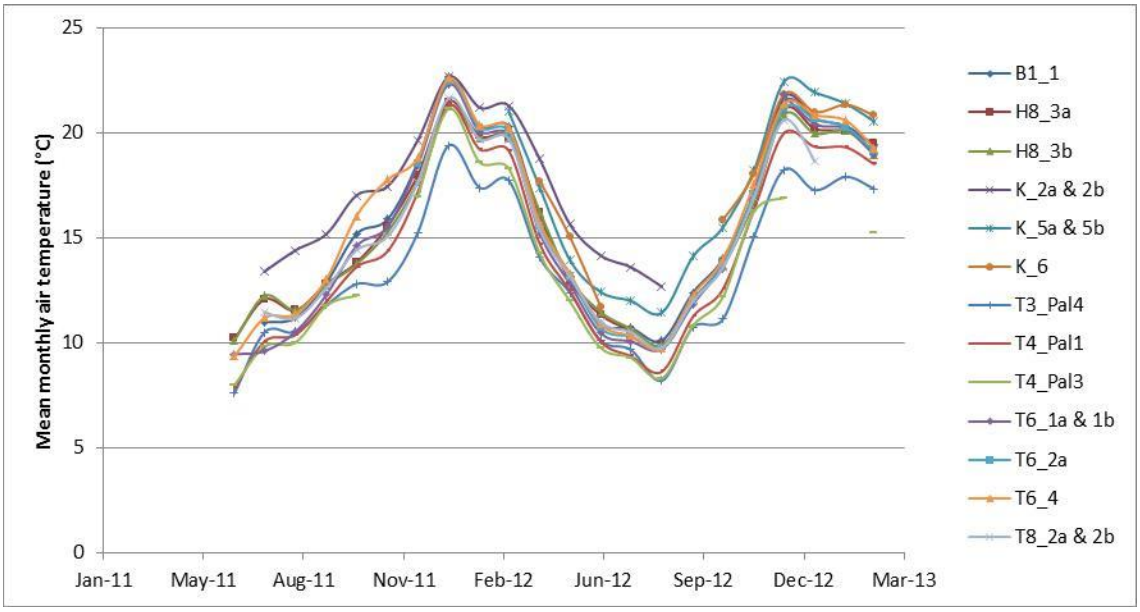


Figure 2.5. Mean monthly air temperature at the ecosites.

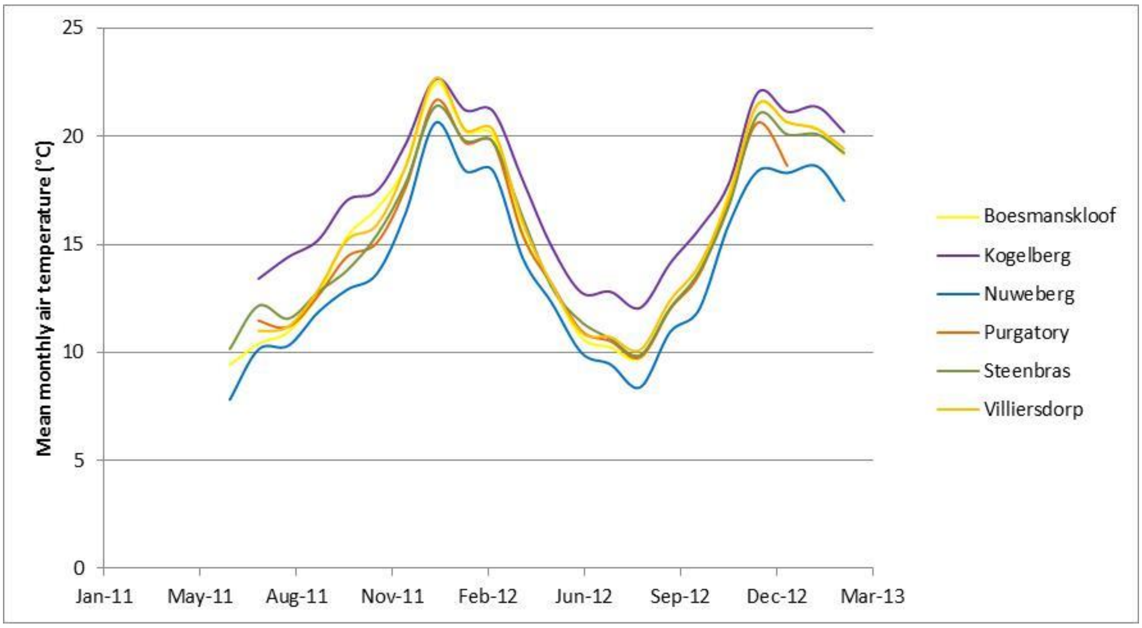


Figure 2.6 Mean monthly air temperature, averaged for each TSA.

3 GROUNDWATER LEVEL AND TEMPERATURE

3.1 Introduction

The objectives for the collection of groundwater level and temperature data in EPM2 were to document spatial and temporal variability in these variables across the study area and in the ecoseeps. These data were used to inform our understanding of the aquifer characteristics and behaviour, to provide a baseline against which future data may be evaluated and contextualised, and to interpret monitoring data in other disciplines.

Groundwater level and water temperature data were downloaded and analysed from data loggers in 22 piezometers (located in ten ecoseeps), ten regional boreholes, and ten exploration and monitoring boreholes. Water level data only were also obtained from DWA for eighteen of their regional boreholes. Data were downloaded from four barometric loggers for pressure compensation of the raw water level data.

The following datasets were collected:

- Hourly time series of water level as mbgl and, correcting for altitude using survey data, as mamsl; and
- Hourly time series of groundwater temperature.

For data analysis, the water level time series data were graphed along with rainfall data from the nearest ("best") or second best rainfall station, in the event that there were rainfall data gaps. Summary water level statistics, the annual and daily maximum and minimum values were calculated and shown graphically, to provide information on temporal trends in water level. The groundwater temperature data were graphed as time series.

3.2 Results for TMGA exploration and monitoring boreholes

3.2.1 Steenbras

Two exploration boreholes established at Steenbras in 2009 at depths of 190 and 300 m, showed virtually identical fluctuations in water level, with a prolonged maximum water level (ca. 15 and 10 mbgl for H8A1 and H8A3 respectively, Figure 3.1a) from about April to November and a shorter period when water levels declined about 6 m from this maximum. Seasonal minima were lowest in 2011, but the 2013 minimum was similar to that at the start of monitoring in both boreholes so the trend was fairly stable (Figure 3.1b).

3.2.2 Wemmershoek

Three exploration boreholes were established at Wemmershoek in 2009, at depths of >300 m - two in the Zachariashoek catchment (W7_D1 and W7_F2) and one, an artesian borehole, adjacent to Wemmershoek Dam (W7_K1).

A jump in water level in October 2009, which was observed at W7D1 and W7F2, coincided with a heavy rain event measured at the rain gauge CRG6 (Figure 3.2a and b). However, no similar response was observed with the greater and prolonged rainfall the following May 2010. The trend of declining water level at both boreholes (Figure 3.2a and b) seemed to track climate shifts, rather than individual rain events, since rainfall during 2008 - 2009 was substantially higher than 2010 – 2011 (refer to Figure 2.3) and recharge was improved after the 2012 winter rain rainfall. These trends were far more discernible than those presented for the Steenbras boreholes, which suggested that the Skurweberg Aquifer is not as responsive to these climatic changes.

Data for the artesian borehole W7K1 (Figure 3.2c) are only presented for the period from November 2010, as the data collected prior to EPM2 had not been verified, and were thus excluded from the final analyses (refer to TMGA Monitoring EPM2: Volume 3: Data Report). These showed an annual fluctuation of some 2 m, with no apparent differences between years (Figure 3.2c).

3.2.3 Nuweberg

Five exploration boreholes were established in 2009 at Nuweberg at altitudes between 587 and 630 mamsl, with borehole depth ranging from 176 to 327 m. Figure 3.3 and Figure 3.4 show a fairly smooth pattern of seasonal increases and decreases in groundwater, in the order of 4 - 8 m, with little direct response to rainfall except at T4_E2, and to an extent at T4_C3, where water level maxima coincided with the wet season and fluctuated in the wet season in response to rain events. T4_E2 is the only borehole in the Nuweberg area where water levels are close to the surface (ca. 4 – 7 mbgl). The data for the other boreholes indicated a lag in groundwater maxima of about six months from peak rainfall.

Water levels (maxima and minima) were elevated in 2012 compared with 2010 and 2011 (Figure 3.3 and 3.4). Where four years of monitoring data were available (e.g. T4_D1, T4_E2 in Figure 3.4a and b), these showed patterns similar to those in the Wemmershoek boreholes, where a trend of declining levels, linked to low rainfall was reversed by the high rainfall and recharge in 2012. The time series data for T4C2 showed a similar pattern, except for a clearly artificial jump in the data in September 2010 that has not been resolved.

3.3 Results for TMGA regional Boreholes

The loggers fitted in the regional boreholes drilled in the Kogelberg and Purgatory areas now provide up to nearly seven years of data, albeit with some significant data gaps.

3.3.1 Kogelberg

Water levels at the Kogelberg boreholes (Figure 3.5 to 3.7) ranged from < 1 m (TMG485, a shallow piezometer of only 1 m depth in the Cedarberg formation between the Oudebos cabins and the stream) to 6 m (TMG456), but most were in the 2-m range (Figure 3.5). TMG458, the artesian borehole, and TMG466 on the coast alongside the R44 east of Betty's Bay, showed a pronounced lag in water level relative to rainfall, with maximum water level (i.e. level closest to the surface) in November/December (Figure 3.7), whilst the other boreholes had their maxima more closely aligned to wet season recharge (July/August). The shallow piezometer at TMG485 (Figure 3.6) unsurprisingly showed a rapid response to individual rainfall events, with minimum levels at the end of the dry season.

Most of the boreholes showed no trend in annual maxima or minima over time – e.g. the shallow piezometer TMG485 and shallow borehole (16 m) TMG544; the deep TMG466 and TMG457. In contrast, the semblance of a declining water level over time at TMG456 was due to an initial tranche of data that was separated from the more recent period by a gap of four years. Some uncertainty exists about the compatibility of the data, but if correct then it is the only borehole suggestive of a fairly strong trend in the Kogelberg area (Figure 3.5). The data set for the artesian borehole TMG458, intact since 2005 (Figure 3.7), indicated that 2009 was a wetter year than other years, with lower max / min values being recorded both before and after 2009.

3.3.2 Purgatory

Four boreholes in the Purgatory area, one artesian, provide similar time series data to those from Kogelberg, except at a higher altitude (ca. 350 mamsl compared with 40 – 80 mamsl at Kogelberg) (Figure 3.8 and 3.9). The data from all four Purgatory boreholes showed a similar periodicity, with minimum water levels in July / August. Water levels fluctuated seasonally by between 1 and 2.5 m, with the smallest amplitude observed in the deep borehole TMG461. TMG462 did not show the same response to rainfall as did TMG485 at Kogelberg (Figure 3.6), despite both being shallow boreholes adjacent to stream courses or in wetlands.

No clear trend in water level was suggested by the artesian TMG459 of the shallow alluvial TMG462 (Figure 3.7 and Figure 3.8 respectively), except for a trend of slightly increasing annual maxima in the former and decreasing annual minima in the latter. Data from TMG461 (Figure 3.9) were divided into two periods with a large data gap. The discrepancy between the two has not been resolved, but taking only the more recent period, there was no suggestion of a trend in water level.

In contrast, manual measurements taken from TMG460 during the period from 2008 to 2010, a period when no logging took place, showed a consistent seasonal fluctuation in water level from 2.5 mbgl maxima to 4 mbgl minima, with a slight decline in the maximum water level over time. The 2010 – 2012 data showed the same pattern (Figure 3.8).

3.4 DWA Regional Boreholes

This section provides data from eight boreholes in the Hawequas / Wemmershoek and Franschhoek mountain reserves (prefix W7), and ten boreholes in the Purgatory, Groenlandberg and Eikenhof Dam surrounds (Wesselsgat River) (prefix T4) that have been monitored by Department of Water Affairs since approximately 2008.

3.4.1 Hawequas / Wemmershoek and Franschhoek (W7)

Boreholes W7_1, W7_3, W7_4 and W7_5 are located south and west of Zachariashoek / Wemmershoek or drain northwards off the Klein Drakenstein Mountains. These all showed strong responses to rainfall, generally showing a close match between winter rainfall and maximum water levels, and spikes in water level associated with rain events (Figure 3.10 and Figure 3.11). This was a different signature from that shown by the Wemmershoek exploration boreholes W7_D1, W7_F2 and W7_K1 (refer to Figure 3.2). However, temporal trends were similar, with gradually declining water levels between 2008 (or 2009) and 2011, and a reversal in 2012. As with the exploration boreholes, this is likely to reflect responses to annual rainfall.

In the area north of the town of Franschhoek, the DWA borehole W7_6 displayed somewhat irregular patterns, with prolonged elevated water levels until mid-summer, followed by a dramatic reduction (ca. 20 m decline) and thereafter erratic summer patterns, suggesting possibly that the borehole is utilised during summer months (Figure 3.12). W7_10 is within 1 km of this borehole, and did not exhibit the same behaviour, with annual fluctuations of only around 1 m. A dramatic increase in water level was shown in 2012 with water level 0.5 m higher than at any other maximum (Figure 3.12). Again this time series supported other data suggesting inter-annual patterns linked to wet and dry rainfall years.

W7_7 (Franschhoek Pass) and W7_9 (Wemmershoek Dam) displayed intra-annual and longer term patterns similar to the Wemmershoek exploration boreholes (compare with Figure 3.13 and Figure 3.2), with a lag between rainfall and annual maxima in groundwater, no response to individual rain events and the same water level trends between 2008 and 2013. These patterns were notably more pronounced in these boreholes than in most of the others in this monitoring data set.

3.4.2 Purgatory, Groenlandberg and Eikenhof surrounds (T4)

The DWA boreholes T4_7 and T4_11, both located on the farm road between Boesmanskloof and Purgatory, showed nearly identical patterns in groundwater behaviour, with annual maxima strongly linked to rainfall response, and levels fluctuating somewhat with individual rain events during winter (Figure 3.14). The annual fluctuation in water level ranged from 1.5 m at T4_7 to 4 m at T4_11. Although the annual maxima appeared stable in both boreholes, the minimum levels showed a trend of declining levels at T4_7. At T4_11 the minima were more erratic, suggesting possible logger malfunction in the 2010 – 2011 period.

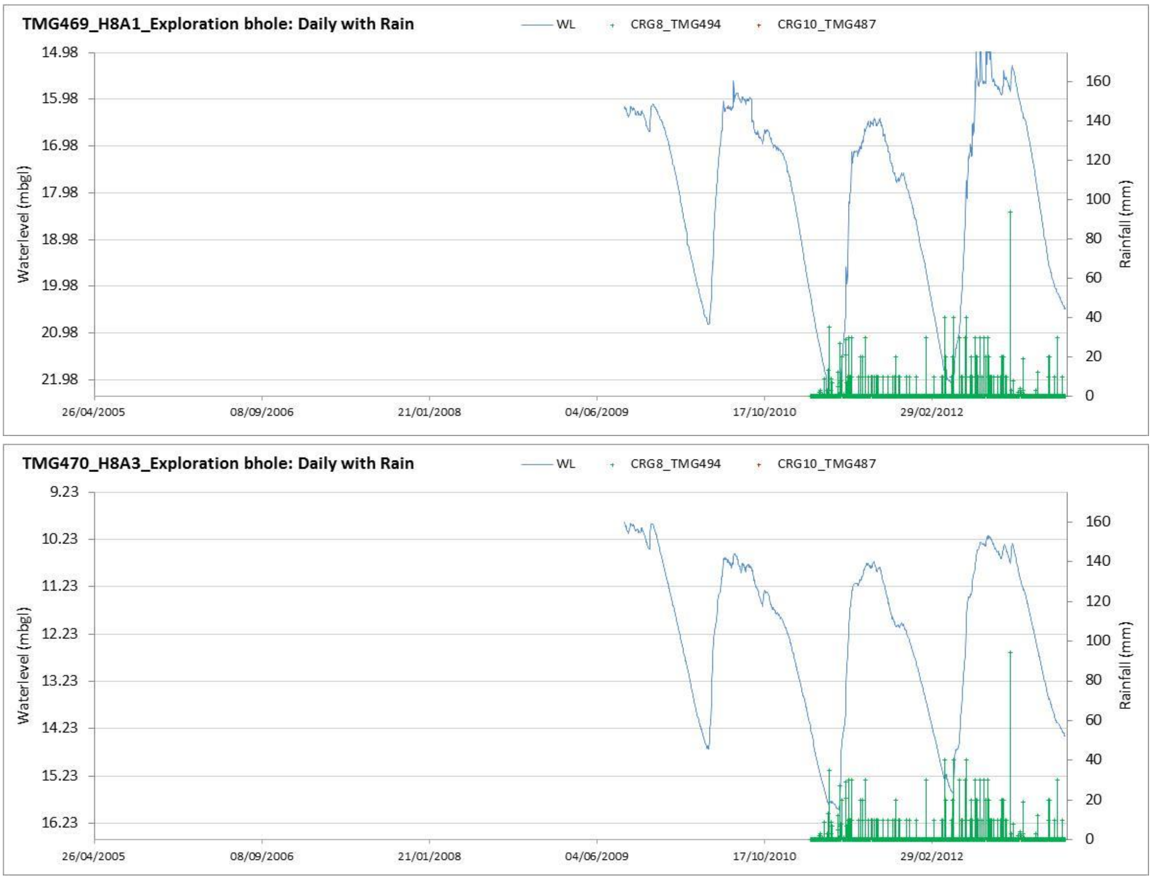
Slightly different trends were observed at T4_1 and T4_2 (Figure 3.15), both located in the upper reaches of the Riviersonderend, or close to where it enters Theewaterskloof Dam, upstream of farmed land. Despite their close proximity, T4_1 showed a greater lag and less response to rain events than did T4_2 which was highly “flashy”. Both boreholes showed little in the way of temporal trends, with only a slight decline in annual minima over the data period at T4_2.

On the northern Groenlandberg, T4_8 and T4_10 showed similar fluctuations in water level over the annual cycles (5-6 and 3-4 m respectively), but a fairly pronounced lag between rainfall months and annual maxima (Figure 3.16), especially at T4_8, which showed October / November maxima sustained for some three months, and less so at T4_10 where there was more influence of rain events on water level and the peak levels were not sustained for as long. Over the period of data, there was a trend of declining levels at both sites.

Borehole T4_3 in the Wesselsgat catchment displayed a similar lag, intra-annual fluctuation and temporal trends as at T4_8 to the east, whilst T4_9 showed a stronger link to rainfall but a similar temporal trend of declining water level (Figure 3.17).

Finally, to the east of Eikenhof Dam water levels at T4_5 and T4_6 were associated with 5 – 6 m fluctuations in water level over the year, but showed a sizeable lag between winter rain and annual maxima (Figure 3.18). There were no trends in temporal patterns between 2008 and 2013 at T4_6, but water level minima increased at T4_5, a rather unusual pattern given the trends at the other boreholes in the region.

a



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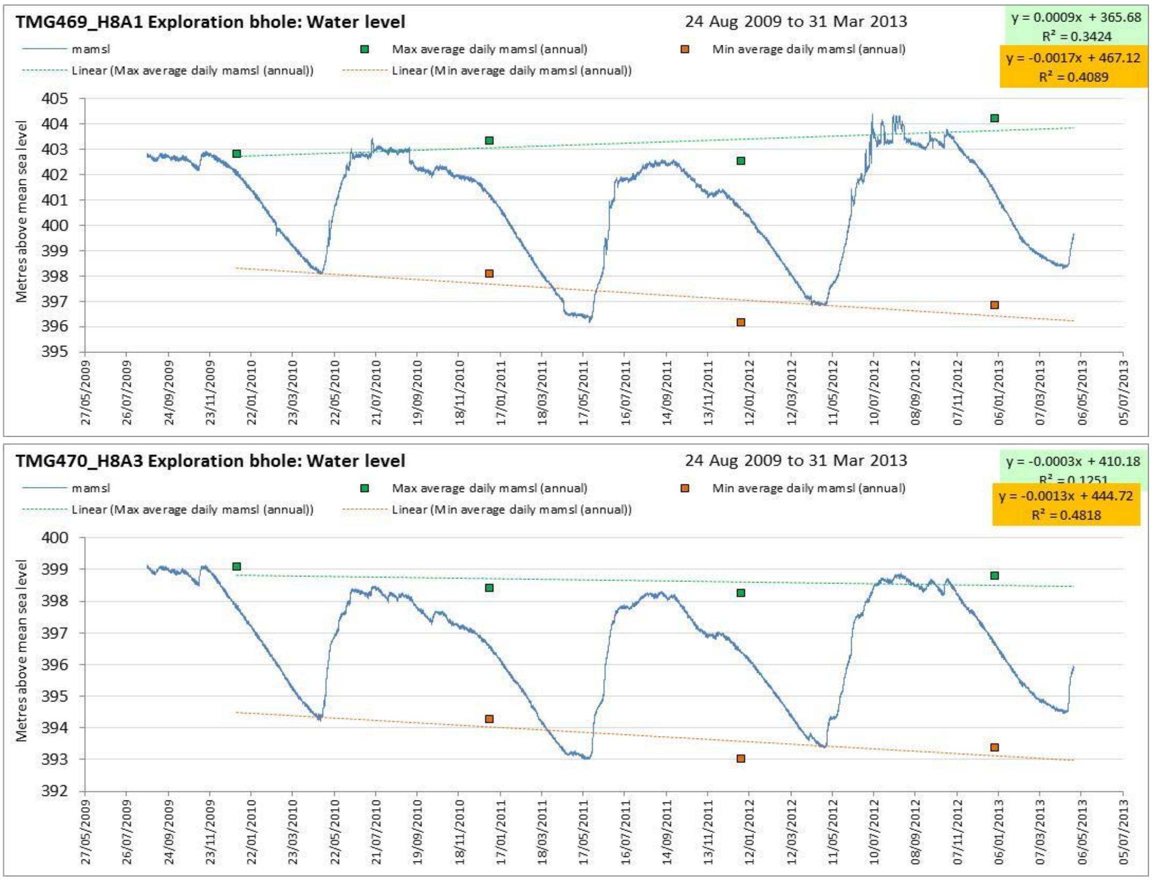
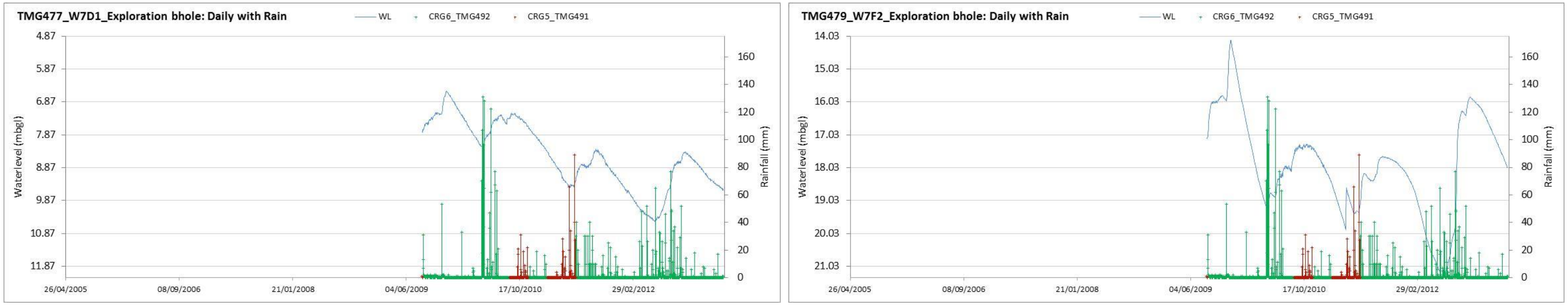


Figure 3.1. Time series of water level from Steenbras exploration boreholes, H8_A1 and H8_A3: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a



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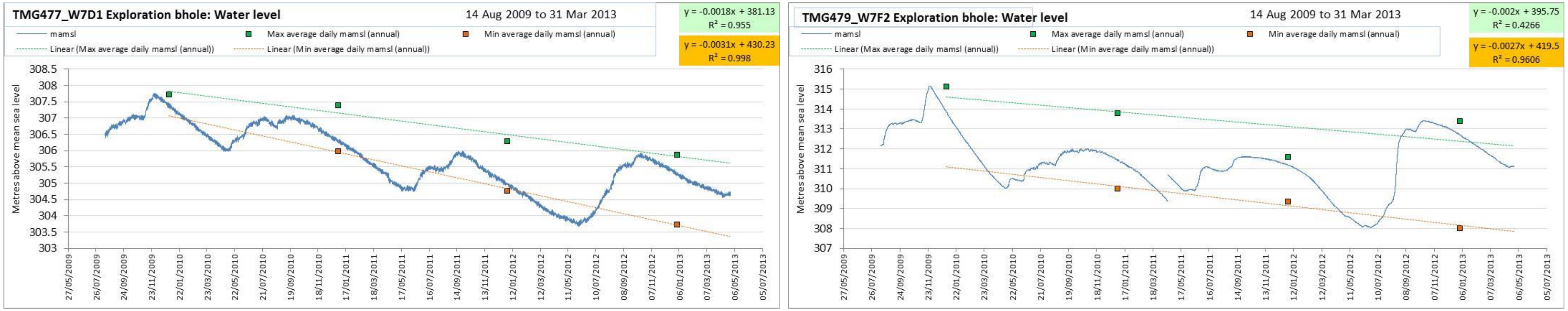

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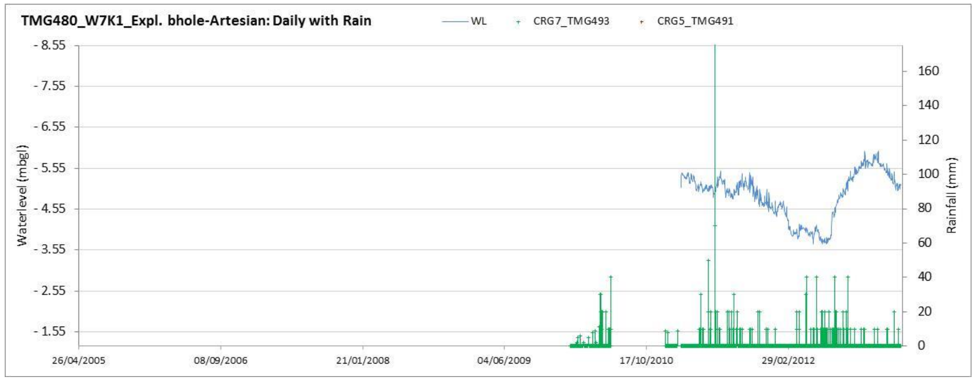
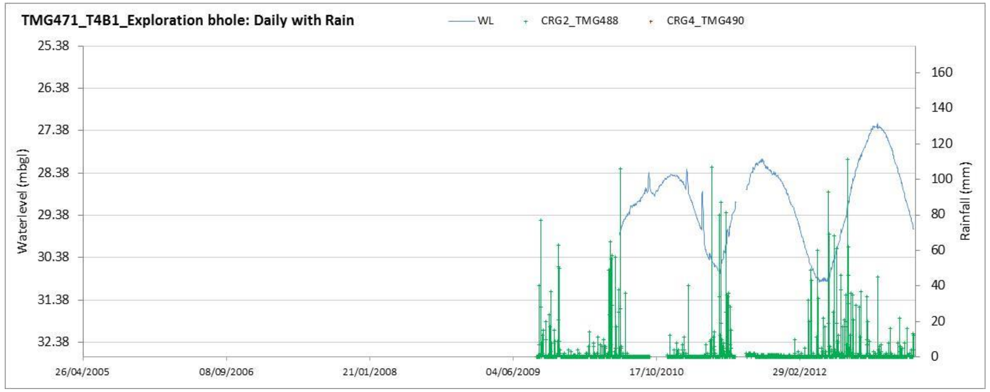
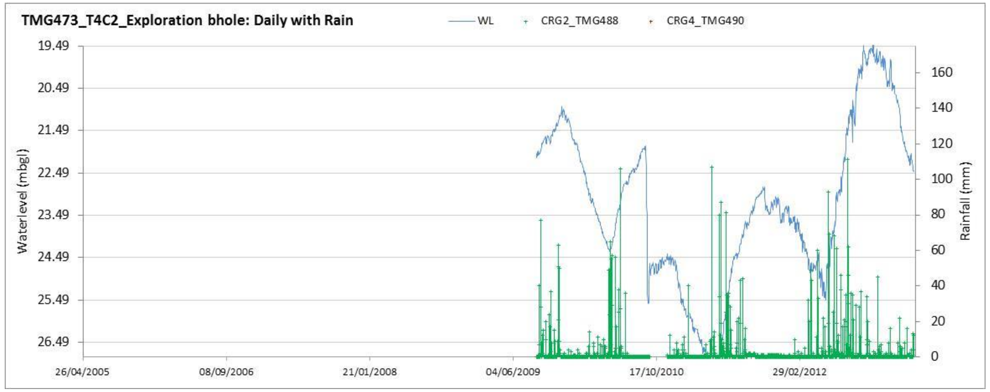


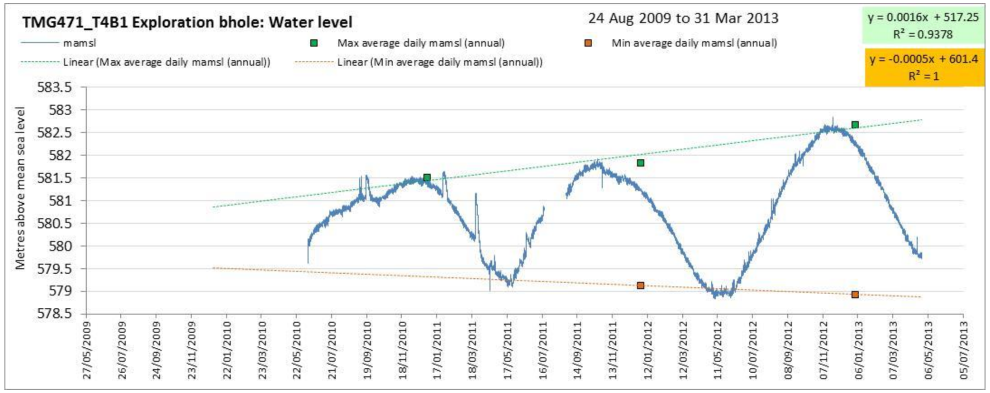
Figure 3.2. **Time series of water level from Wemmershoek exploration boreholes, W7_D1, W7_F2 and W7_K1: a) and c) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.**

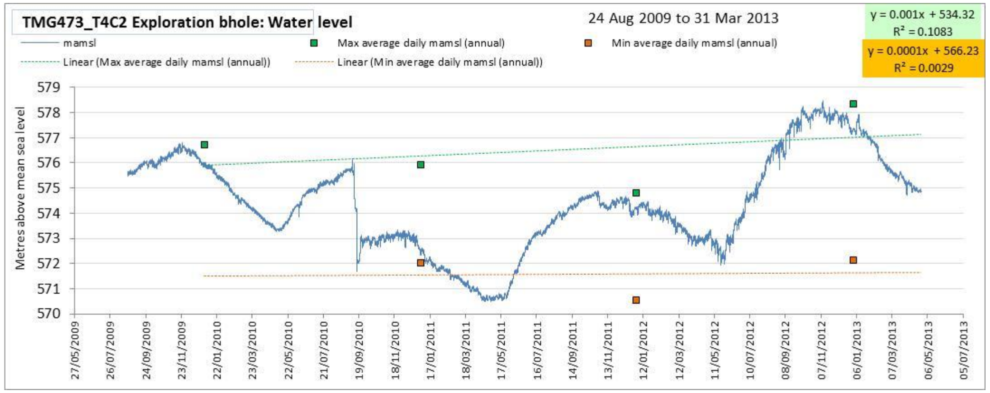
a





b





c

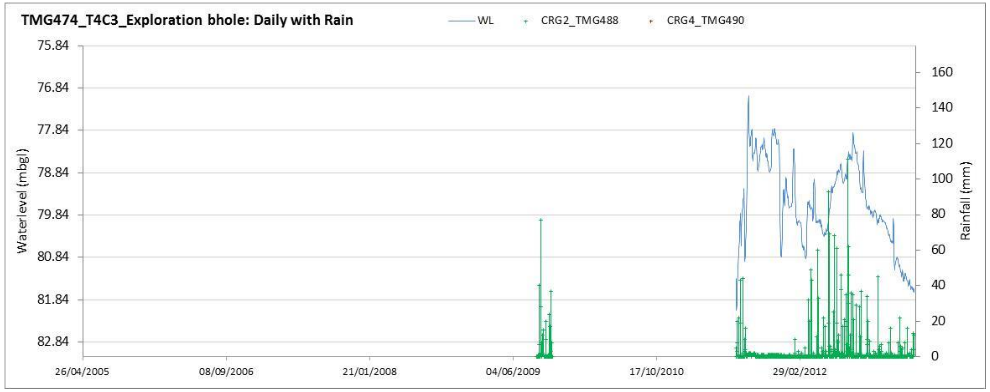
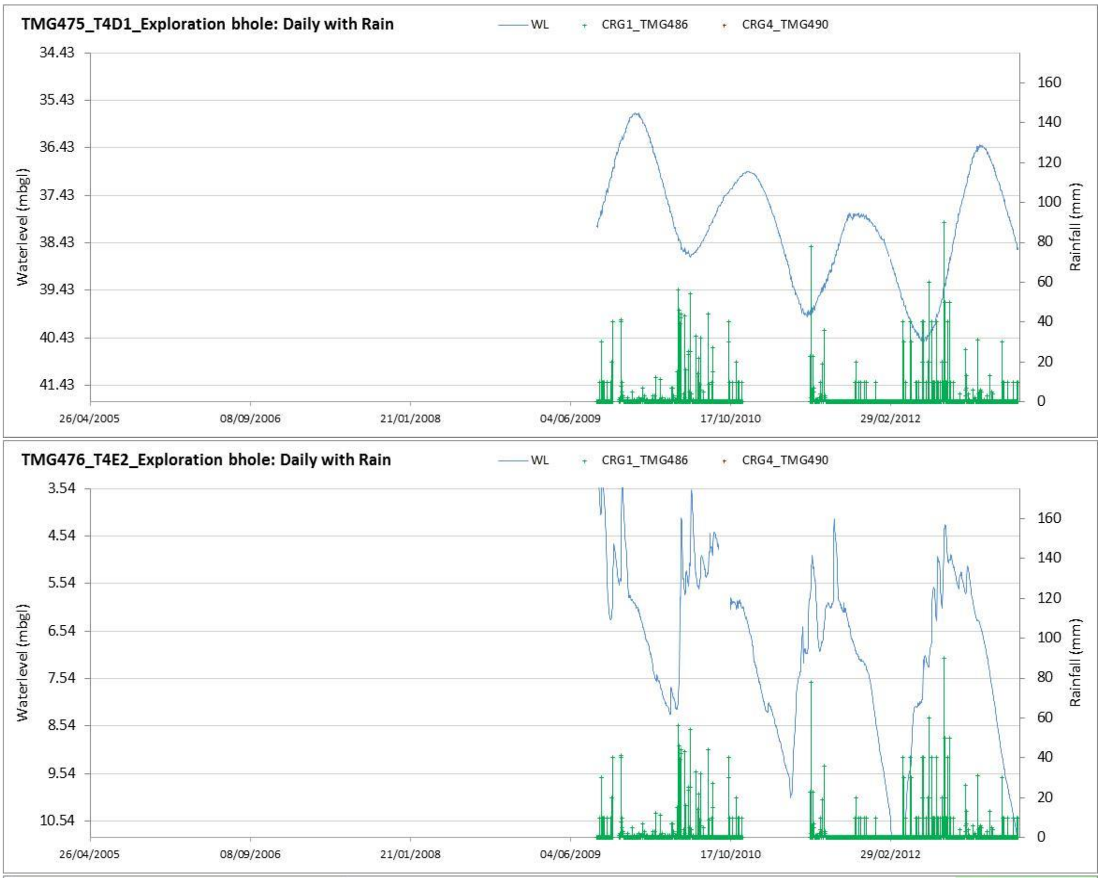


Figure 3.3. Time series of water level from Nuweberg exploration boreholes, T4_B1, T4_C2 and T4_C3: a) and c) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a



b

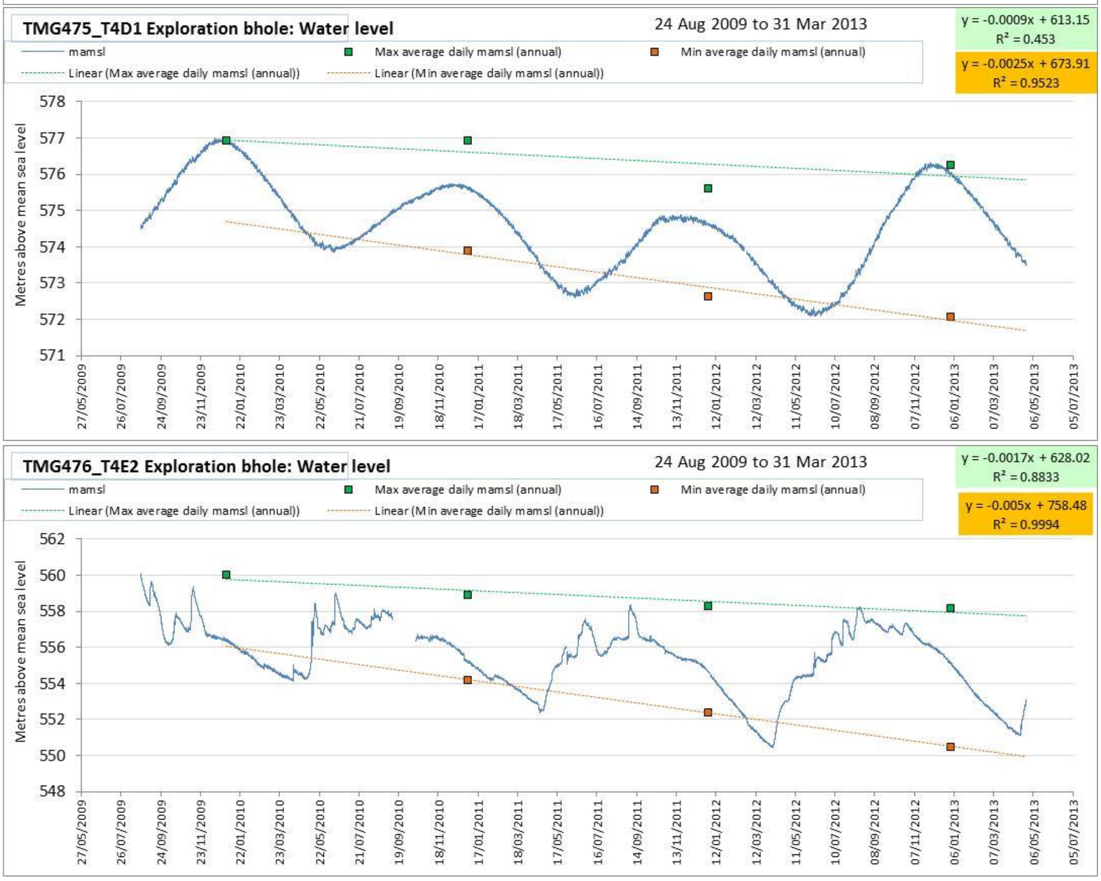


Figure 3.4. Time series of water level from Nuweberg exploration boreholes, T4_D1 and T4_E2: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a

b

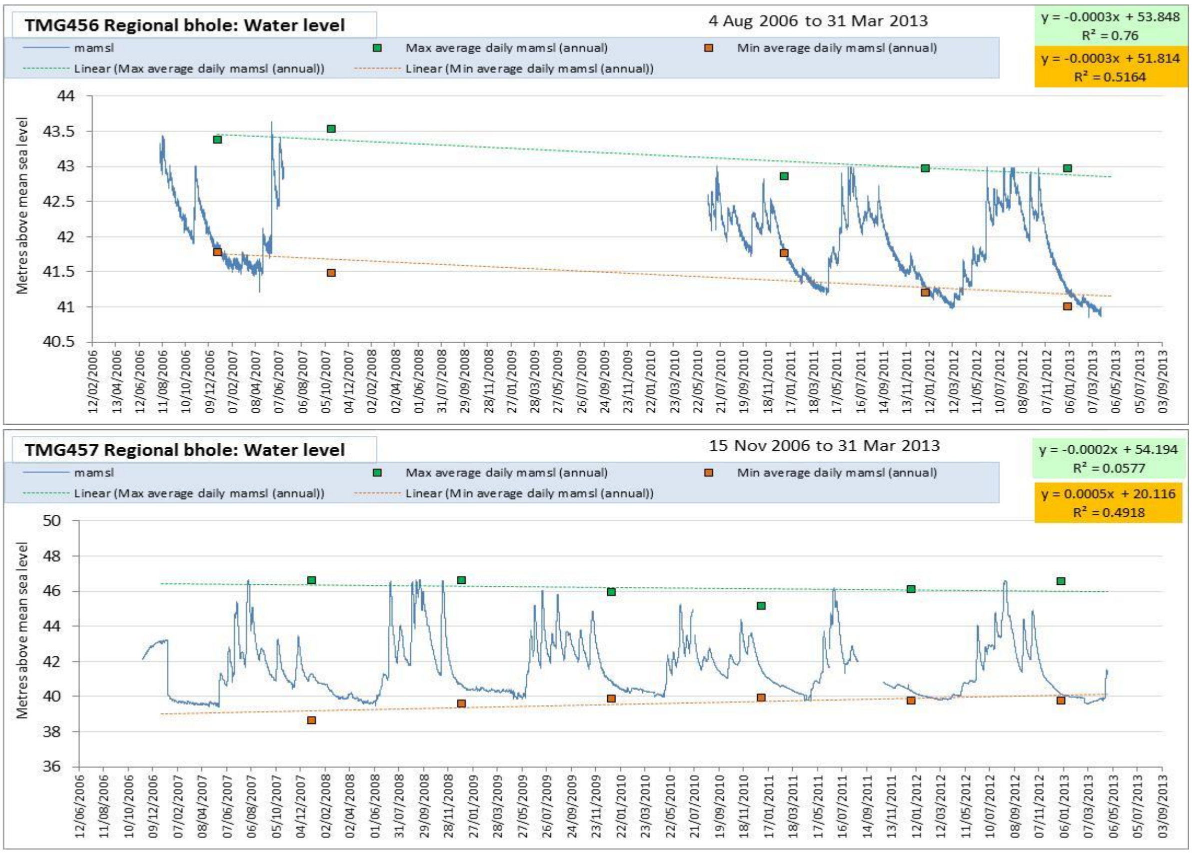
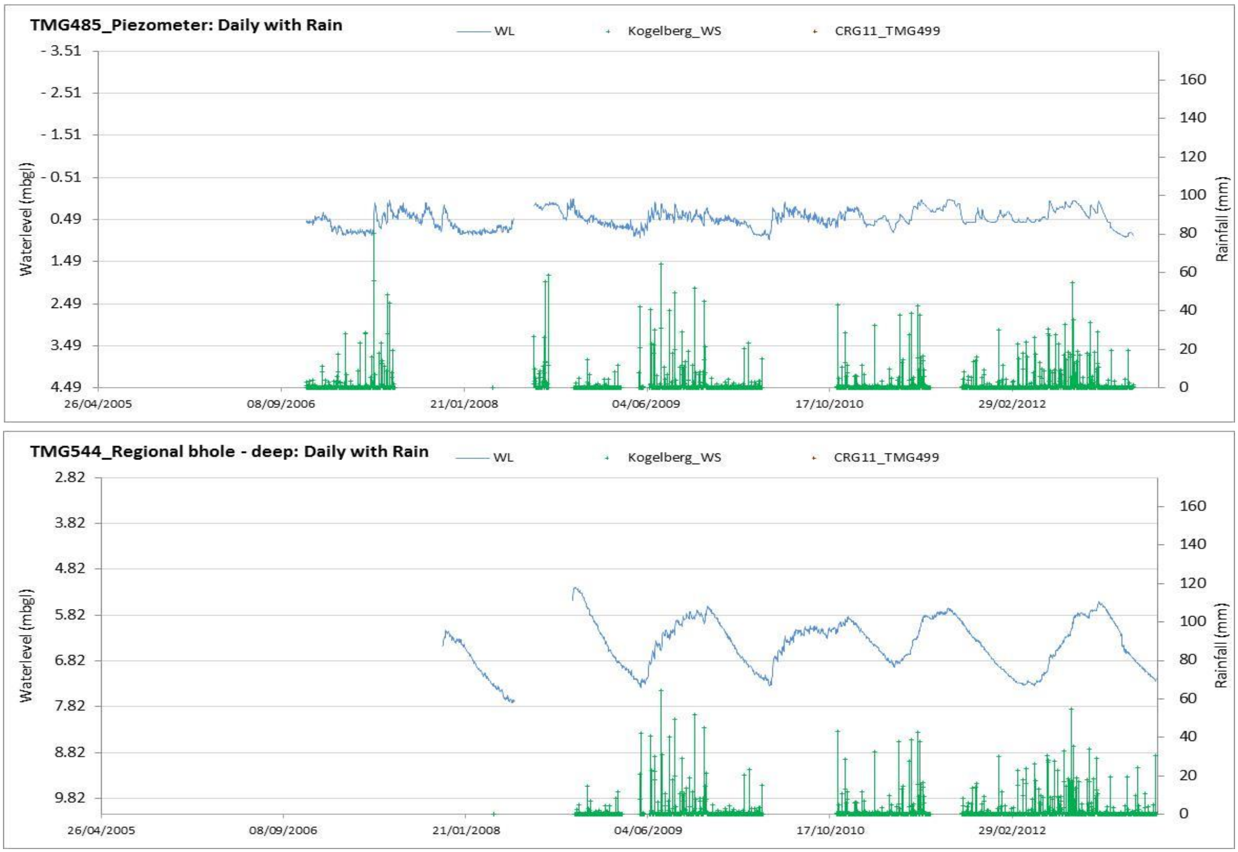


Figure 3.5. Time series of water level from Kogelberg regional boreholes TMG456 and TMG457: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a



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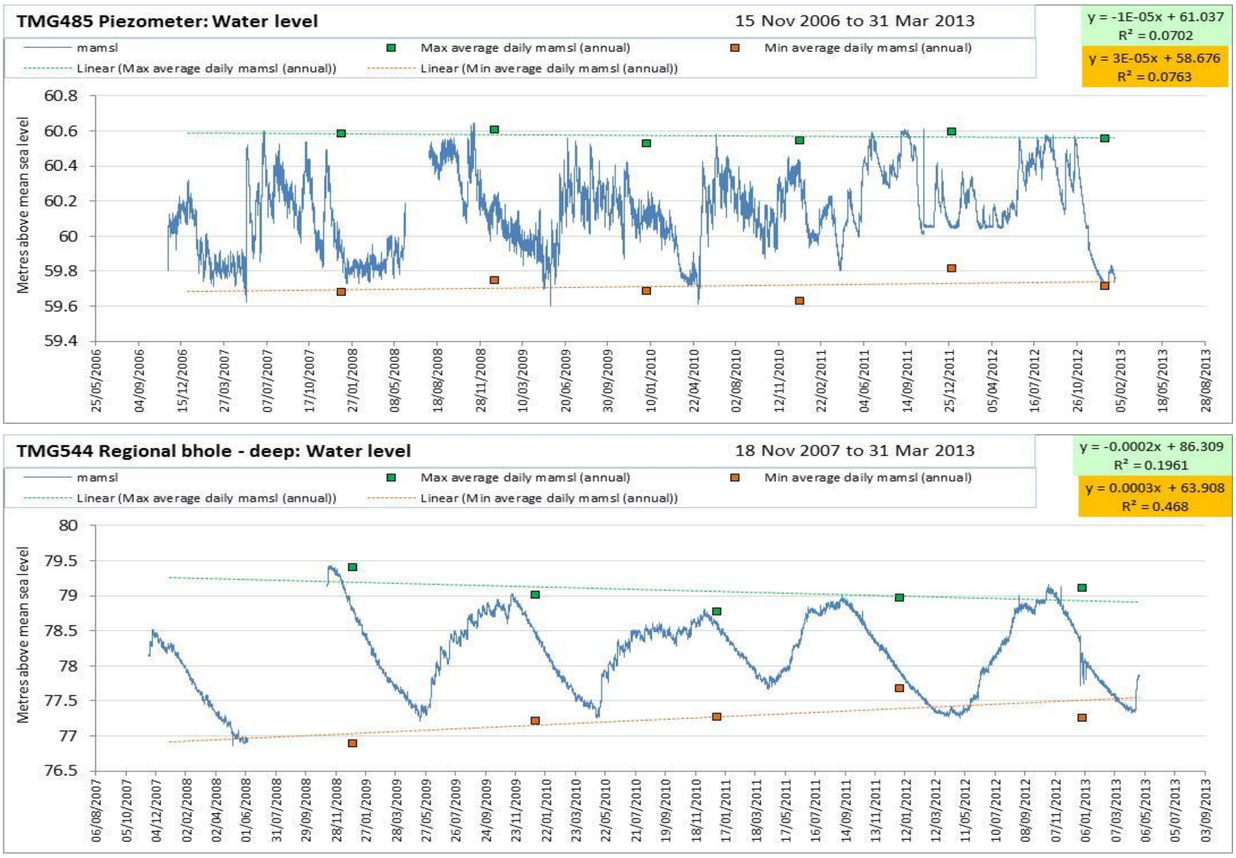
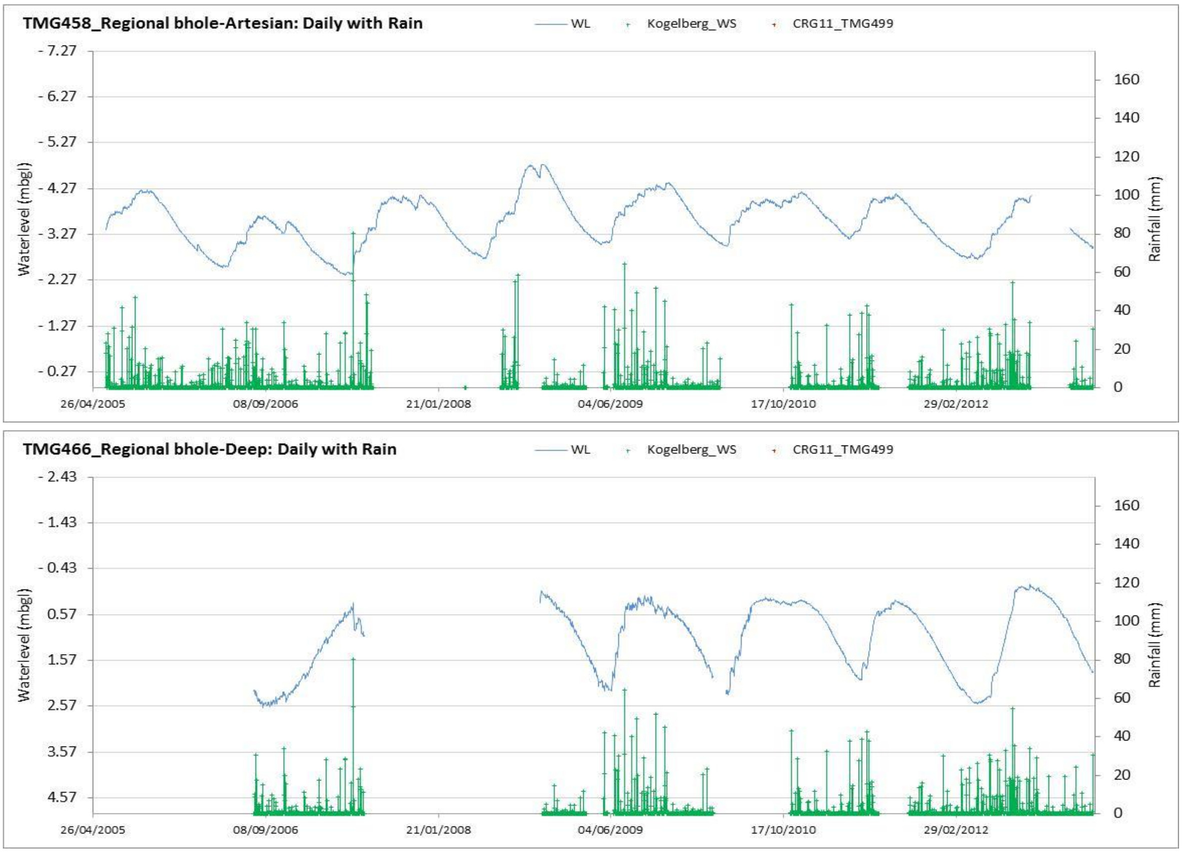


Figure 3.6. Time series of water level from Kogelberg regional boreholes TMG485 and TMG544: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a



b

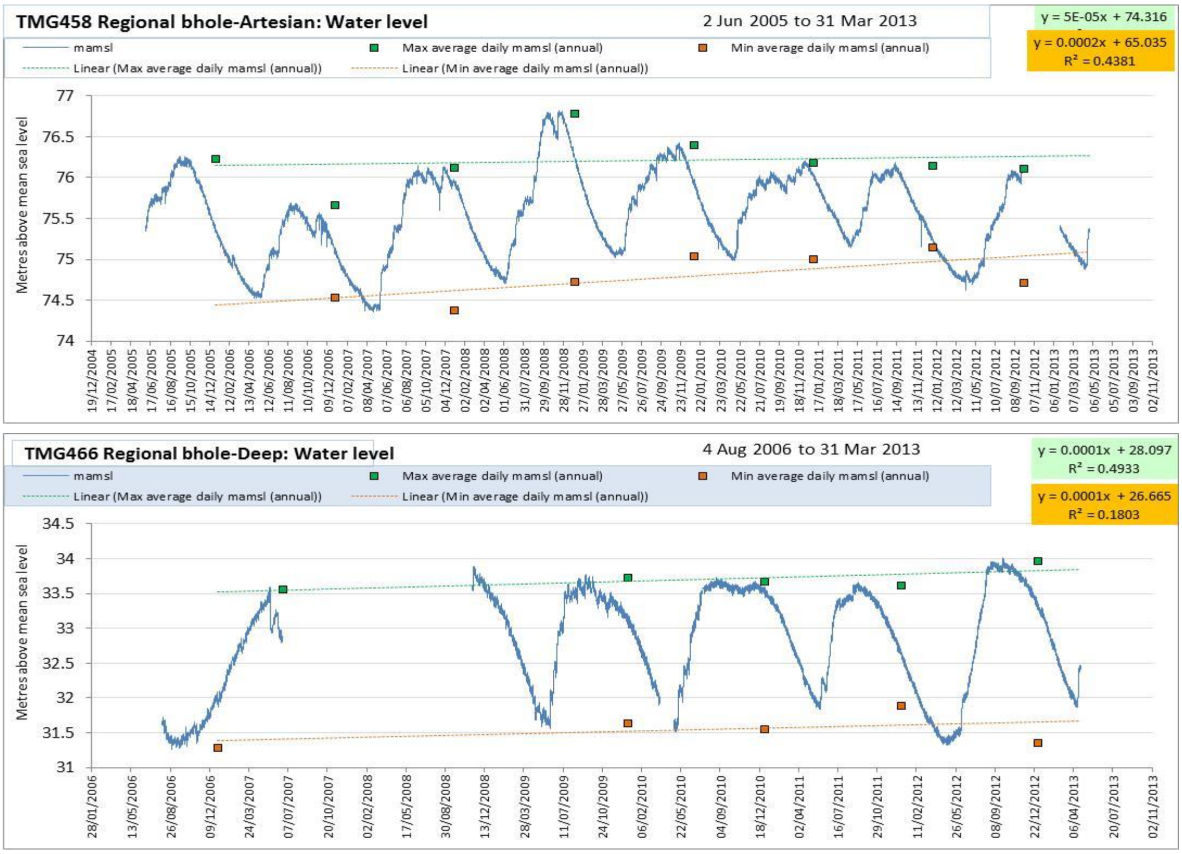


Figure 3.7. Time series of water level from Kogelberg regional boreholes TMG458 and TMG466: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a

b

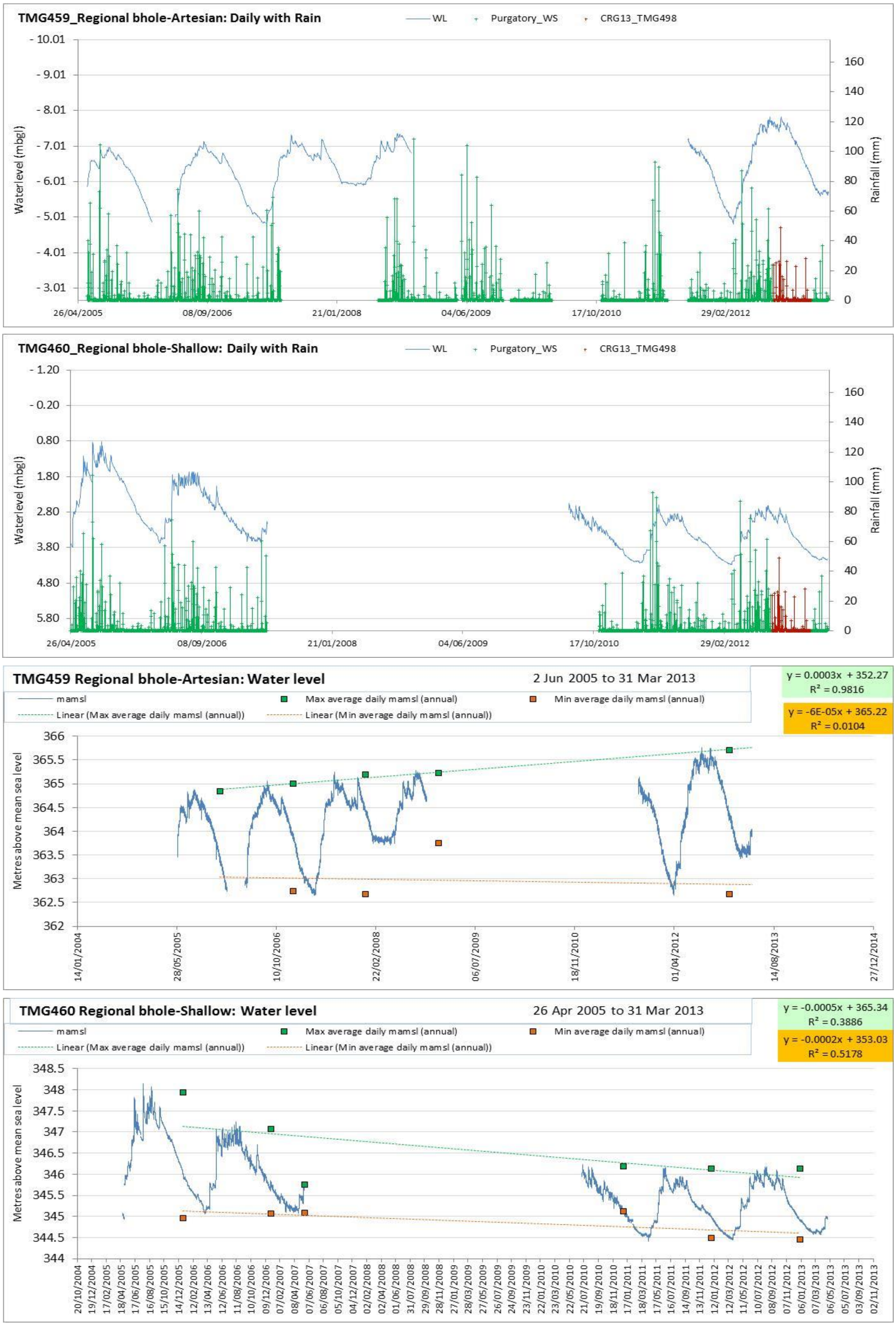


Figure 3.8. Time series of water level from Purgatory regional boreholes TMG459 and TMG460: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a

b

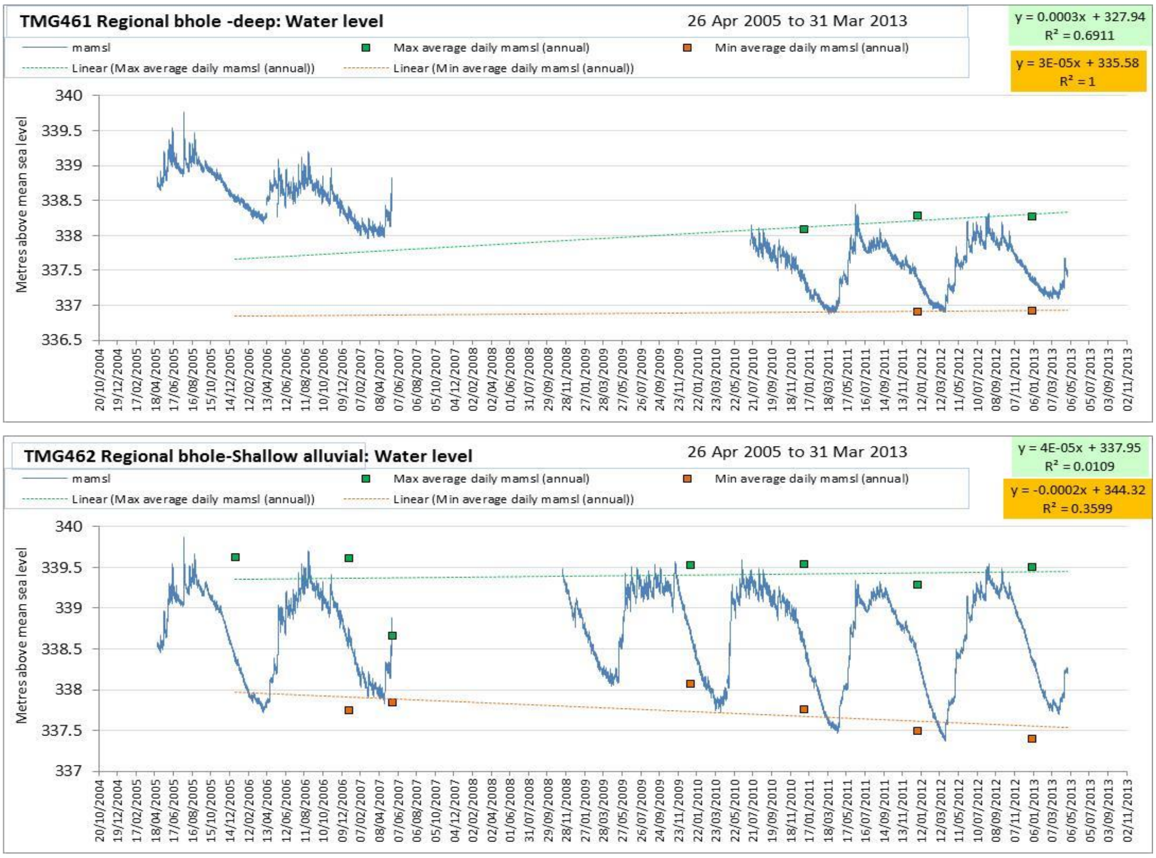
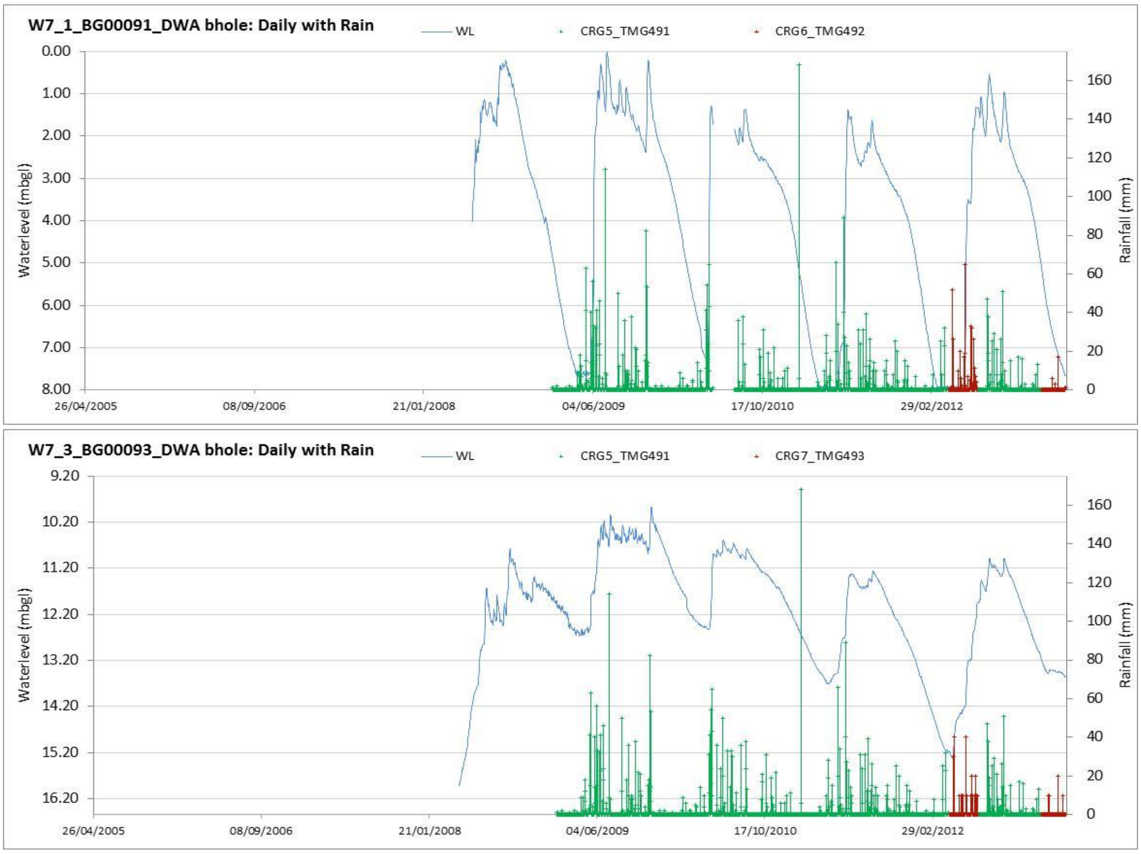


Figure 3.9. Time series of water level from Purgatory regional boreholes TMG461 and TMG462: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data were available.

a



b

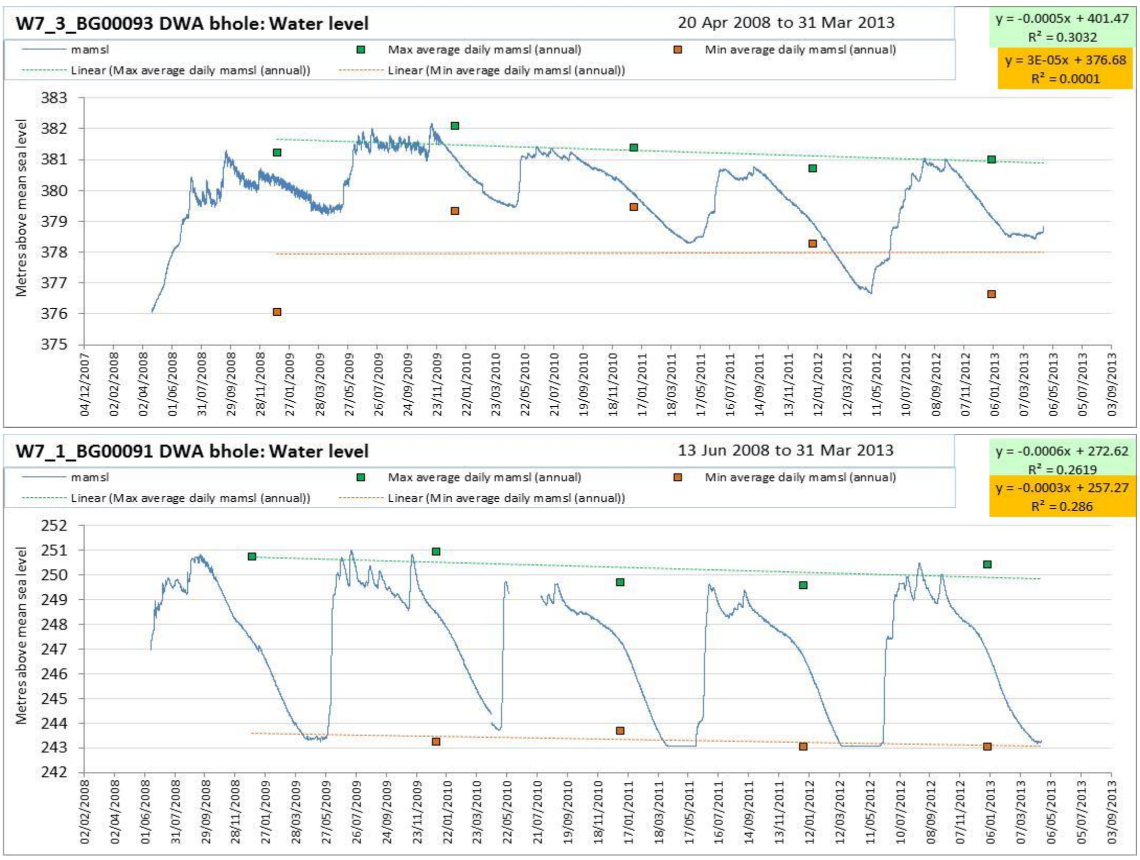
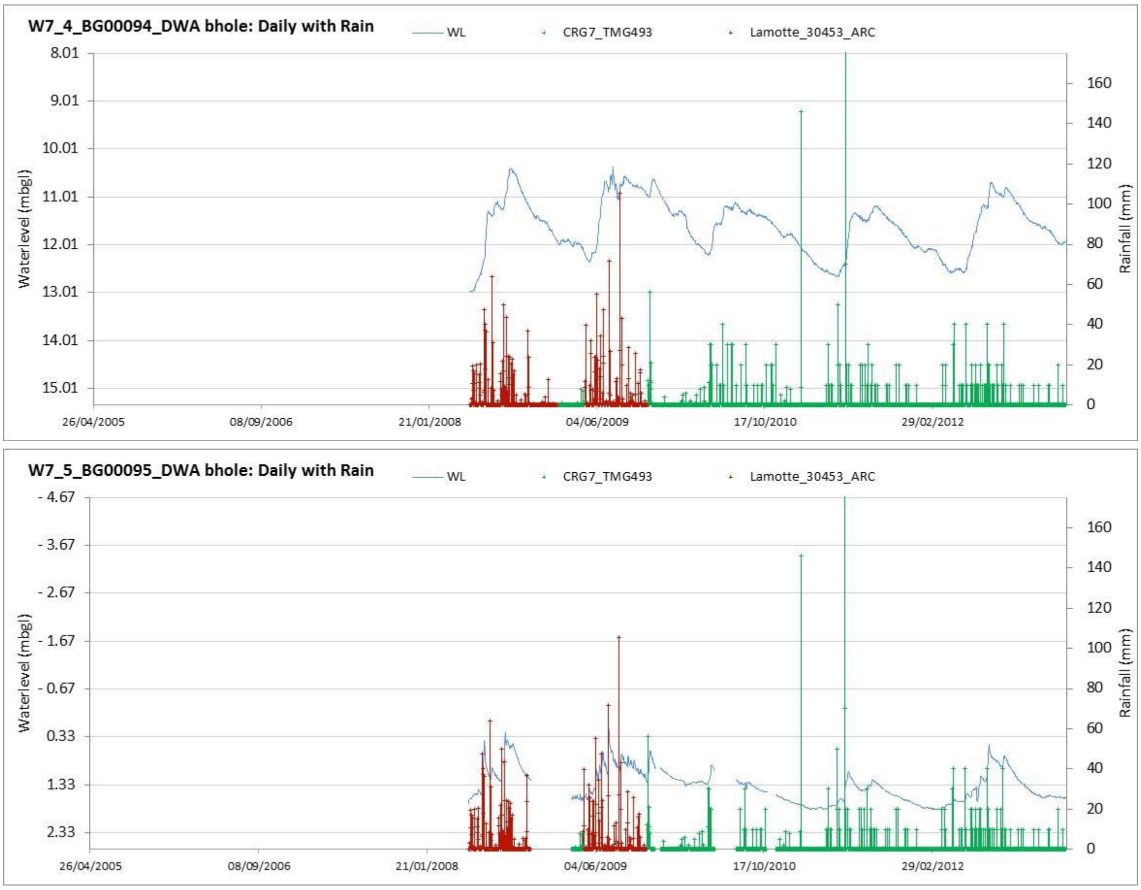


Figure 3.10. Time series of water level from Department of Water Affairs regional boreholes W7_1 and W7_3: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

a



b

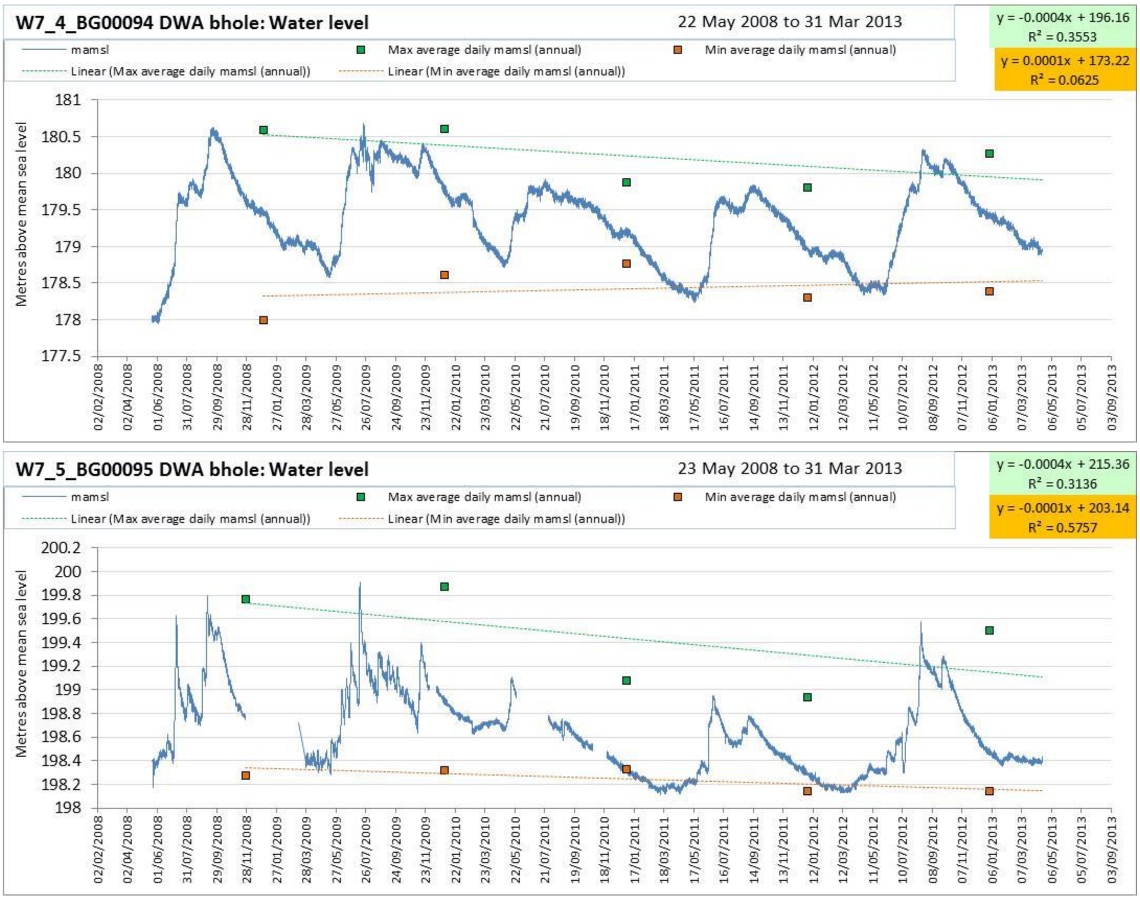


Figure 3.11. Time series of water level from Department of Water Affairs regional boreholes W7_4 and W7_5: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

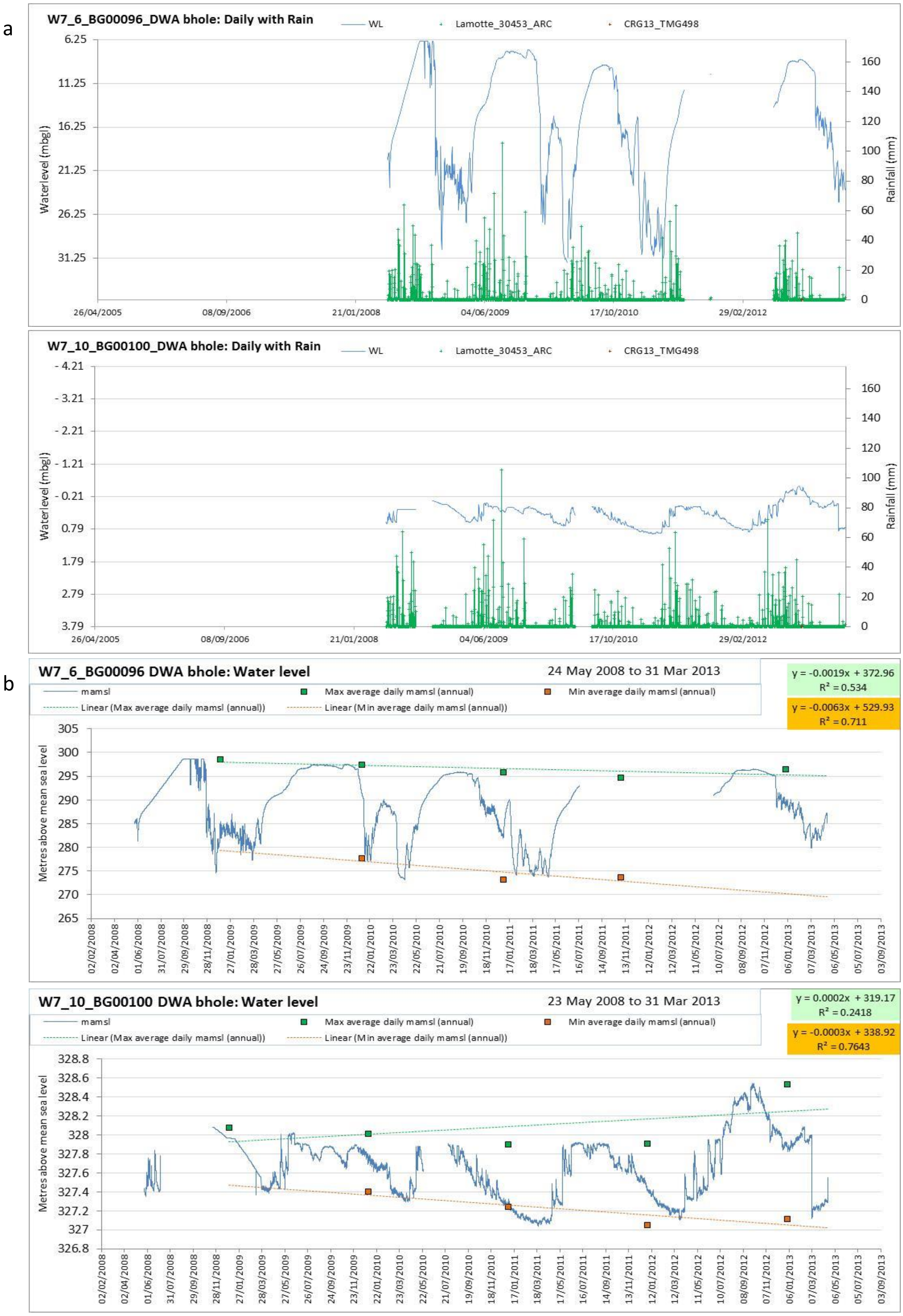


Figure 3.12. Time series of water level from Department of Water Affairs regional boreholes W7_6 and W7_10: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

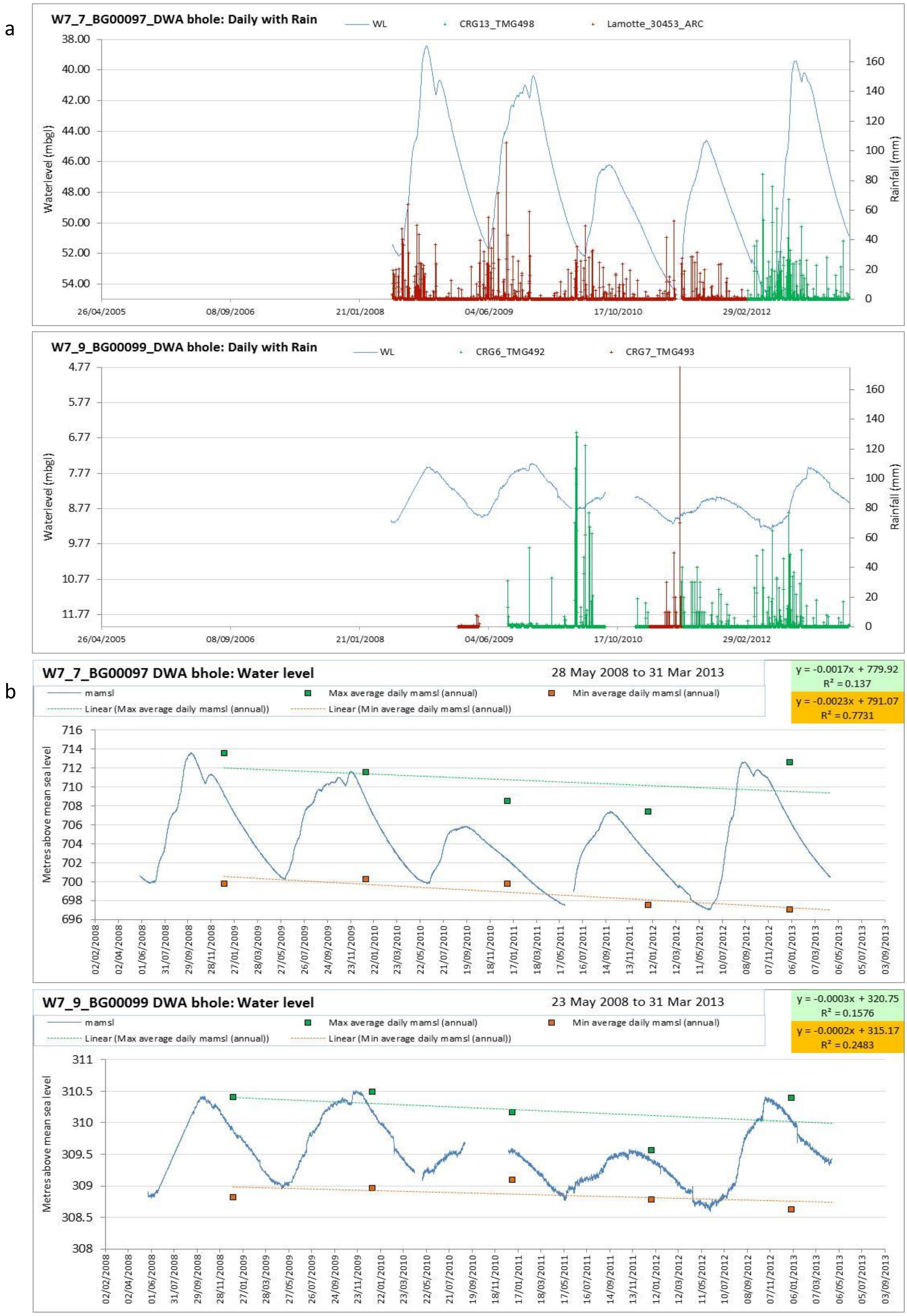
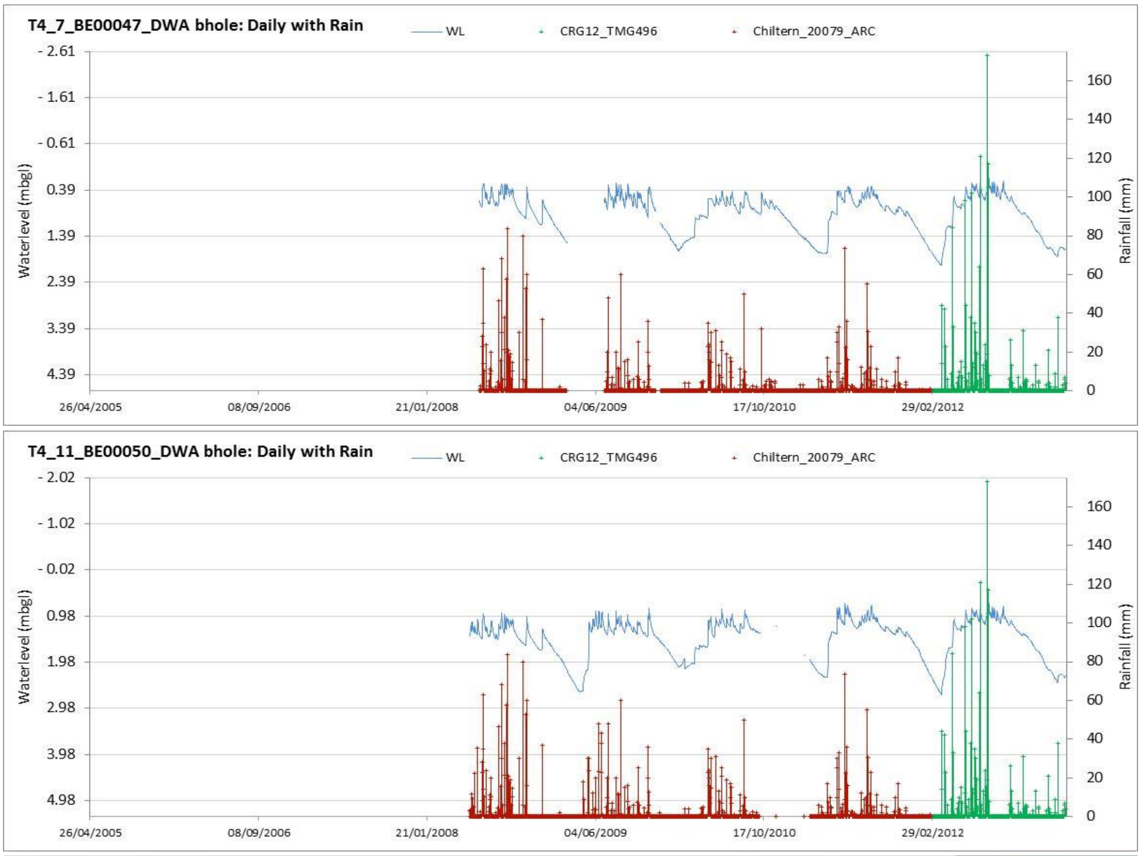


Figure 3.13. Time series of water level from Department of Water Affairs regional boreholes W7_7 and W7_9: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

a



b

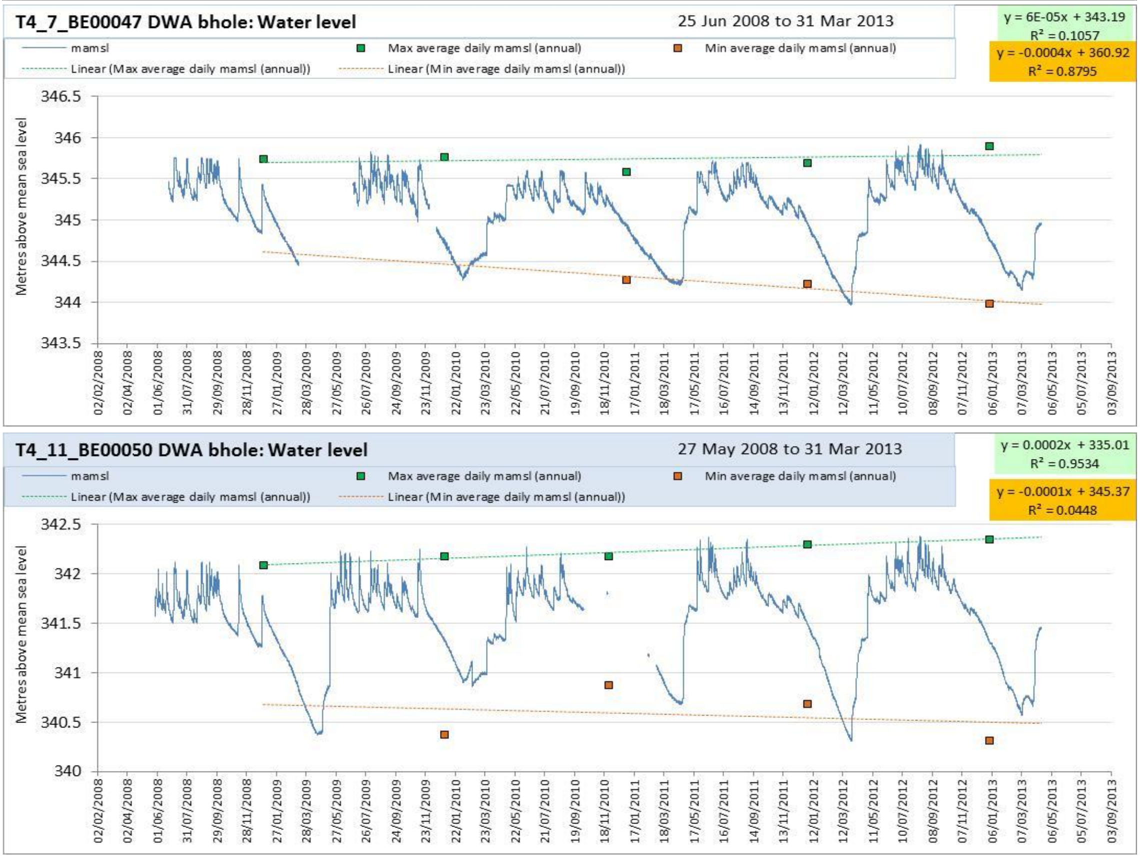


Figure 3.14. Time series of water level from Department of Water Affairs regional boreholes T4_7 and T4_11: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

a

b

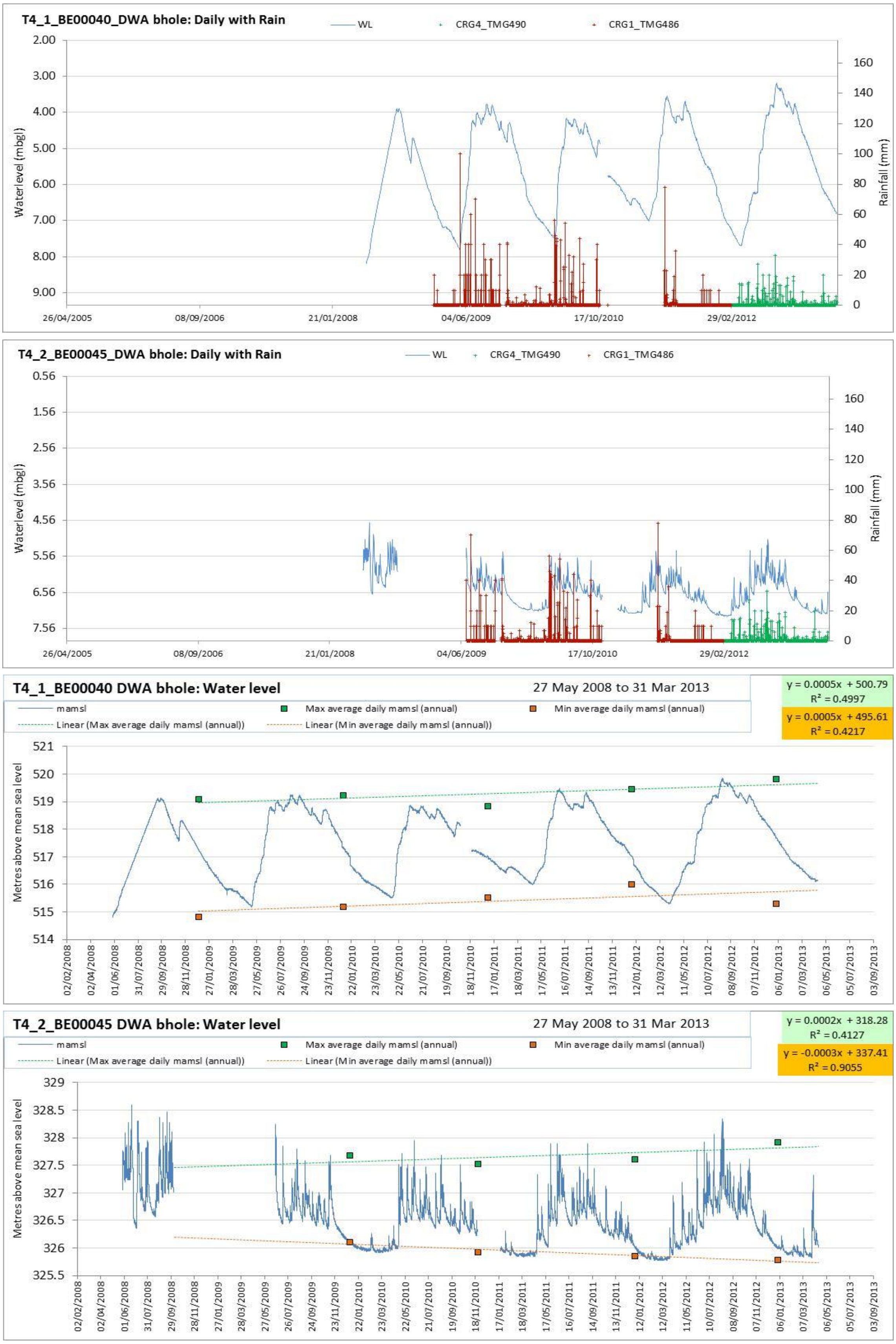
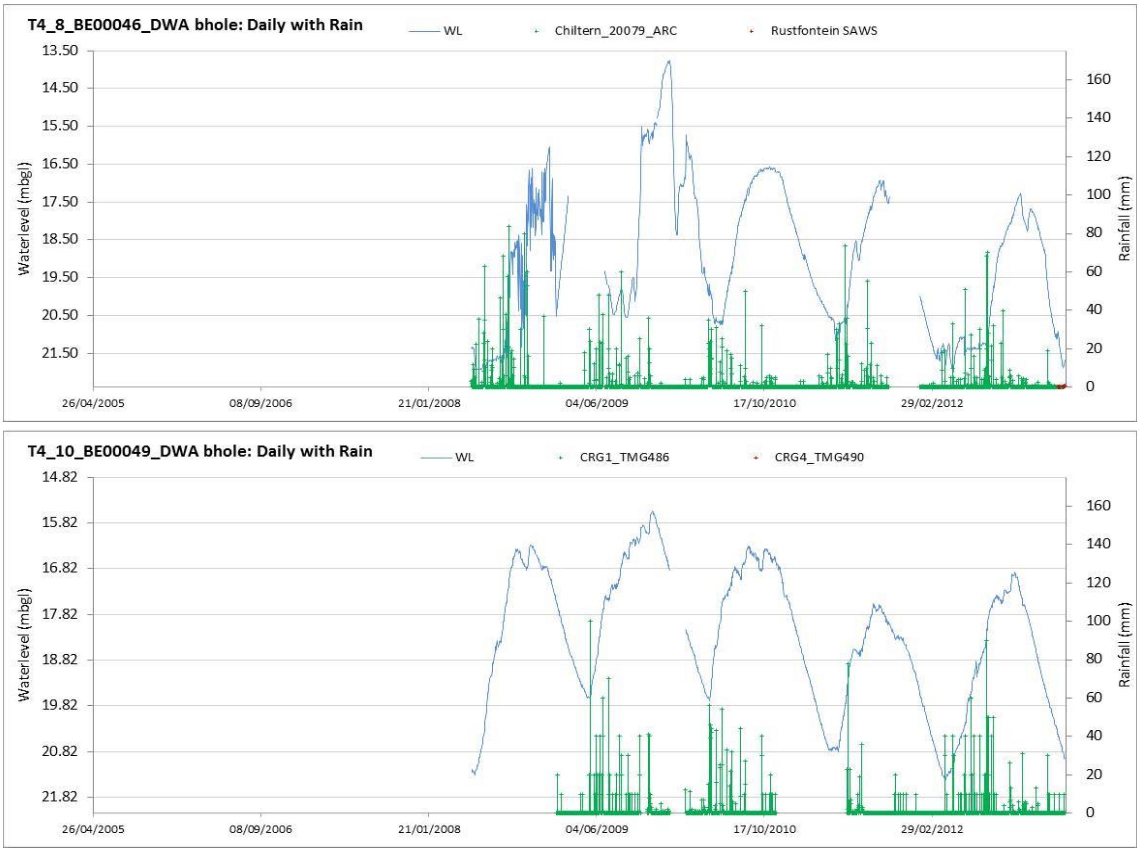


Figure 3.15. Time series of water level from Department of Water Affairs regional boreholes T4_1 and T4_2: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

a



b

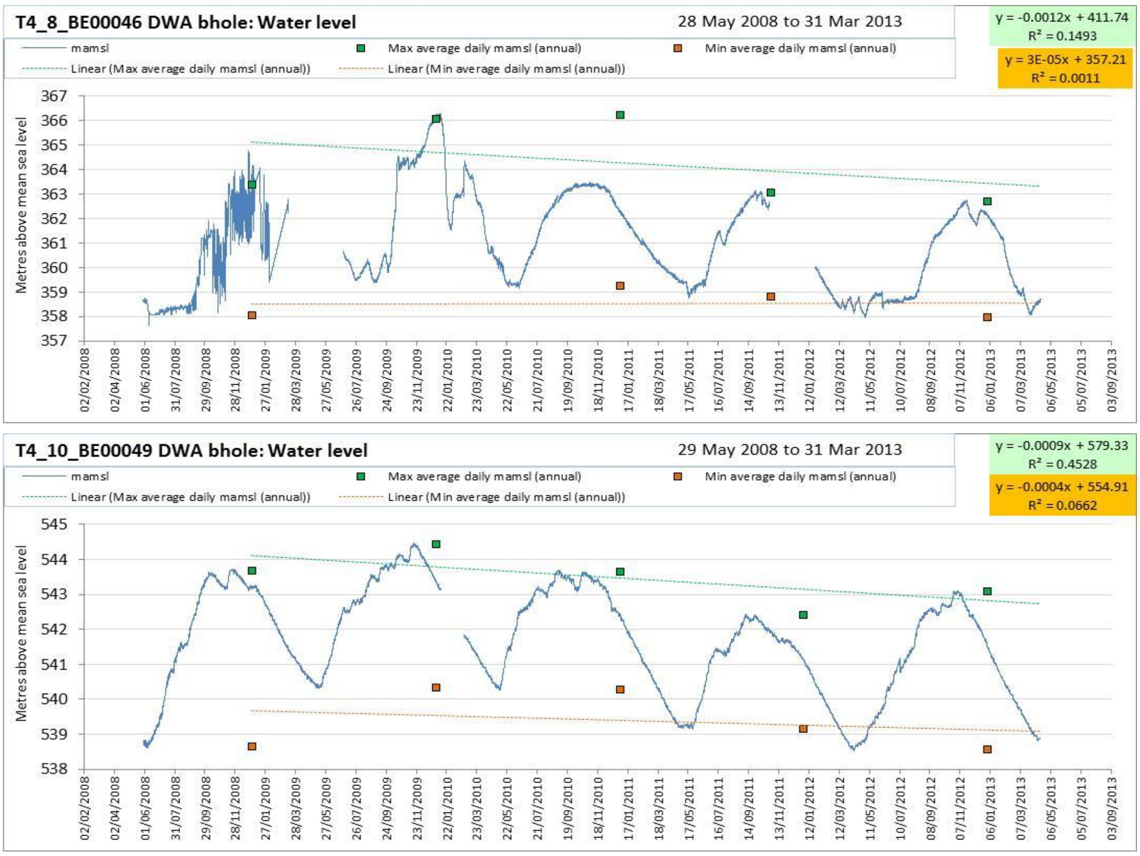


Figure 3.16. Time series of water level from Department of Water Affairs regional boreholes T4_8 and T4_10: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

a

b

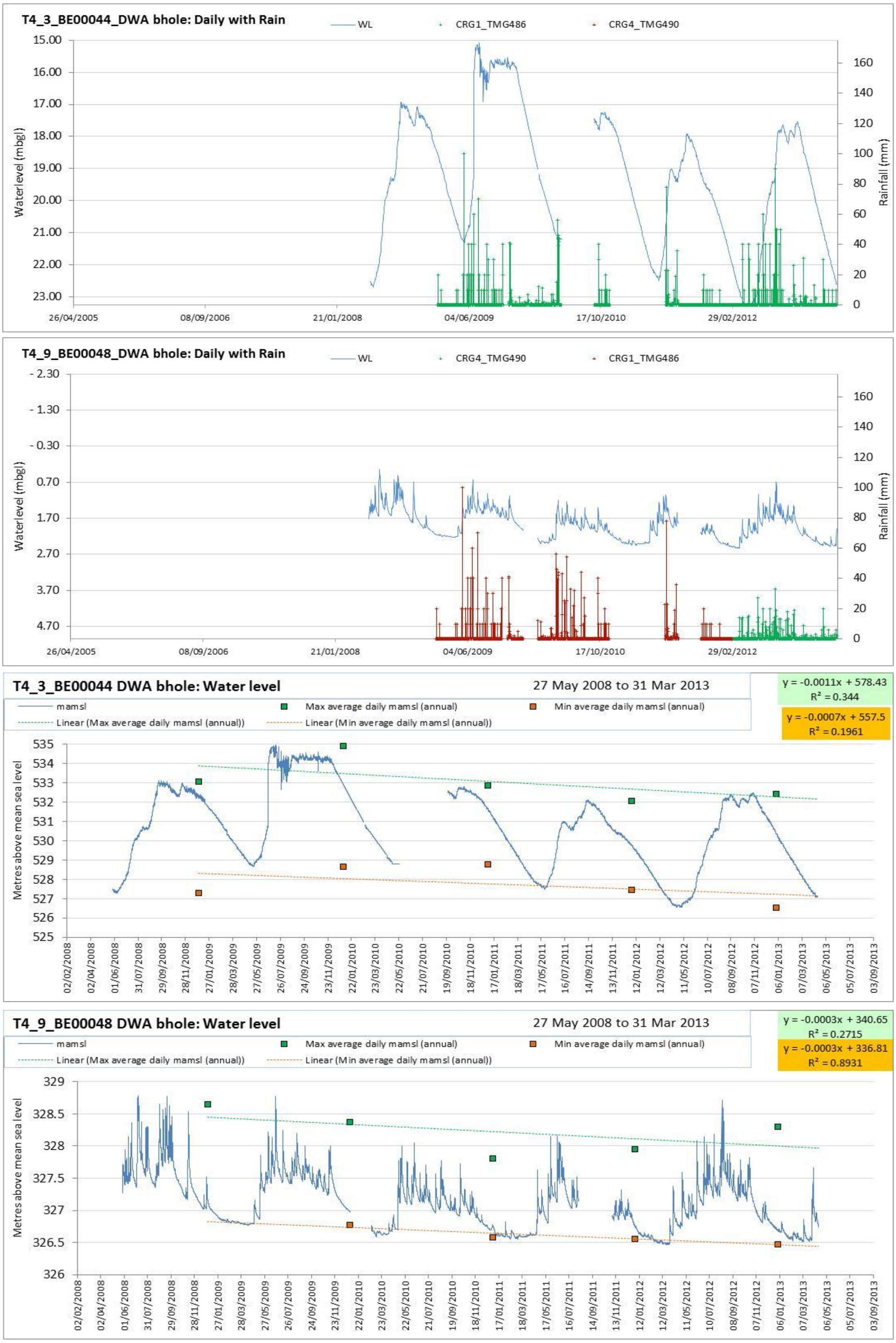


Figure 3.17. Time series of water level from Department of Water Affairs Regional boreholes T4_3 and T4_9: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

a

b

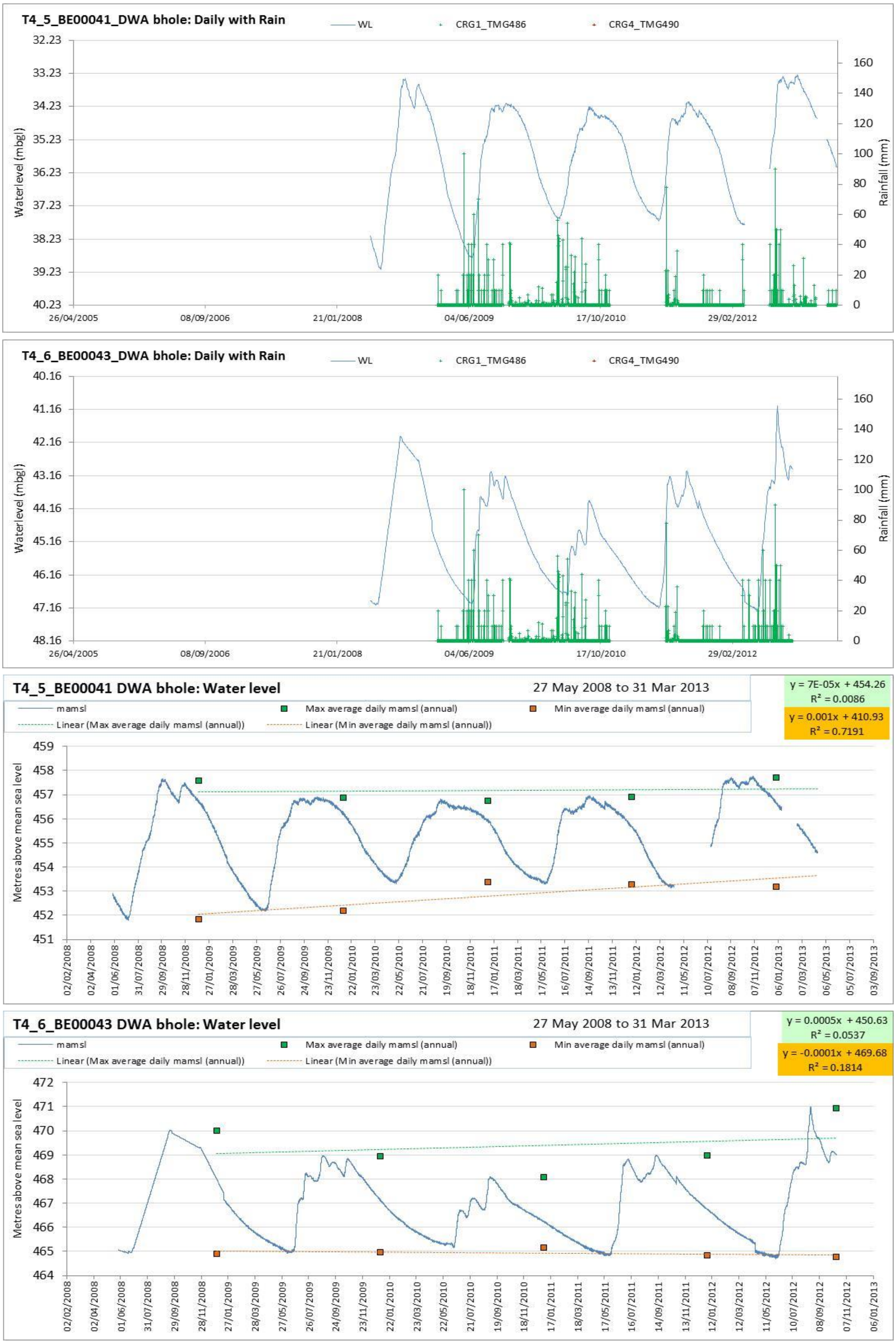


Figure 3.18. Time series of water level from Department of Water Affairs Regional boreholes T4_5 and T4_6: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the rainfall graphs represents the full time period for which all borehole data are available.

3.5 Temperature patterns in monitoring boreholes

Temperature data are presented in composite Figure 3.19, with the y-axis scale set to a similar range to facilitate comparison of patterns. No temperature data were available for the DWA boreholes.

Differences between the deep (depths range from 176 – 427m) exploration boreholes and the shallower (1 – 63 m) regional boreholes were striking:

- Temperatures in the exploration boreholes showed little or no seasonal fluctuation over the four years of record, with the exception of H8_A1 where there appeared to be a seasonal "injection" of colder water over a short period. Faint seasonal fluctuations in temperature at W7_D1 and H8_A3 were discernible but less than 0.3 ^{o}C in amplitude.
- Seasonal fluctuations in temperature in the regional boreholes were between 1 and 2 ^{o}C, with the exception of two boreholes in the Kogelberg - TMG456 (35 m deep) and TMG485 (1 m deep) - where temperature had a range of 4 and 9 ^{o}C (see below). Except for these latter two boreholes, the seasonal minimum occurred close to November, illustrating a lag between surface and groundwater temperatures.
- Temperatures in the exploration boreholes were mostly colder than in the regional boreholes, around 14 – 15.5 ^{o}C compared with 16 – 19 ^{o}C in the two sets. Exceptions to this were:
  - The exploration boreholes at Wemmershoek (W7_D1 and W7_F2) registered temperatures in the region of 17.5 – 19.5 ^{o}C
  - Regional boreholes TMG456 and TMG485 recorded regular temperature fluctuations between 16 and 21 ^{o}C and 12 and 21 ^{o}C respectively.

In four of the Exploration and three of the regional boreholes there was a trend of declining temperature. Supplementary loggers installed in the boreholes indicated that this may be a real pattern, rather than instrument error (although the comparison to date is based on a short record).

3.6 Ecoseeps

Wetland hydrology is typically categorised based on the seasonality of water close to the surface and the depth below ground to which water levels decline. The threshold value on 0.5 mbgl is used to define hydroperiod, since this is considered to be the maximum rooting depth of many wetland plants and thus a determination of the perenniality or otherwise of water suplpy[3]. Water level fluctuations in the piezometers reflect the hydrology of only a part of the ecoseeps, with the piezometers P1 located at the head (top) of the seep and P2 at the lower end of the seep.

Table 3.1 is a summary of the piezometer depths and maximum and minimum water levels at each piezometer in the ecoseeps, with a comment on perenniality of saturation and seasonal variation in hydrology. In most cases, the upper piezometer in the ecoseeps showed both greater seasonality in water level and a tendency to be only seasonally saturated near the surface than the lower portion of the seep which was perennial and showed less variation in water level. Exceptions to this were at B1_1, T3_Pal4 where the upper part of the ecoseep was strongly perennial but the lower portion non-perennial with strong seasonal variation, and at K_1 and K_6 where both P1 and P2 displayed strongly seasonal patterns in saturation.

These patterns are discussed in more detail for each ecoseep in the sections that follow.

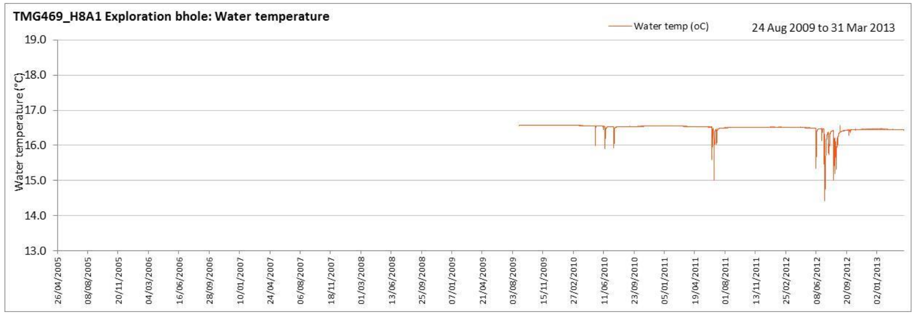
[3] *According to the wetland definitions, wetlands are categorised as seasonal, perennial or ephemeral according to the period of time in which conditions at / above the surface, and within 50 cm of the surface, are saturated. As is highlighted by these ecoseep results, this pattern of wetness if highly variable over the wetland (refer to the Soil Moisture chapter for further examination of within--site variability).*

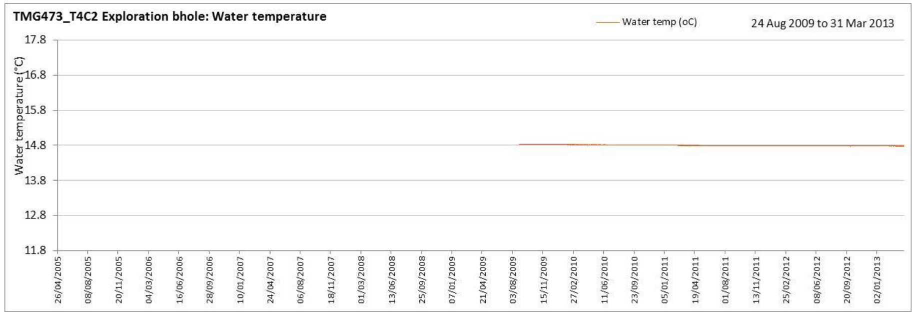
Table 3.1. Summary of water level fluctuations at the ecoseep piezometers over the period of record to March 2013.

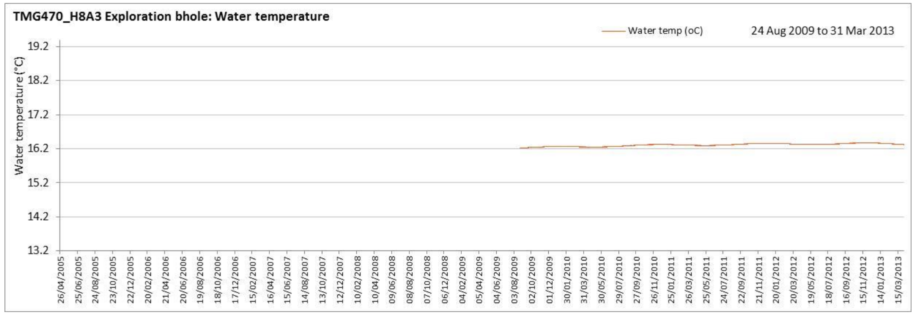
Site	Piezo-meter	Cable length (piezometer depth)	Water level range (m)	Min water level (mbgl)	Max water level (mbgl)	Perrennially saturated close to surface?	Comment on seasonal variation
B1_1	P1	1.99	0.85	0.50	Inund.	Yes	Seasonal fluctuation, but within upper 0.5 m
	P2	2.13	2.20	2.08	Inund.	No	Strong seasonal fluctuation
H8_3b	P1	1.34	0.56	0.58	0.02	Yes	Seasonal fluctuation, but generally within upper 0.5 m Slight dip below 0.5 m in one of two years of record
	P2	2.98	0.61	0.33	0.01	Yes	Seasonal fluctuation, but generally well within upper 0.5 m. Slight dip below 0.5 m in one of four years of record
	P3	2.04	0.24	0.21	Inund.	Yes	Very little seasonal variation in water level
K_1	P1	1.06	0.60	0.83	0.23	No	Strong seasonal fluctuation
	P2	1.63	1.10	1.43	0.33	No	Strong seasonal fluctuation
K_2b	P1	1.42	1.06	1.29	0.22	No	Strong seasonal fluctuation
	P2	1.38	0.78	0.75	Inund.	No (only just)	Seasonal fluctuation all years, but only just below 0.5 m
K_5b	P1	1.11	0.53	0.74	0.21	Possible (1 year record)	Only one year of record, some seasonal variation
	P2	1.54	0.09	Inund.	Inund.	Yes	No seasonal variation in water level
K_6	P1	1.41	1.21	1.20	Inund.	No	Strong seasonal fluctuation
	P2	1.47	1.09	1.14	0.04	No	Strong seasonal fluctuation
T3_Pal4	P1	1.54	0.35	0.09	Inund.	Yes	Very little seasonal variation in water level
	P2	1.35	0.32	1.14	0.72	Never saturated near surface	Seasonal variation, but at depth
T6_1b	P1	1.69	1.29	1.41	0.12	No	Strong seasonal fluctuation
	P2	0.81	0.50	0.43	Inund.	Yes	Little seasonal fluctuation in most years (early data = erratic)
T6_4	P1	2.85	0.48	0.60	0.12	Yes	Seasonal fluctuation, but within upper 0.5 m Slight dip below 0.5 m in one of five years of record
	P2	0.86	0.12	0.12	Inund.	Yes	Little seasonal fluctuation
T8_2b	P1	1.74	1.03	1.45	0.42	No	Strong seasonal fluctuation
	P2	1.41	0.74	0.63	Inund.	Yes	Seasonal fluctuation, but generally well within upper 0.5 m. Slight dip below 0.5 m in one of five years of record

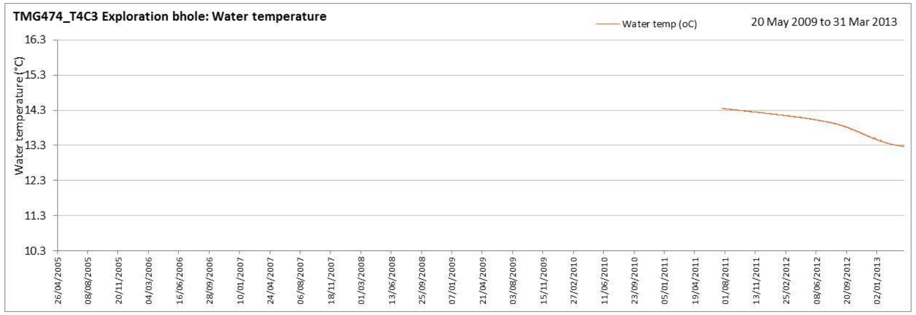
3.6.1 Ecoseep B1_1

Hydrological patterns varied in different parts of B1_1 over the study period, as indicated by the data from P1 and P2 (Figure 3.20), which showed a mix of permanently saturated conditions close to the surface (P1) and seasonally saturated conditions (P2). Seasonality was present but only pronounced at P2. The trend in water level over time, based only on data from P1 which has a sufficiently long record, including the EPM1 monitoring, was stable. Water temperature at B1_1 (P1) showed seasonality, with an average of about 17 ^{o}C, and a 2.5 ^{o}C range.









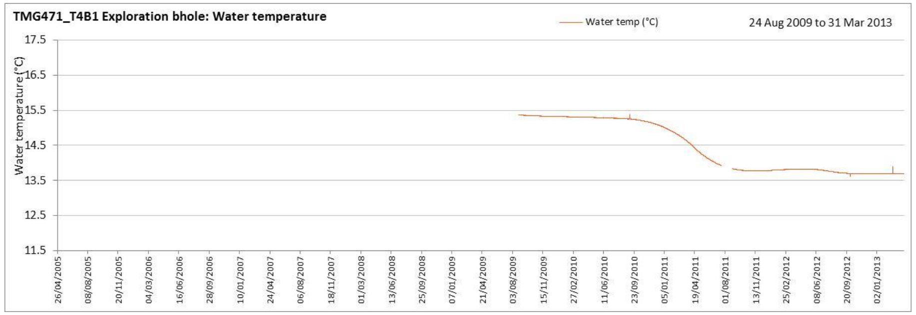
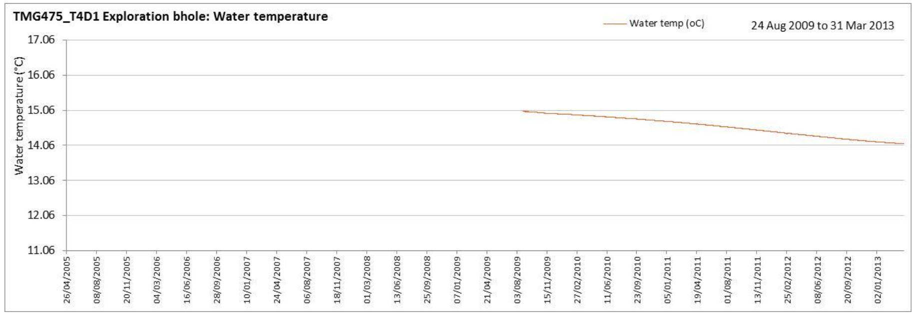
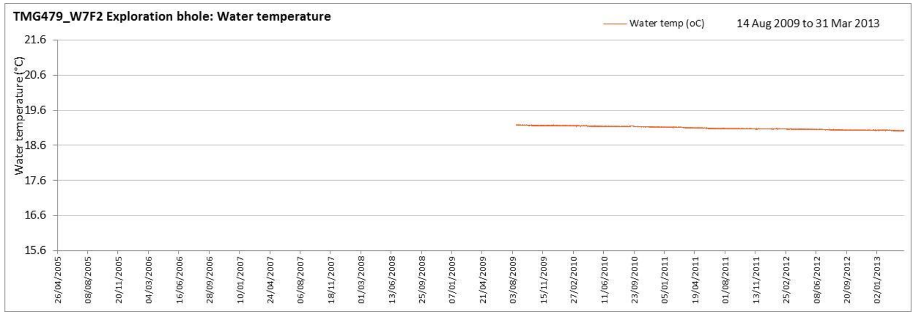
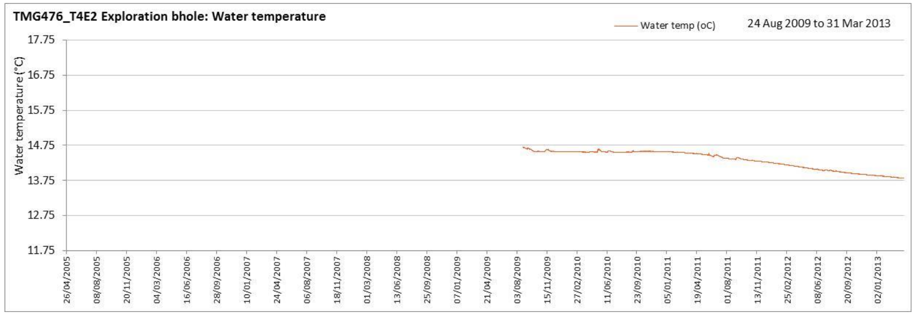
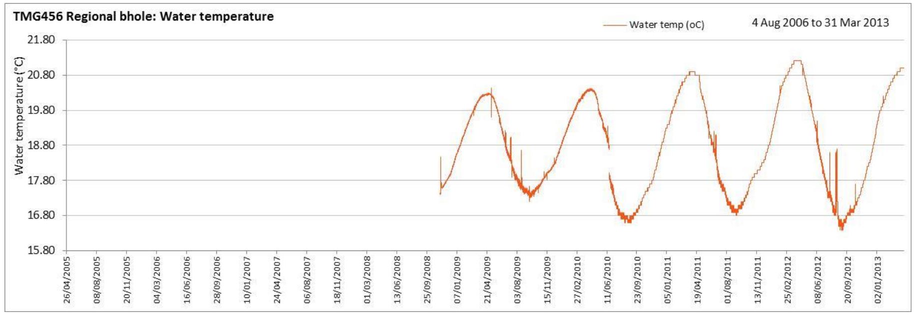


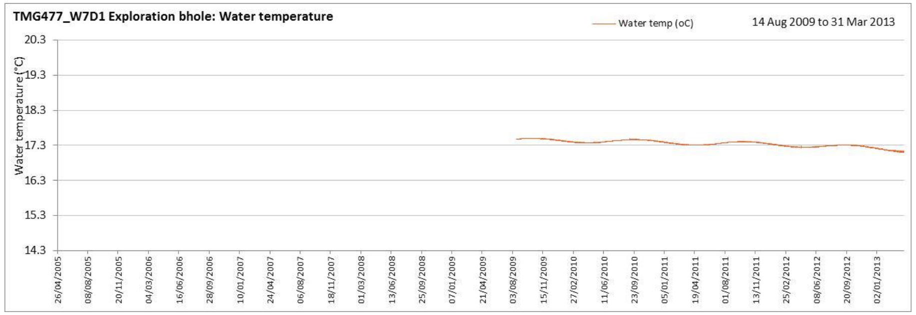
Figure 3.19 Composite figure showing time series temperature for nine non-artesian exploration Boreholes (176 – 427 m deep) and eight non-artesian regional Boreholes (1-65 m deep) over the period of monitoring (continue over next two pages).

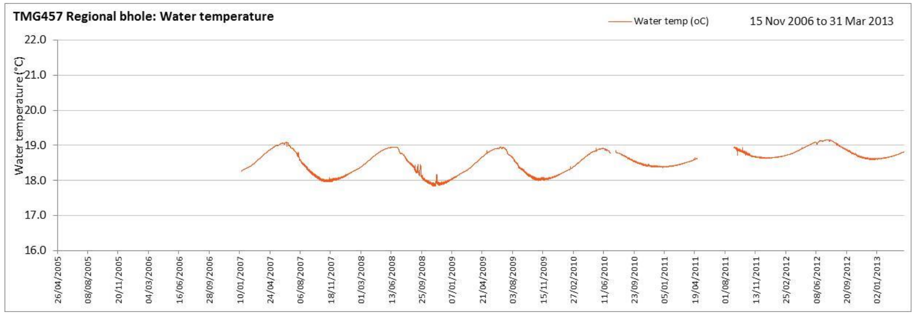

TMG475_T4D1 Exploration bhole: Water temperature
Water temp (oC)
24 Aug 2009 to 31 Mar 2013
Water temperature (°C)

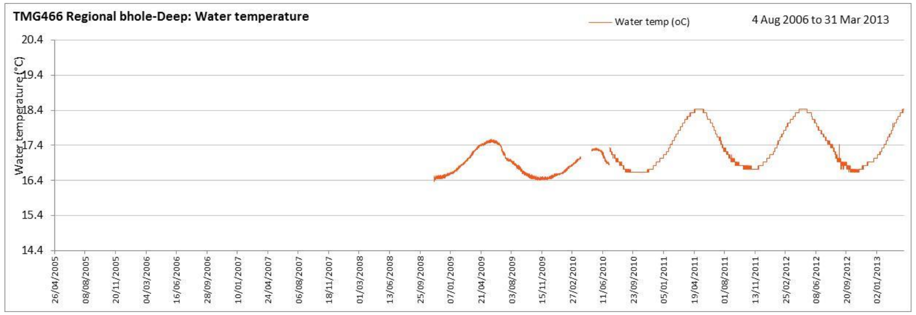

TMG479_W7F2 Exploration bhole: Water temperature
Water temp (oC)
14 Aug 2009 to 31 Mar 2013
Water temperature (°C)

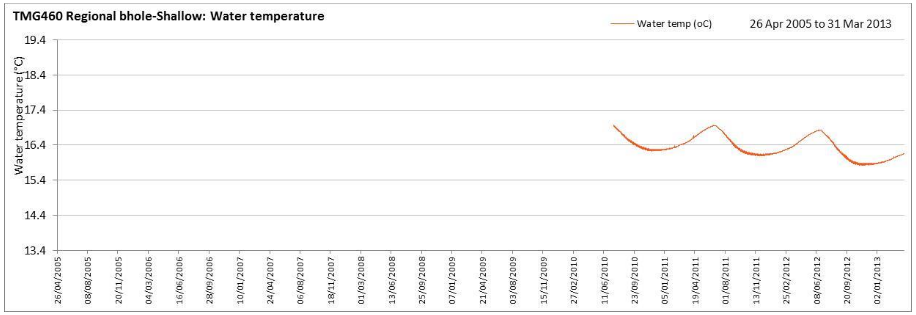

TMG476_T4E2 Exploration bhole: Water temperature
Water temp (oC)
24 Aug 2009 to 31 Mar 2013
Water temperature (°C)

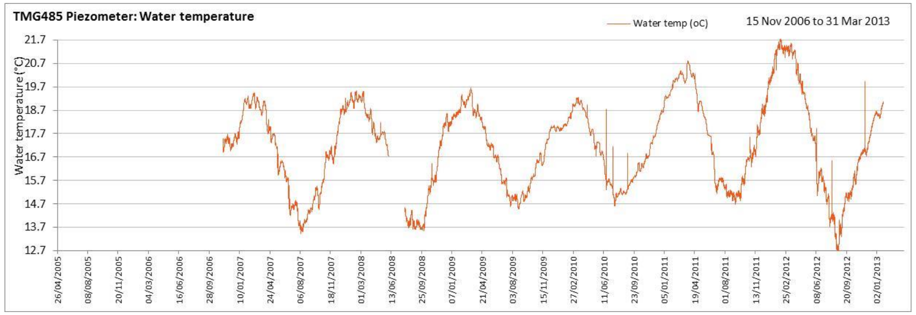

TMG456 Regional bhole: Water temperature
Water temp (oC)
4 Aug 2006 to 31 Mar 2013
Water temperature (°C)

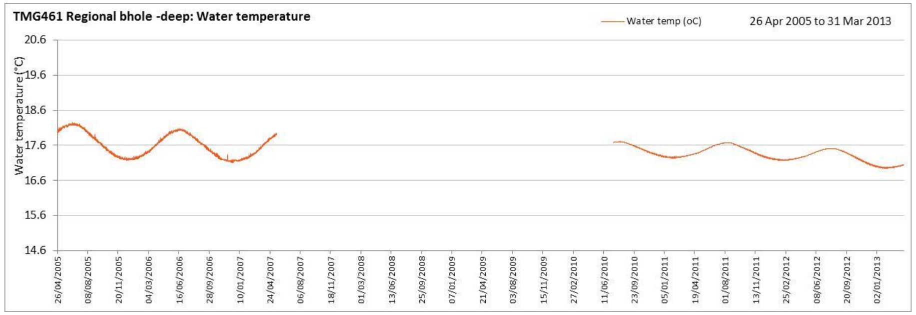

TMG477_W7D1 Exploration bhole: Water temperature
Water temp (oC)
14 Aug 2009 to 31 Mar 2013
Water temperature (°C)

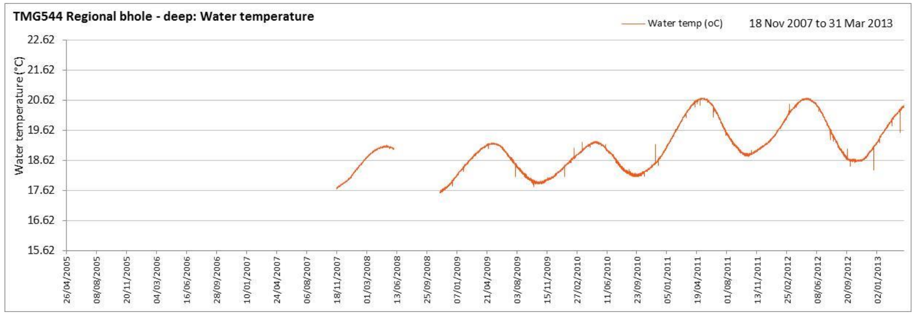

TMG457 Regional bhole: Water temperature
Water temp (oC)
15 Nov 2006 to 31 Mar 2013
Water temperature (°C)

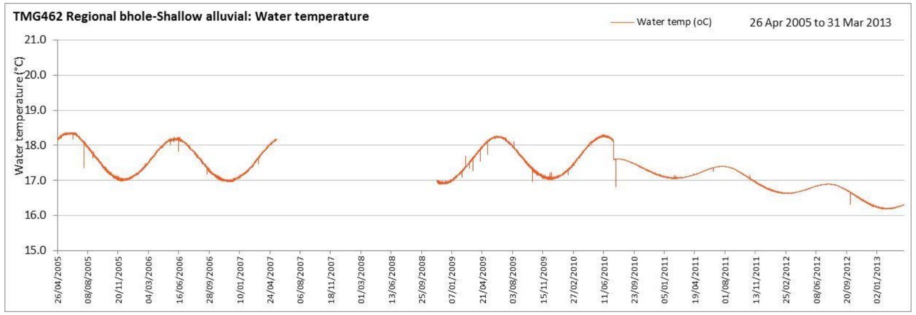

TMG466 Regional bhole-Deep: Water temperature
Water temp (oC)
4 Aug 2006 to 31 Mar 2013
Water temperature (°C)
20.4
19.4
18.4
17.4
16.4
15.4
14.4


TMG460 Regional bhole-Shallow: Water temperature
Water temp (oC)
26 Apr 2005 to 31 Mar 2013
Water temperature (°C)
19.4
18.4
17.4
16.4
15.4
14.4
13.4


TMG485 Piezometer: Water temperature
Water temp (oC)
15 Nov 2006 to 31 Mar 2013
Water temperature (°C)
21.7
20.7
19.7
18.7
17.7
16.7
15.7
14.7
13.7
12.7


TMG461 Regional bhole -deep: Water temperature
Water temp (oC)
26 Apr 2005 to 31 Mar 2013
Water temperature (°C)
20.6
19.6
18.6
17.6
16.6
15.6
14.6


TMG544 Regional bhole - deep: Water temperature
Water temp (oC)
18 Nov 2007 to 31 Mar 2013
Water temperature (°C)
22.62
21.62
20.62
19.62
18.62
17.62
16.62
15.62


TMG462 Regional bhole-Shallow alluvial: Water temperature
Water temp (oC)
26 Apr 2005 to 31 Mar 2013
Water temperature (°C)
21.0
20.0
19.0
18.0
17.0
16.0
15.0

3.6.2 Ecoseep H8_3b

There are three piezometers at H8_3b. P1 and P3 were established for EPM2 and provide just under two years of data, from winter 2011 through to autumn 2013 (Figure 3.21), and P2 was established in July 2008 in EPM1 and provides just less than 5 years of data. Difference in water level patterns between the three piezometers at H8_3b were clear, showing saturation levels closer to the surface from top to bottom of the seep. Water levels at P3 remained within 0.15 m of the surface, with very little seasonal fluctuation, while the levels dropped to around 0.5 mbgl at P1 and P2 by the end of the dry season. Based on a minimum water level of 0.5 mbgl, all piezometer positions were perennially saturated for most years over the sampling period. Inter-annual patterns at P2 illustrate the probable effects of post-fire vegetation growth and evapotranspiration on water levels: after the December 2008 fire, there was no seasonal decrease in water level, in the absence of evapotranspiration at the bare site. That was followed by a gradual increase in drawdown in subsequent years, tracking the re-establishment of the flora. High rainfall in spring 2012 also affected water levels, with drawdown being diminished in the summer of 2012/2013.

Water temperature was on average around 17 ^{o}C but ranged over 4 ^{o}C at H8_3b (P2), with coolest temperatures recorded in August.

3.6.3 Ecoseeps K_1, K_2b, K_6 and K_5b

Figure 3.22 illustrates temporal patterns in water level at K_1 and K_2b, whilst Figure 3.23 shows these for K_6 (closest to K_1 and K_2b) and K_5b. Temperature from one piezometer at each site is compared in Figure 3.25.

The upper piezometer P1 at K_1 showed seasonally saturated conditions for a fairly prolonged period, not linked to rain events, suggesting some groundwater or constant interflow source. However, even during the wettest period, water did not lie at the ground surface, but rather some 0.3 mbgl, a feature that is likely to influence plant communities. Conditions were much drier at P2, which experienced more ephemeral wetland conditions, with water only temporarily reaching within 0.5 mbgl. These patterns were remarkably constant over the two year period.

A contrasting pattern prevailed at K_2b. The ecoseep also displayed spatial differences in moisture levels, but whilst water levels at P1 came close to the surface, the hydroperiod was shorter and far more rain-determined, as seen from the linking of water level fluctuations to rainfall. This suggests that this portion of K_2b was more strongly affected by rainfall and interflow than K_1. The lower portion of K_2b, represented by P2, had a clearer groundwater signal, despite the influence of rainfall. This part of the seep was nearly perennially saturated, with water levels declining each year to only just below 0.5 mbgl.

Both piezometers at K_6 had near-identical patterns in water level, with water at the surface in winter but seasonal fluctuations of over 1 m. Notwithstanding the short data record, patterns were similar to K_1 (P1), but with moisture closer to the surface. The implication is that, whilst groundwater may be present at the site, it is sustained at sufficiently high levels to influence wetland conditions only seasonally, and these data suggest that all parts of the seep are seasonally dry.

In contrast, K_5b, although only represented by a short record, showed a far greater constancy in water level, with minimal fluctuation at P2 and only a short draw-down period at P1.

Temperature patterns at the Kogelberg ecoseeps illustrated further the strength of the groundwater connection: K_5b recorded temperatures between 12.5 and 17.5^{o}C, whilst the range at K_2b (P2) and K_6 was 4 – 5 ^{o}C, with a maximum temperature of 19 and 21 ^{o}C respectively. In contrast water at K_1 was between 16.5 and 23 ^{o}C (Figure 3.24). No temporal patterns were evident in temperature or water level at these sites, aside from the seasonality described.

3.6.4 Ecoseep T4_Pal3

As with the other ecoseeps, differences in hydroperiod between the different portions of the seep were substantial. Here, however, the upper piezometer P1 had a consistently elevated water level, implying permanent saturation close to the surface, with little response to individual rain events. P2, on the other hand, in more fractured rocky substratum closer to the channel extending along the northern edge of the seep, did not have a wetland signature, i.e. water levels did not reach within 0.5 mbgl (Figure 3.25).

The difference both in temperature range and in maximum values suggests different water sources within the ecoseep.

3.6.5 Ecoseep T6_1b

The time series of water levels for P1 at T6_1b was slightly longer than that for P2, beginning in April 2011 as opposed to late June 2011 (Figure 3.26). P1 appeared to be seasonally wet, since water levels remained within 0.5 m of the surface for eight to nine months. However, maximum water level was *ca.* 0.3 m from the surface, suggesting that this upper portion of the seep was never saturated at the surface or inundated. P2 in the centre of the seep was much wetter. Aside from what are suspected to be some erroneous data readings at P2 the water levels reflected permanently saturated conditions close to the surface, which matched field observations. The higher than average rainfall in 2012 did not appear to affect (i.e. reduce) seasonal drawdown at P1, which was more marked in summer 2012 than in 2011.

3.6.6 Ecoseep T6_4

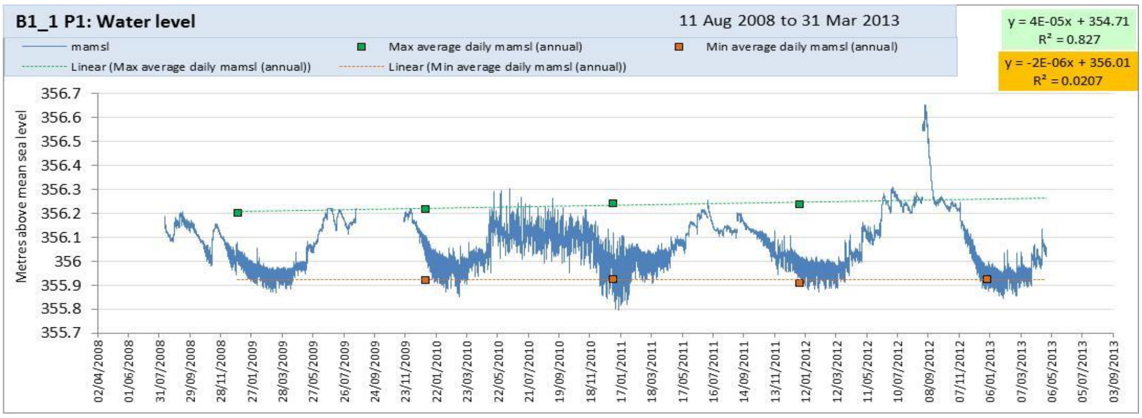
P1 was established in EPM1 (Figure 3.27). Both portions of the seep appeared to be strongly perennial with respect to saturation - seasonal fluctuations at P1 were most small, except for one year, although the level of saturation was variable, with water levels reaching the surface in some years but not in others. At P2 the data showed a seasonal decline from surface saturation to around 0.12 mbgl. A slight decrease in seep water levels was evident from the four year dataset at P1. In terms of temporal trends (Figure 3.27b), some periods showed a failure of water levels to recover after the summer drawdown, roughly matching the annual rainfall volume (Figure 3.27a) but since 2010 the summer minima have been closer to the surface, again tracking the better rainfall.

3.6.7 Ecoseep T8_2b

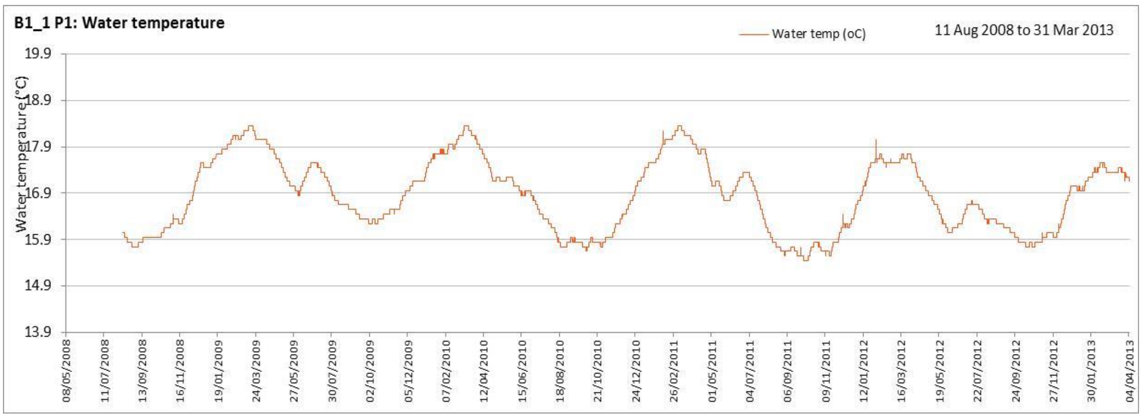
P2 was established at this site in EPM1 and the data now extend over four years (Figure 3.28a). This portion of the seep was seasonally saturated, with water level fluctuating within 0.5 m of the ground in four of the five summers monitored and only marginally lower than this in the drier years. A trajectory of declining summer minima from 2009 to 2012 was reversed in the 2013 summer, with a shift to perenniality once more (Figure 3.28b).

Quite a different picture emerged from the record at P1: like P2 at T3_Pal4 and P2 at K_1, this portion of the ecoseep was only intermittently saturated. Water level was never close to the surface, even with the high rainfall in winter 2012 when there were short periods when the level approached 0.4 mbgl (Figure 3.28a). Water level receded below the depth of the piezometer in the dry season.

a



b



c

Figure 3.20. Time series of water level at P1 and P2 in ecoseep B1_1: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. c) Temperature patterns at P1 (longest record). The x-axis scale for the graphs in (a) represents covers EPM1 and EPM2.

Figure 3.21. Time series of water level at P1, P2 and P3 in ecoseep H8_3b: a) as mbgl, with daily rainfall for the EPM2 period and b) as mamsl, showing trends in annual maximum and minimum water levels. c) Temperature patterns at P2 (longest record). The x-axis scale for the graphs in (a) covers EPM1 and EPM2.

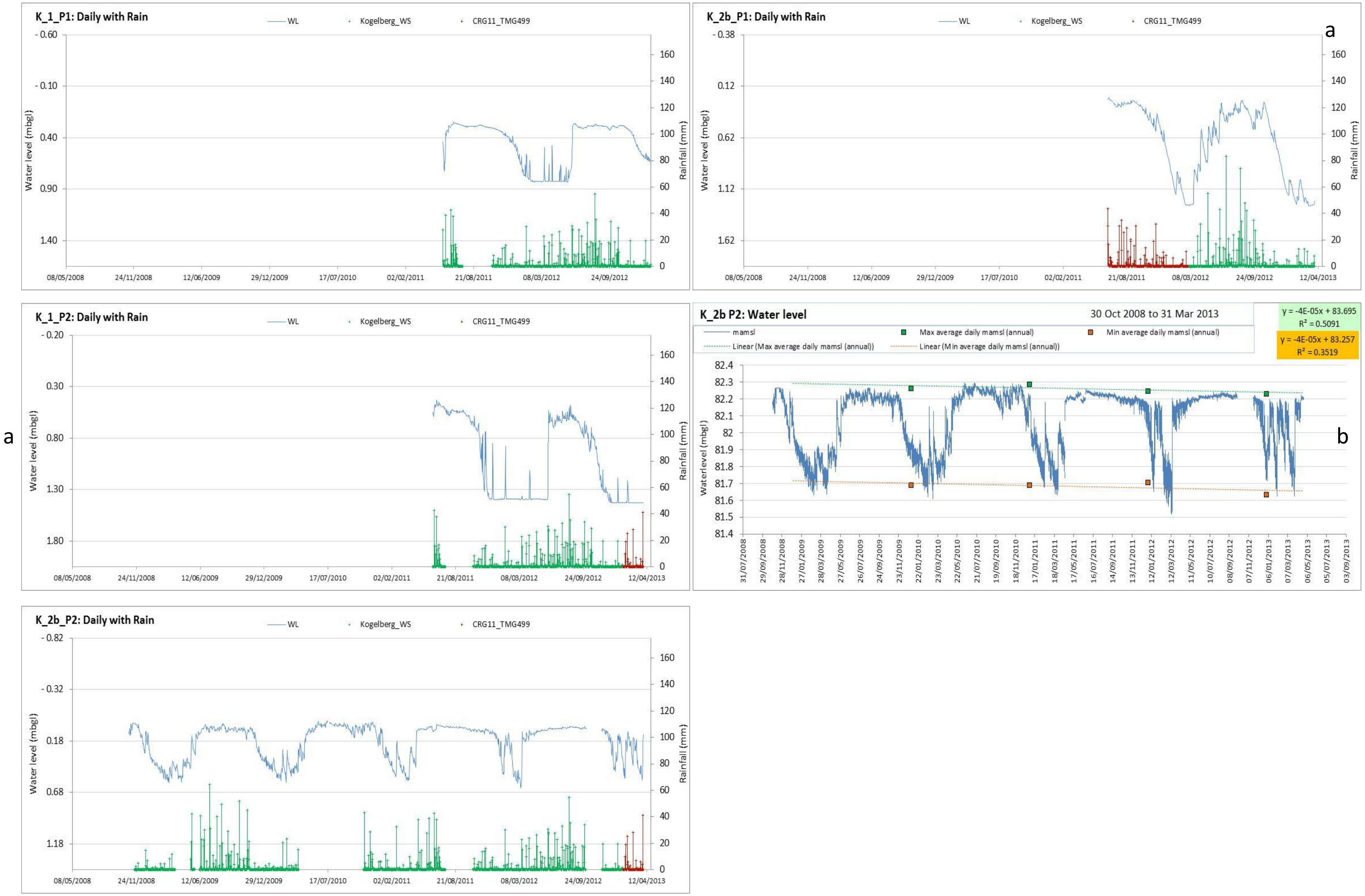


Figure 3.22. Time series of water level at P1 and P2 in ecoseeps K_1 and K_2b: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. The x-axis scale for the graphs in (a) covers EPM1 and EPM2.

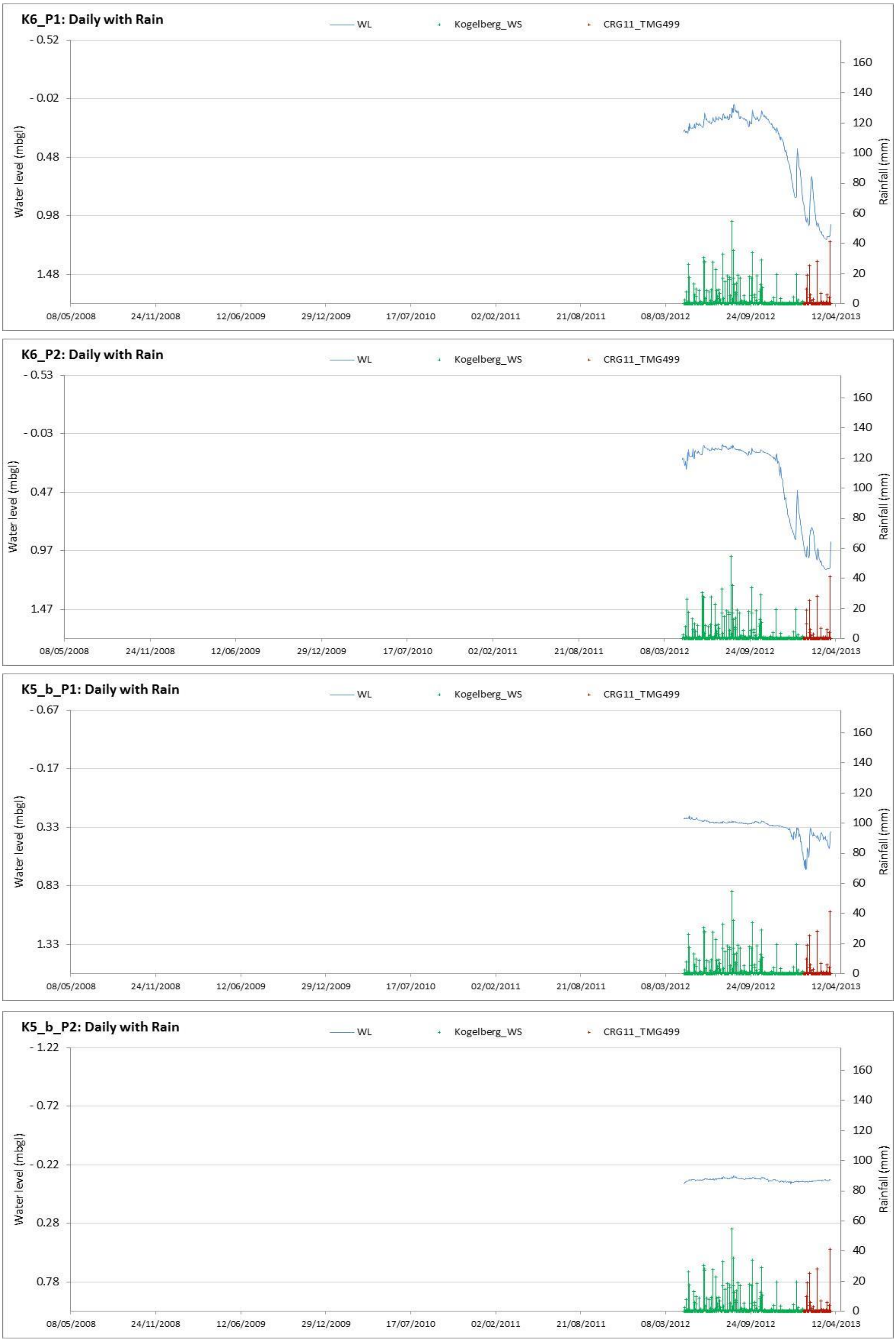


Figure 3.23. Time series of water level at P1 and P2 in ecoseeps K_6 and K_5b as mbgl, with daily rainfall for the EPM2 period. The x-axis scale for the graphs covers EPM1 and EPM2.

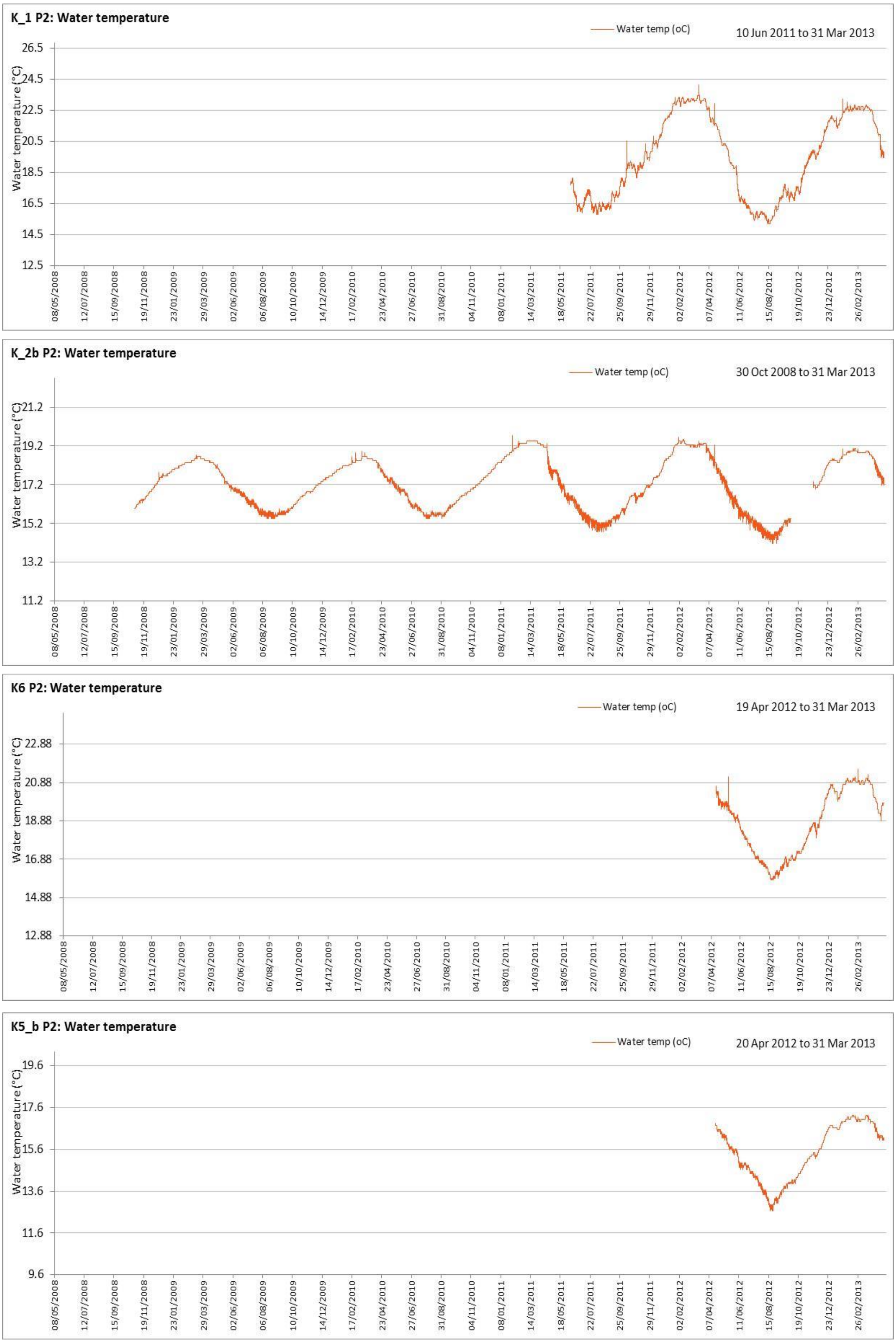


Figure 3.24. A comparison of temperatures at the Kogelberg ecoseeps. The x-axis scale for the graphs covers EPM1 and EPM2. Note: y-axis scale not constant.

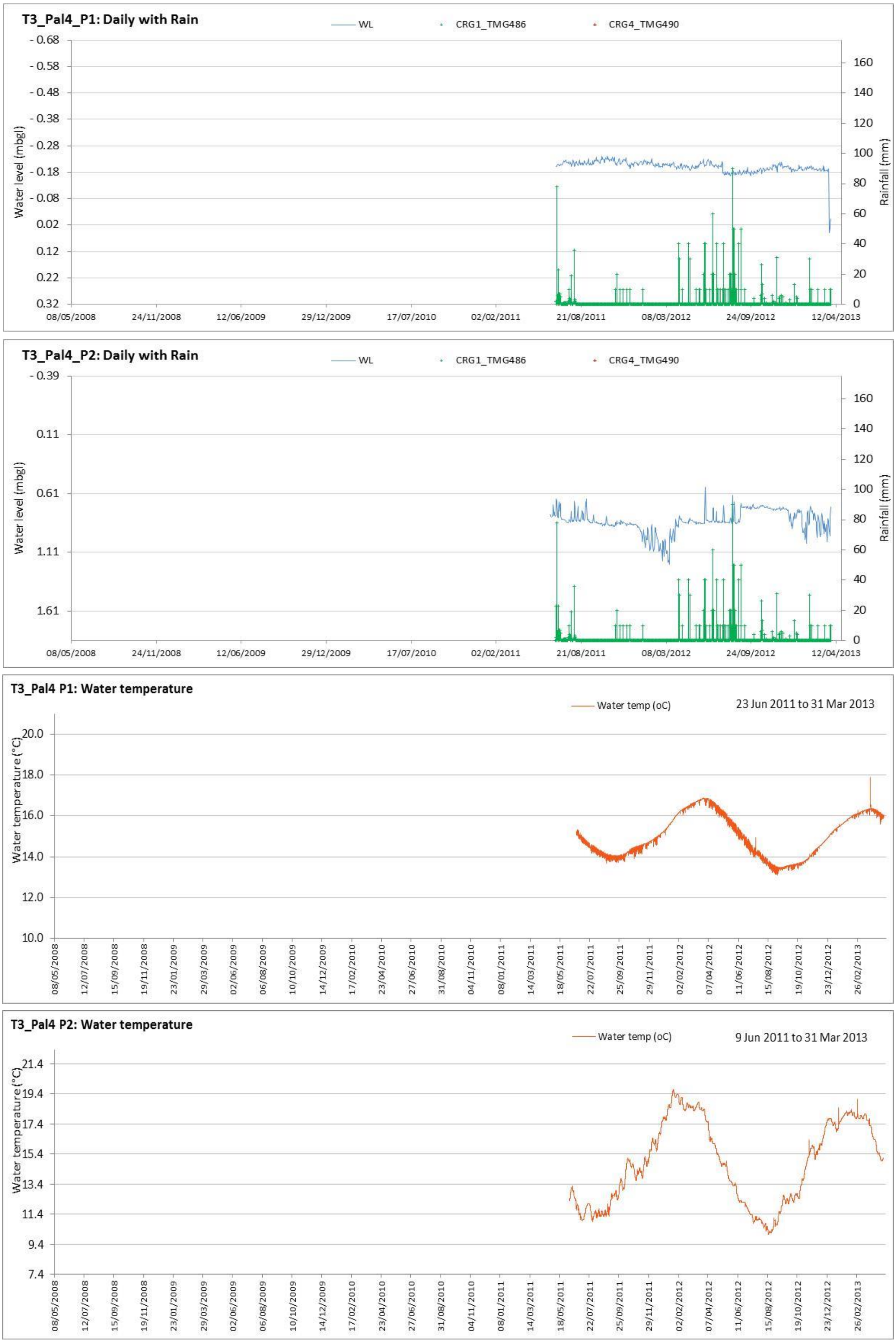


Figure 3.25. a) Time series of water level as mbgl, with daily rainfall for EPM2 and b) temperature patterns at P1 and P2 in ecoseep T3_Pal4. The x-axis scale for the graphs covers EPM1 and EPM2.

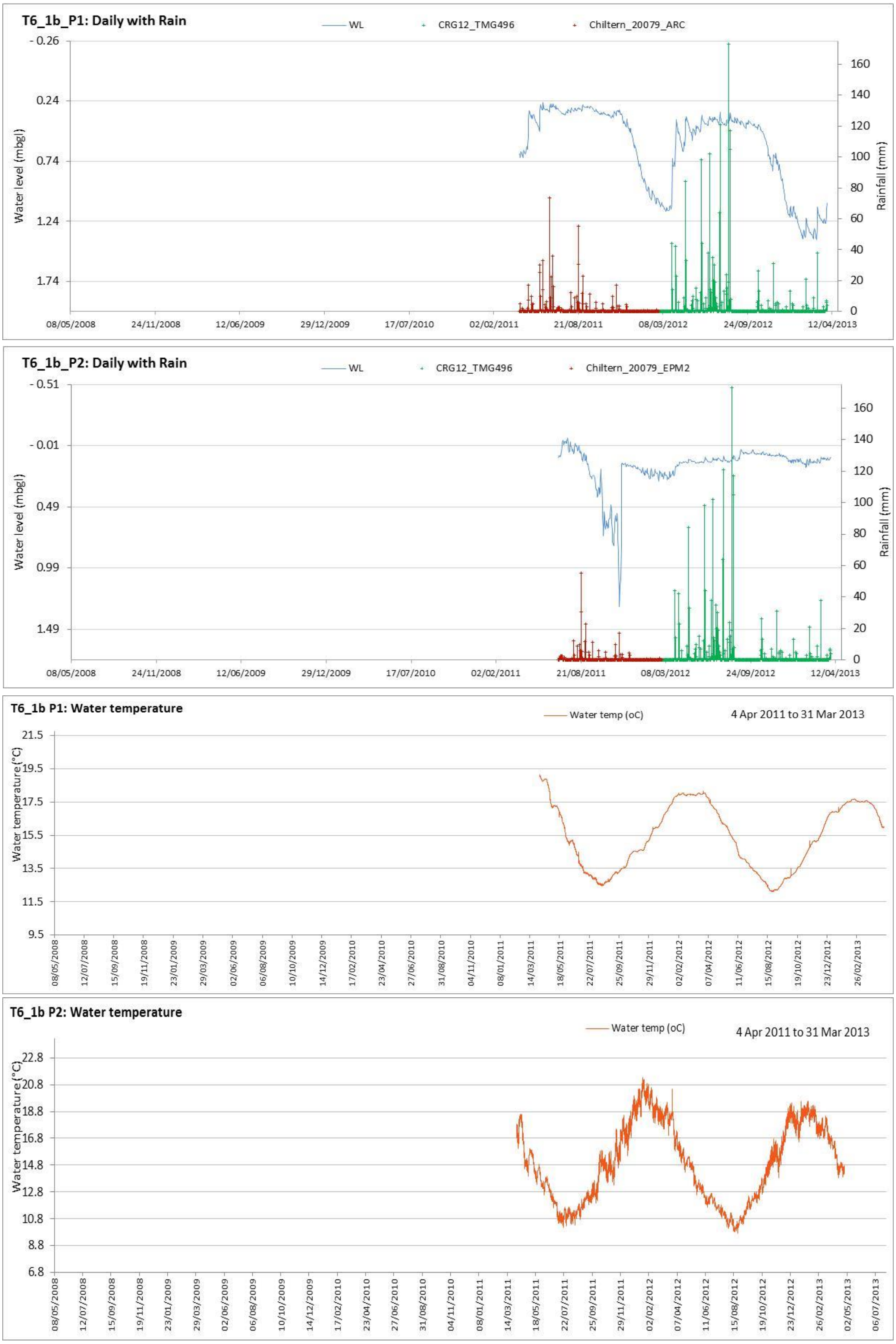
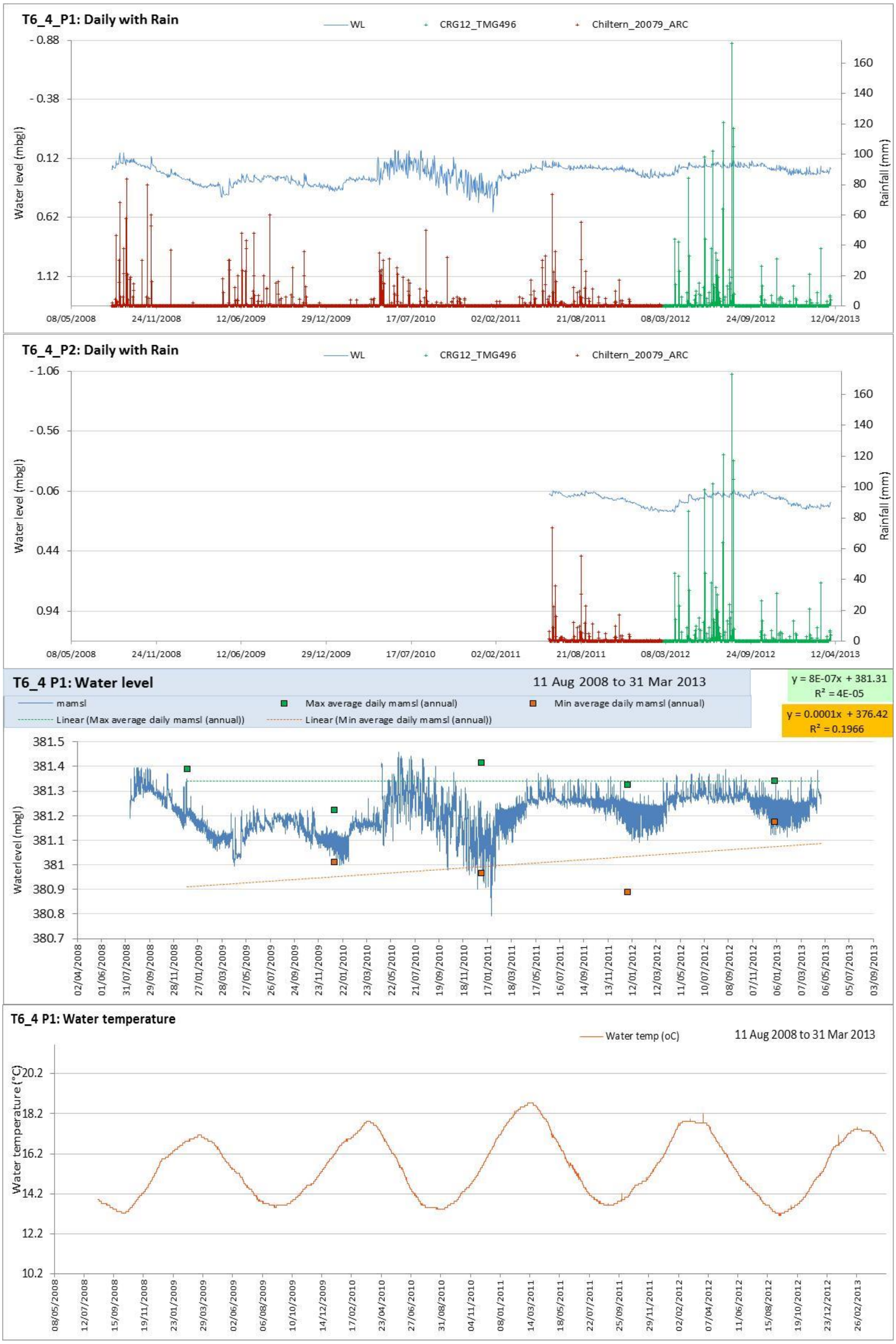


Figure 3.26. a) Time series of water level as mbgl, with daily rainfall for EPM2 and b) temperature patterns at P1 and P2 in ecoseep T6_1b. The x-axis scale for the graphs covers EPM1 and EPM2.



a

b

c

Figure 3.27 **Time series of water level at P1 and P2 in ecoseep T6_4: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. c) Temperature patterns at P1 (longest record). The x-axis scale for the graphs in (a) covers EPM1 and EPM2.**

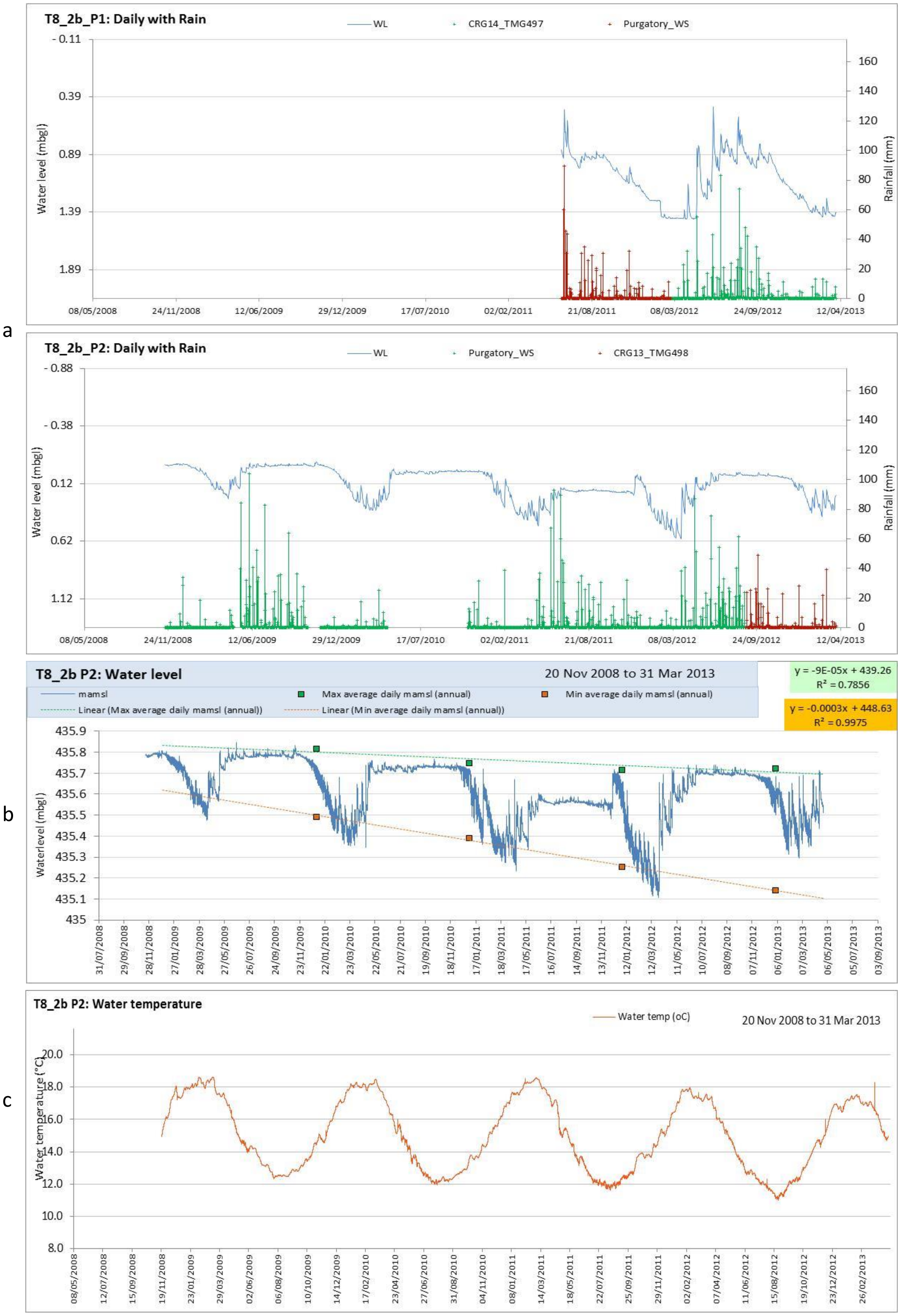


Figure 3.28 Time series of water level at P1 and P2 in ecoseep T8_2b: a) as mbgl, with daily rainfall for EPM2 and b) as mamsl, showing trends in annual maximum and minimum water levels. c) Temperature patterns at P1 (longest record). The x-axis scale for the graphs in (a) covers EPM1 and EPM2.

4 SURFACE WATER LEVEL AND TEMPERATURE

4.1 Introduction

Continuous logging of surface water level and temperature data at interface sites (ecochannels) and collation of flow data from selected DWA gauges was undertaken to to document spatial and temporal variability in these variables across the study area and in the ecochannels. These data provide a baseline against which future data can be evaluated and contextualised, and to interpret monitoring data in other disciplines.

Four sets of data were collected:

- Hourly water level and temperature time series at 11 stilling wells located in nine ecochannels;
- Daily discharge time series downloaded for five DWA gauging stations on unimpacted rivers within the TMGA study area;
- Cross-sectional profiles for 11 stilling wells; and
- Flow rates across river profiles.

4.2 Ecochannels

Flow patterns at the nine ecochannels (including W7_4 at Wemmershoek, which is not a biological sampling site) are presented in Figures 4.1 – 4.3. The period of record was not identical in each case, but the graphs have not been standardised for time period, in the interests of examining more closely the patterns at each individual site.

The ecochannels were all perennial and showed a strong response to rainfall, in terms of both the timing and duration of the winter rains and isolated summer showers. H8_3a (Figure 4.1) had a particularly strong response to summer rains in both 2011/12 and 2012/13. By contrast, the responses in the Nuweberg ecochannels (Figure 4.2) were less marked. The annual minimum flows at all sites were in March/April.

The flow record at T4_Pal1 started in August 2008 in EPM1, and shows the marked inter-annual variability of flow characteristic of the Western Cape. Highest summer baseflow was recorded at this site in summer 2012/13, clearly a consequence of the sustained floods and spates logged there from May to November. These elevated 2012 baseflows were a feature of all the ecochannels.

The old water level logger at T6_1a (Figure 4.3) was retained from EPM1, despite the record prior to May 2011 being poor (this was as a result of the repeated re-positioning of the stilling well following floods). The intention in EPM2 and beyond was to obtain a sufficiently long record to allow for patching or adjustment with the new gauge, and thus extend the usable record at this site by three years.

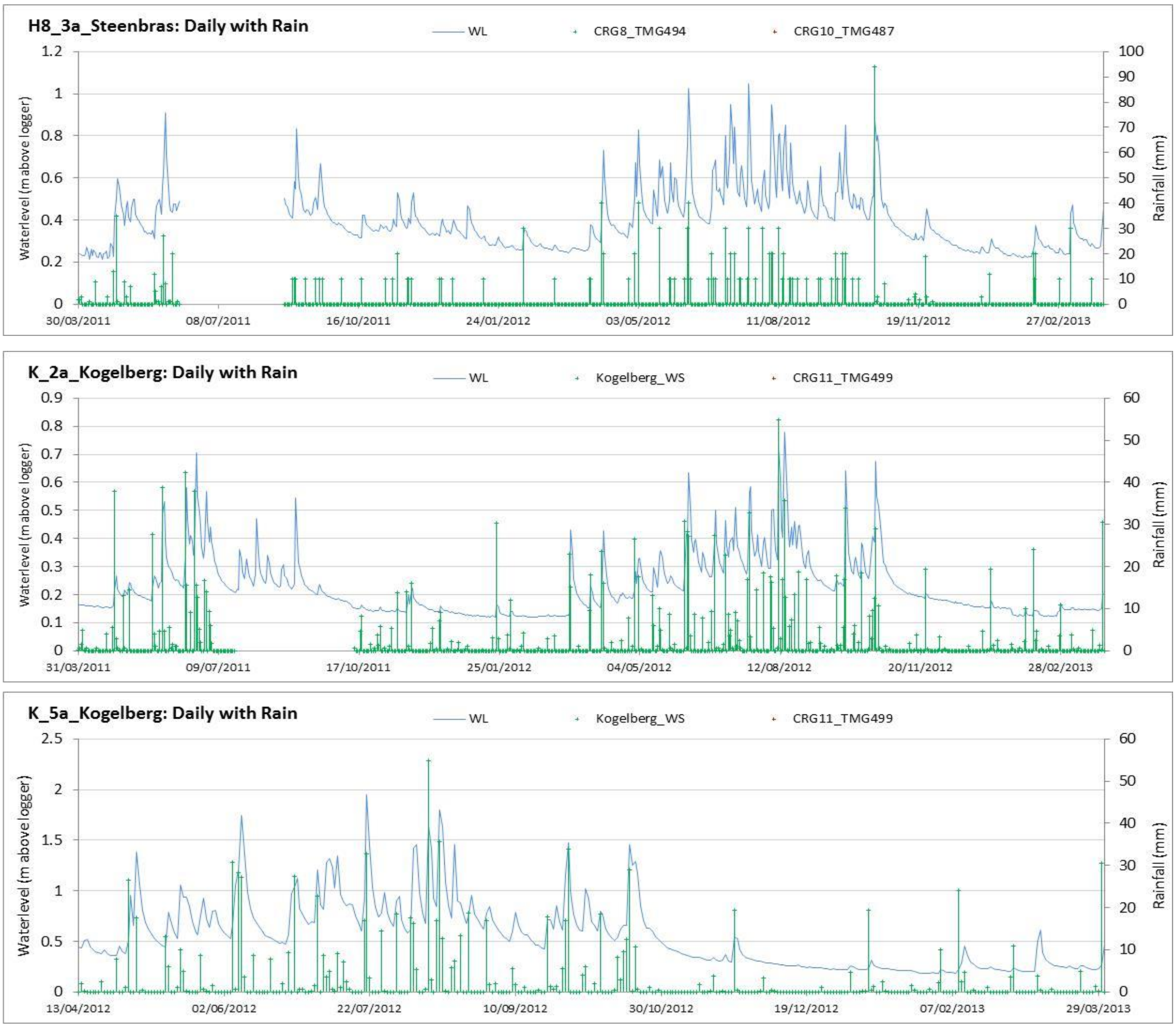


Figure 4.1 Time series surface water level data from Steenbras and Kogelberg ecochannels, with rainfall from the nearest rain gauge.

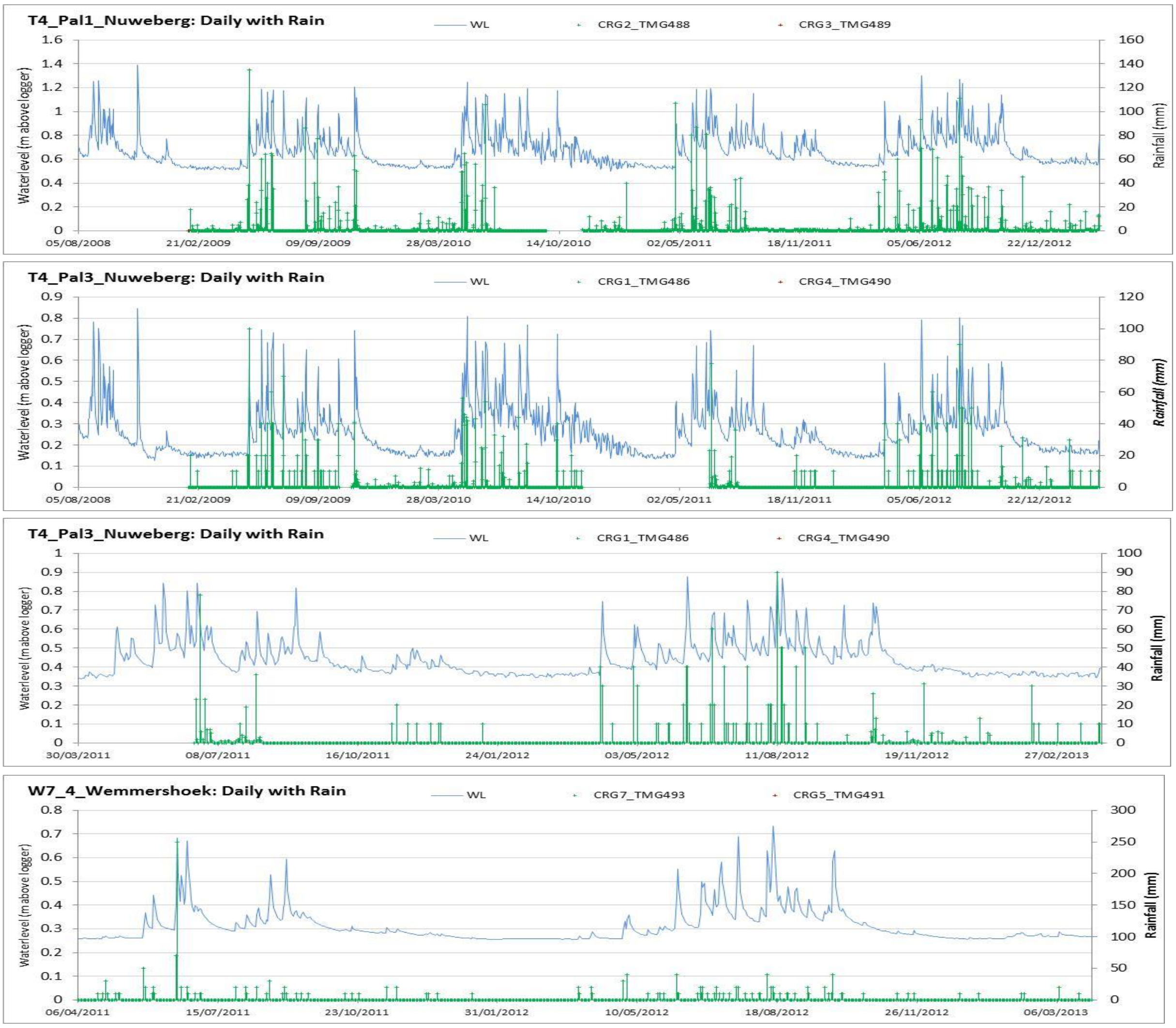


Figure 4.2 **Time series of surface water level data from Nuweberg and Wemmershoek ecochannels, with rainfall from the nearest rain gauge. Two gauges for T4_Pal3 are the old and new loggers.**

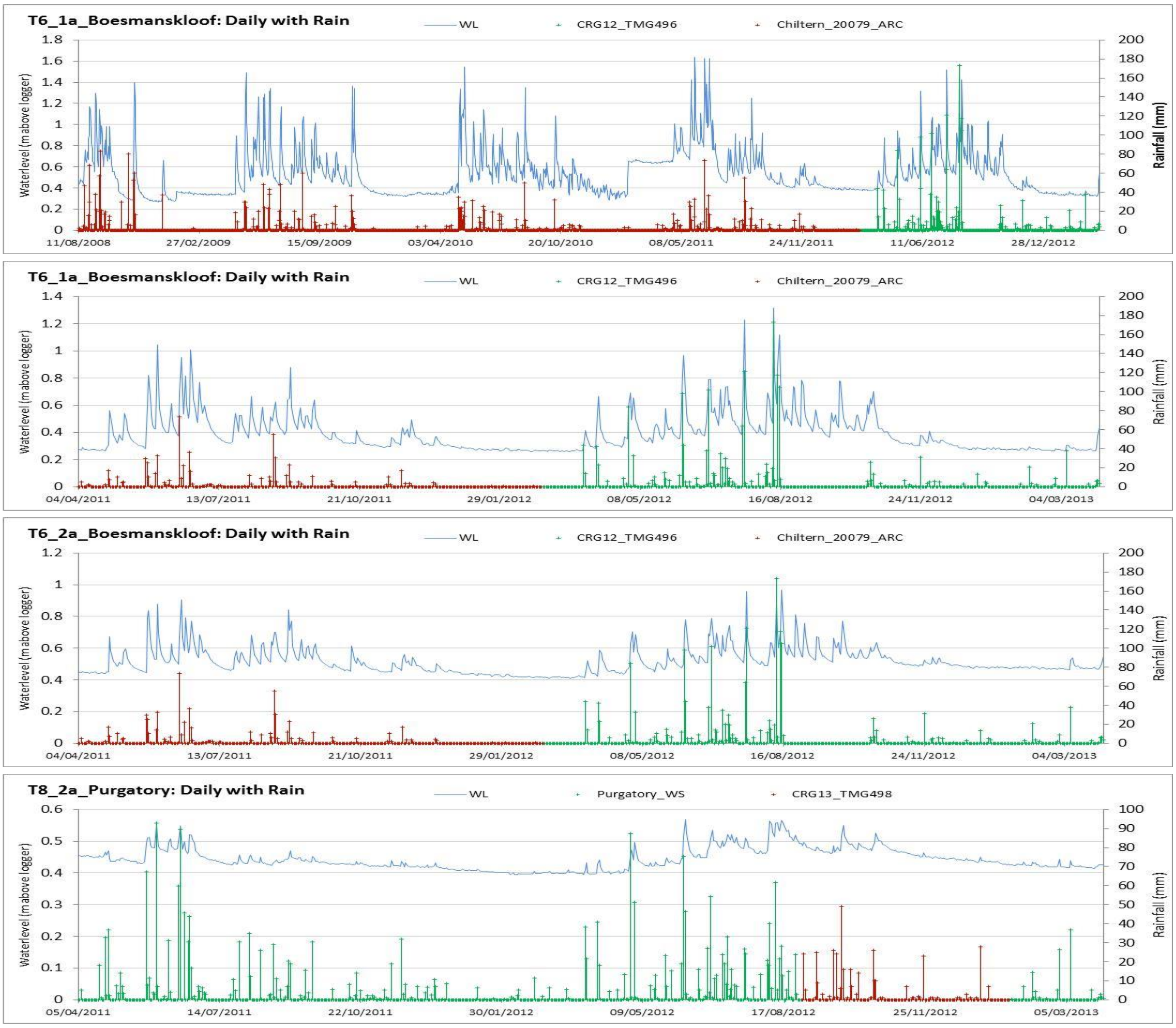


Figure 4.3 Time series water level data from Boesmanskloof and Purgatory ecochannels, with rainfall from the nearest rain gauge. Rainfall data gaps were filled from a "second best" gauge (in red). Two gauges for T6_1a are the old and new loggers.

4.3 DWA gauges

The 7-day minimum flow was calculated as the minimum value of consecutive 7-day running means. These were displayed as time series for the five selected DWA flow gauges (Figures 4.4 – 4.8). The 2-, 5-, 10- and 20- year return period values for the 7-day minimum flow are shown on the graphs, although where the record was insufficiently long these are a poor reflection of a long-term average. For example, although shown, these values were nonsensical for G1H076 (Berg River) given the length of record available (Figure 4.5)[4]. At present, the 1:5-year return period values are probably adequate for examining thresholds of potential concern for the four other gauges.

Three of the proposed gauges are located in the Zachariashoek valley, and had been discontinued for monitoring in the 1990s, but were re-commissioned for the TMGA project in 2008. The Watervals River is outside of the study area but nevertheless has a (mostly) undeveloped catchment and was included for reference.

[4] *This gauge was included because of the stream's size (headwaters, strongly perennial) and natural catchment. The record is too short to allow for statistical analysis at this stage of the TMGA project, but the gauge is of high quality and the data accurate.*

Trends in the 7-day minimum flow were difficult to discern at the Zachariashoek sites because of the long gap in the record. However, G1H011 (Figure 4.4) showed distinctly wet and dry cycles over its 50-year record.

A summary of the averages of the 7-day minimum of the flow record to date, for each gauge, is provided in Table 4.1.

Table 4.1 Summary of the 7-day flow minimum characteristics of each of the five DWA gauges monitored.

Gauge	Average 7-day flow minimum over record (daily Q in m^3 s^{-1})	1:2 year return 7-day flow minimum (daily Q in m^3 s^{-1})	Number of years
G1H011 Watervals River	0.0056	0.002	49
G1H014 Zachariashoek River	0.0042	0.0040	33
G1H016 Kasteelskloof River	0.0083	0.008	28
G1H018 Bakkerskloof Spruit	0.00199	0.002	33
G1H076 Berg River	0.1186	0.126	6

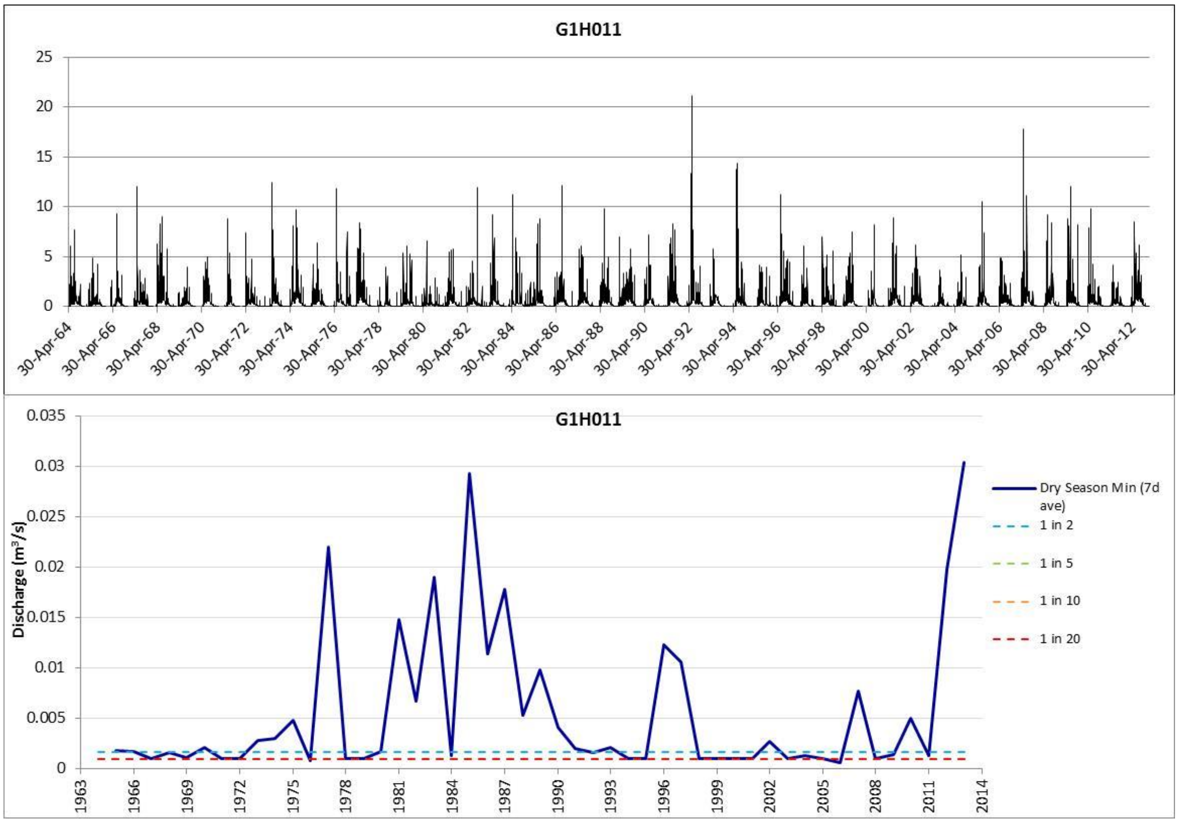


Figure 4.4 (top) Time series discharge data available for G1H011 (Watervals River) and (bottom) 7-day minimum flow (annual minimum value of consecutive 7-day running means) for the period 1964 – 2013.

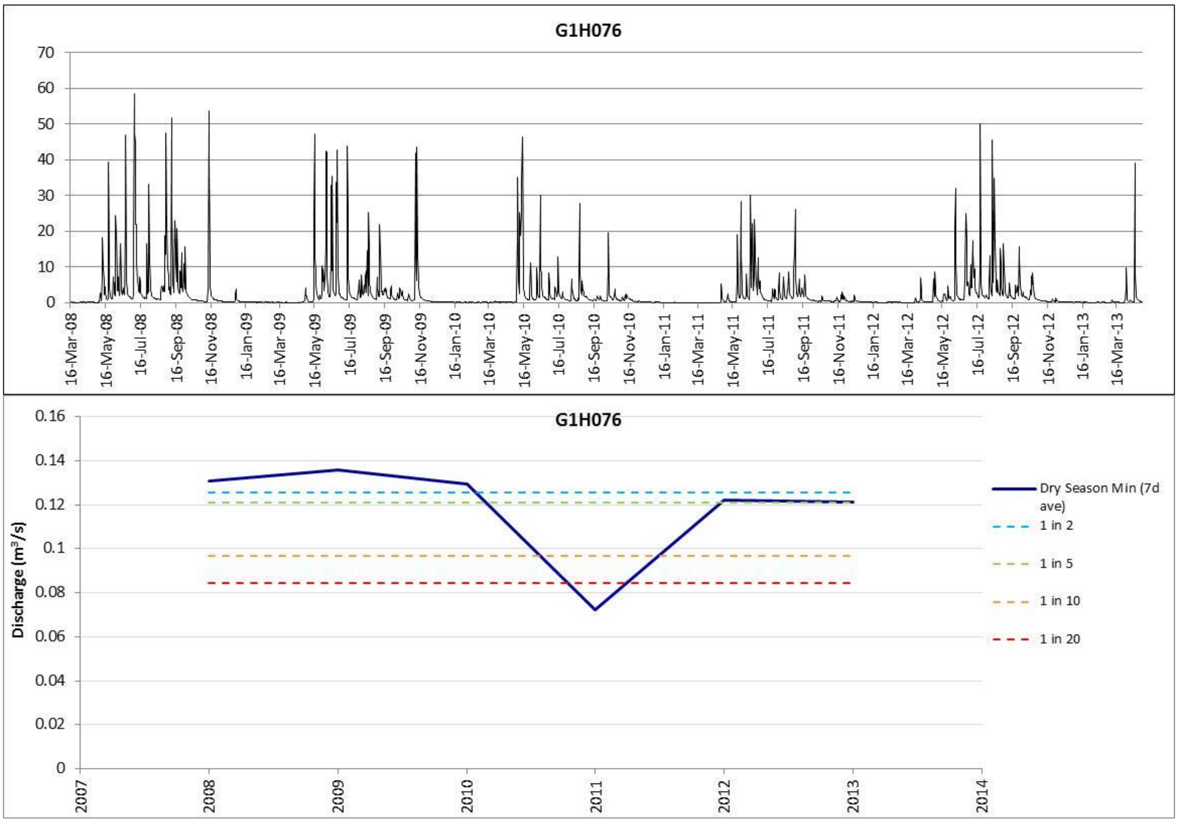


Figure 4.5 (top) Time series discharge data available for G1H076 (Berg River) and (bottom) 7-day minimum flow (annual minimum value of consecutive 7-day running means) for the period 2008 – 2013.

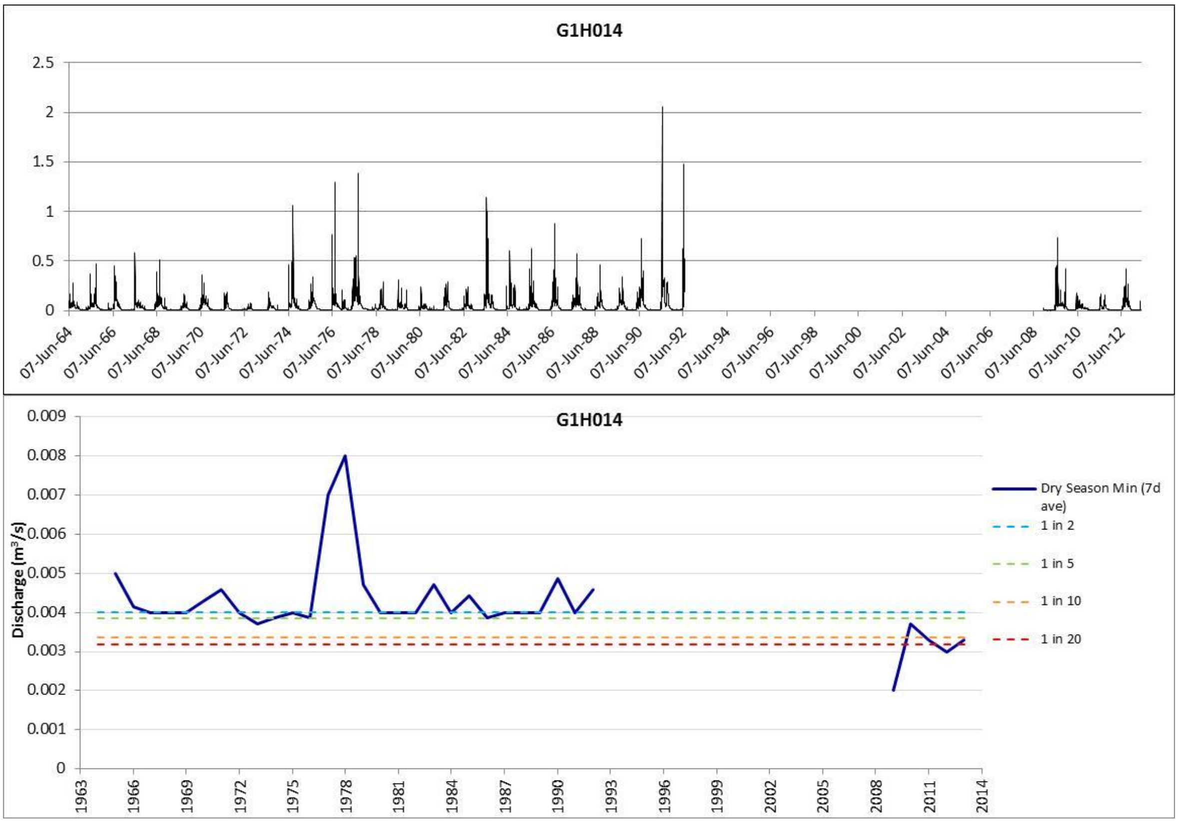


Figure 4.6 (top) Time series discharge data available for G1H014 (Zachariashoek River) and (bottom) 7-day minimum flow (annual minimum value of consecutive 7-day running means) for the period 1964 – 2013 (with 15-year gap 1992 – 2007).

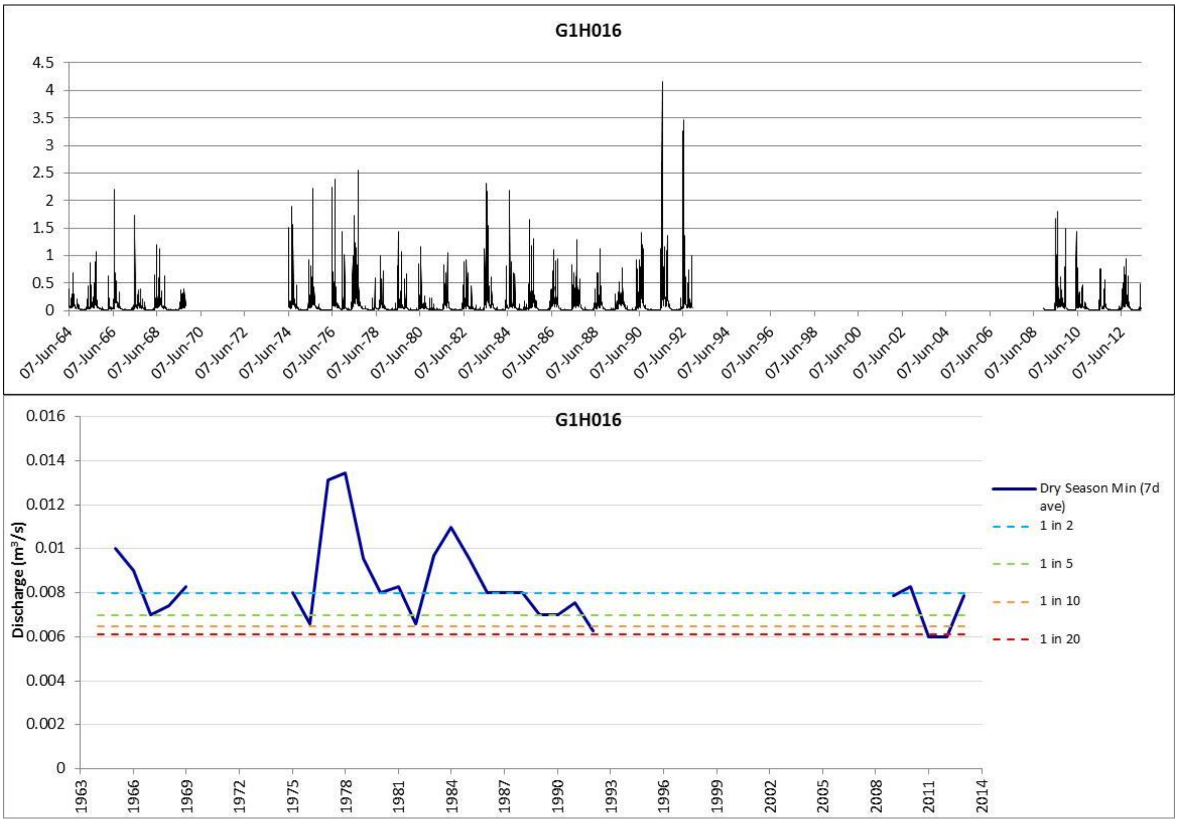


Figure 4.7 **(top) Time series discharge data available for G1H016 (Kasteelskloof River) and (bottom) 7-day minimum flow (annual minimum value of consecutive 7-day running means) for the period 1964 – 2013 (with 15-year gap 1992 – 2007).**

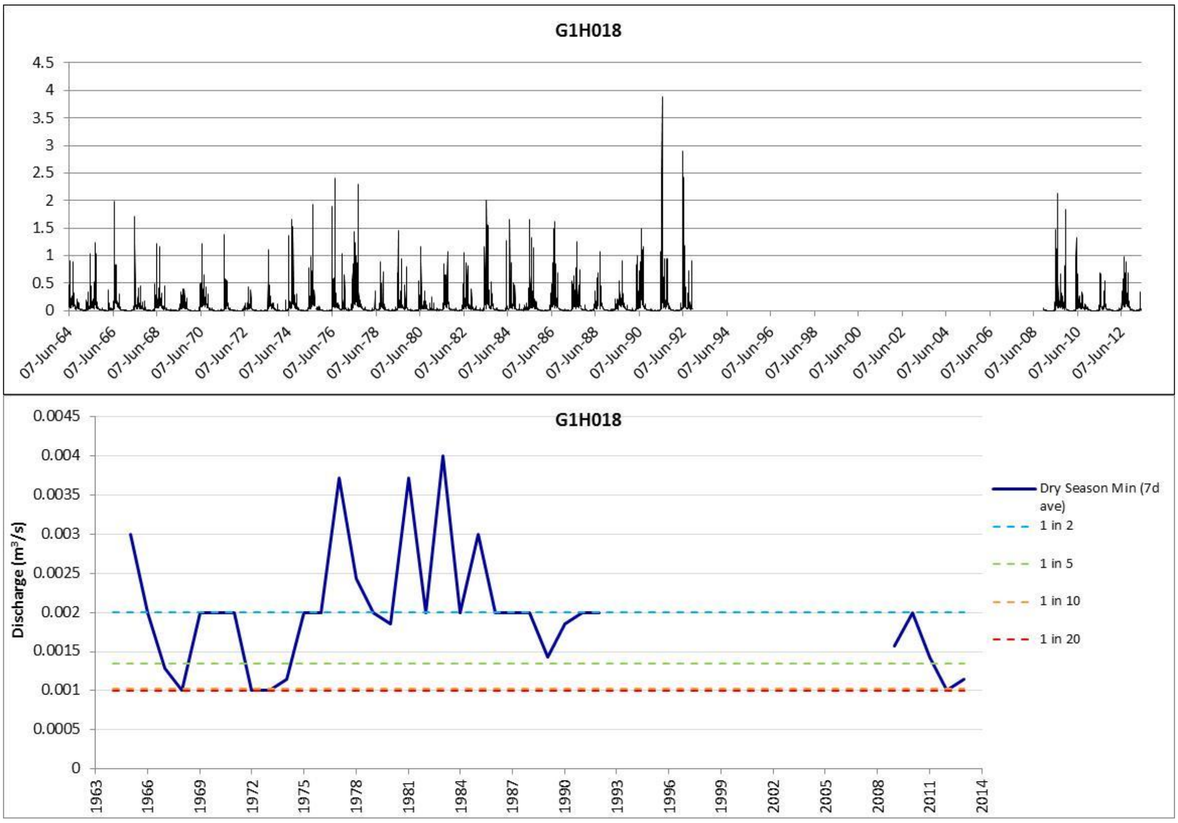


Figure 4.8 **(top) Time series discharge data available for G1H018 (Bakkerskloof Spruit) and (bottom) 7-day minimum flow (annual minimum value of consecutive 7-day running means) for the period 1964 – 2013 (with 15-year gap 1992 – 2007).**

5 RAINFALL AND GROUNDWATER CHEMISTRY

5.1 Introduction

The bi-annual (April and October) collection of water chemistry and isotope data had two objectives:

- To establish the baseline chemical characterisation and isotopic signature of groundwater for further analysis (by the TMGAA) of pathways, residence time and links with surface water ecosystems; and
- To establish the chemical characterisation and isotopic signature of rainwater for comparison with those of groundwater.

Two datasets were collected:

- Bi-annual time series of concentrations of macro-elements (calcium, magnesium, sodium, potassium, alkalinity, chloride, sulphate) nutrients (phosphate, nitrate, ammonia), and trace elements (iron, manganese, silica) and field measurements of pH, EC and water temperature, at 10 regional boreholes and 10 exploration and monitoring boreholes; and
- Bi-annual time series of chloride, relative deuterium and oxygen 18 concentrations, and field measurements of pH and EC at 14 CRGs.

5.2 Water chemistry

The groundwater in boreholes at Steenbras, Kogelberg and Purgatory had a chemical composition typical of TMG-derived water (e.g. Colvin *et al.*, 2009; TMGA-EMA, 2010), which is characterised by a dominance of sodium, potassium and chloride ions, low pH (between 4 and 7), low EC (< 30 mS/m) and low nutrients, although there was some scatter in the data collected to date. The groundwater in boreholes in Nuweberg and Wemmershoek, however, were dominated by sodium, potassium and calcium, which suggests the water in these boreholes is from a different formation (Figure 5.1).

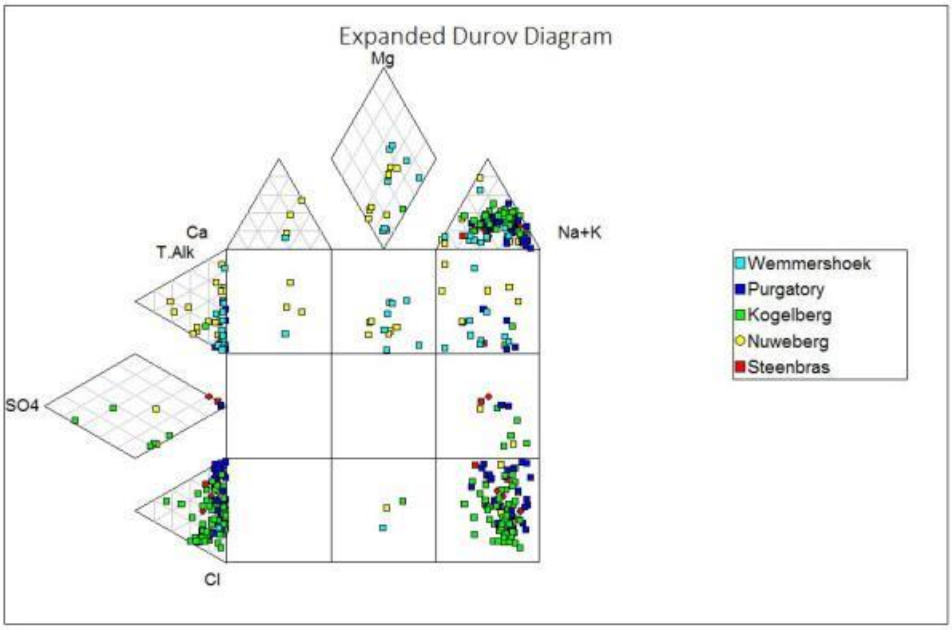


Figure 5.1 Expanded Durov diagram of anions and cations measured up until April 2013 in the regional and Exploration and monitoring boreholes located in five TSAs.

This was not shown in the analysis of data from different target aquifers (Figure 5.2). Here the data from boreholes targeting the Peninsula Aquifer were spread across the Durov diagram, whereas the Skurweberg and Quaternary aquifers had a chemical composition dominated by sodium, potassium and chloride.

The chemical composition of the rainwater sampled from the CRGs was similar to that of the groundwater – pH was low (between 4 and 8), and EC was low (< 12 mS/m). Only chlorides were analysed in the rainwater samples, and while the boreholes samples varied between 7 and 40 mg/litre, the CRGs samples varied between < 2 and 29 mg/litre. The slightly higher concentration of chlorides in the groundwater versus rainwater indicates leaching from rock and soil (e.g. Figure 5.1).

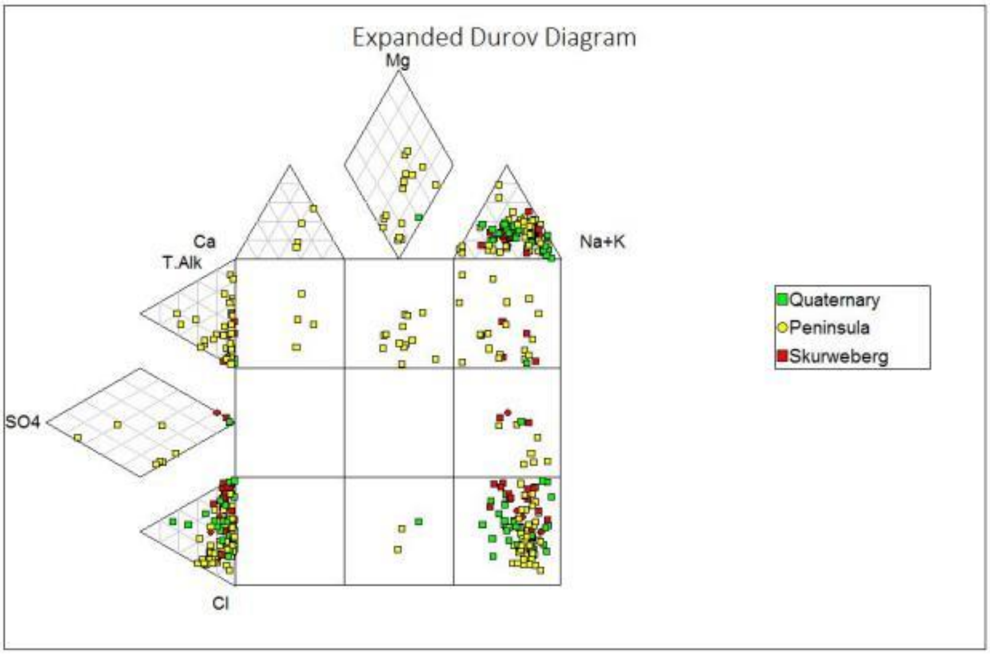


Figure 5.2 Expanded Durov diagram of anions and cations measured up until April 2013 in the regional and Exploration and monitoring boreholes, colour coded according to the aquifer into which they are drilled.

5.3 Isotopes

The isotopic composition of water samples collected from the boreholes in EPM1 and EPM2 showed some variation between boreholes. δD concentrations varied between -27 and -9 parts per thousand or ‰, and δ^{18}O from -5.45 to -2.17‰. The linear regression of δD against δ^{18}O was very weak - $R^2 = 0.31$. The borehole isotope ratio data lay above the GMWL and scattered around the local CMWL. The linear regression line for the boreholes data (although the regression was weak) had a slope that did not lie parallel to the two water lines (see Figure 5.3), which may be indicative of the recharge of the target aquifers predominantly through precipitation but with some isotope fractionation through evaporation.

The isotopic signatures for the boreholes showed some distinction between target aquifers (Figure 5.4). The Peninsula Aquifer isotopic composition was spread across the scatterplot, while the Quaternary and Skurweberg Aquifers overlapped with Peninsula Aquifer samples, but in two fairly distinct groups.

The concentrations of isotopes δD and δ^{18}O in rainwater collected from the CRGs ranged from -35 and -5 ‰, and from -6.22 to -2.20‰ respectively – a wider range than for the boreholes (see Figure 5.5 for comparison). δD against δ^{18}O produced a slightly stronger regression than for the boreholes – R^2 was 0.75 (Figure 5.6). The rainwater data compared more closely with the global and local precipitation data than did the borehole data, as expected. Overall, the isotopic composition of borehole water was not distinct from that of rainwater, confirming that the aquifers are recharged predominantly by rainfall in the upper catchments.

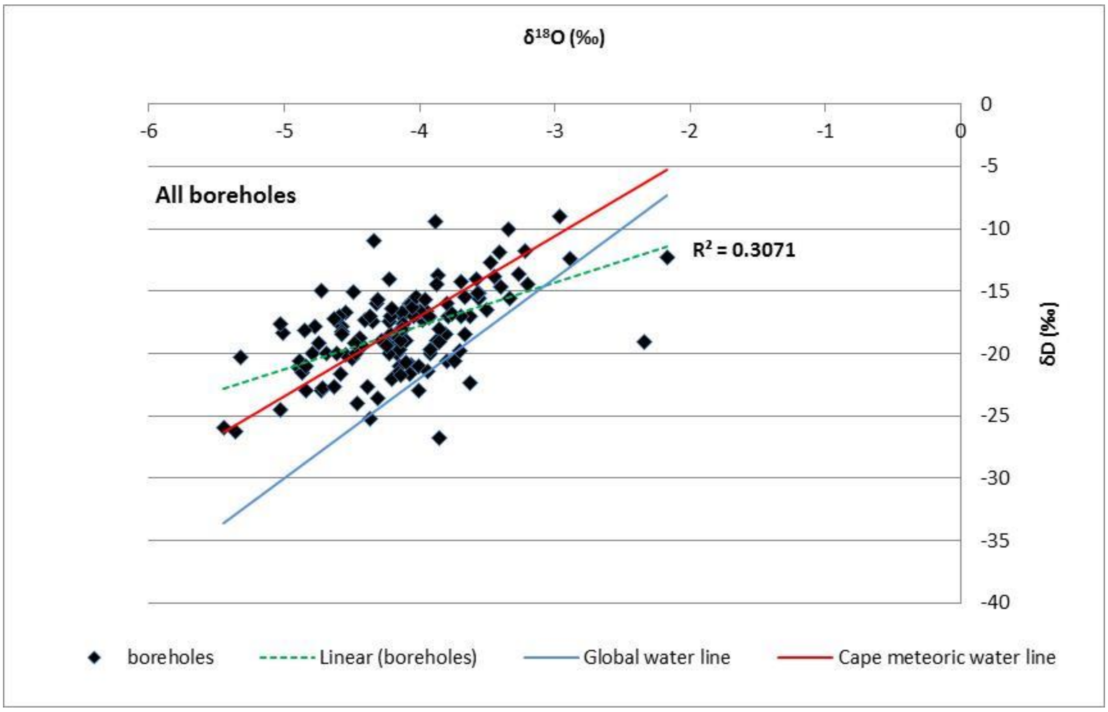


Figure 5.3. Scatterplot of isotope data (ratio of δD against δ^{18}O) for TMGA boreholes. Also shown are the borehole isotopes regression line (green dashed line), the Global Meteoric Water Line (blue line) and the local Cape Meteoric Water Line (red line).

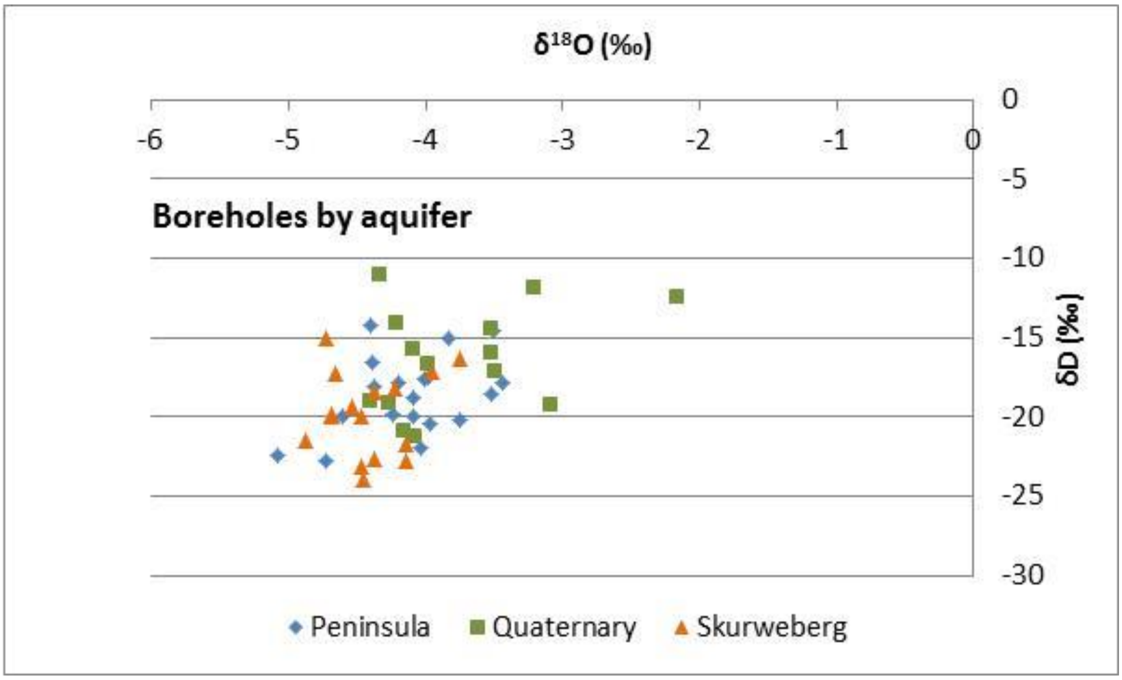


Figure 5.4 Scatterplot of isotope data (ratio of δD against δ^{18}O) for TMGA boreholes, averaged for all boreholes targeting the same aquifer.

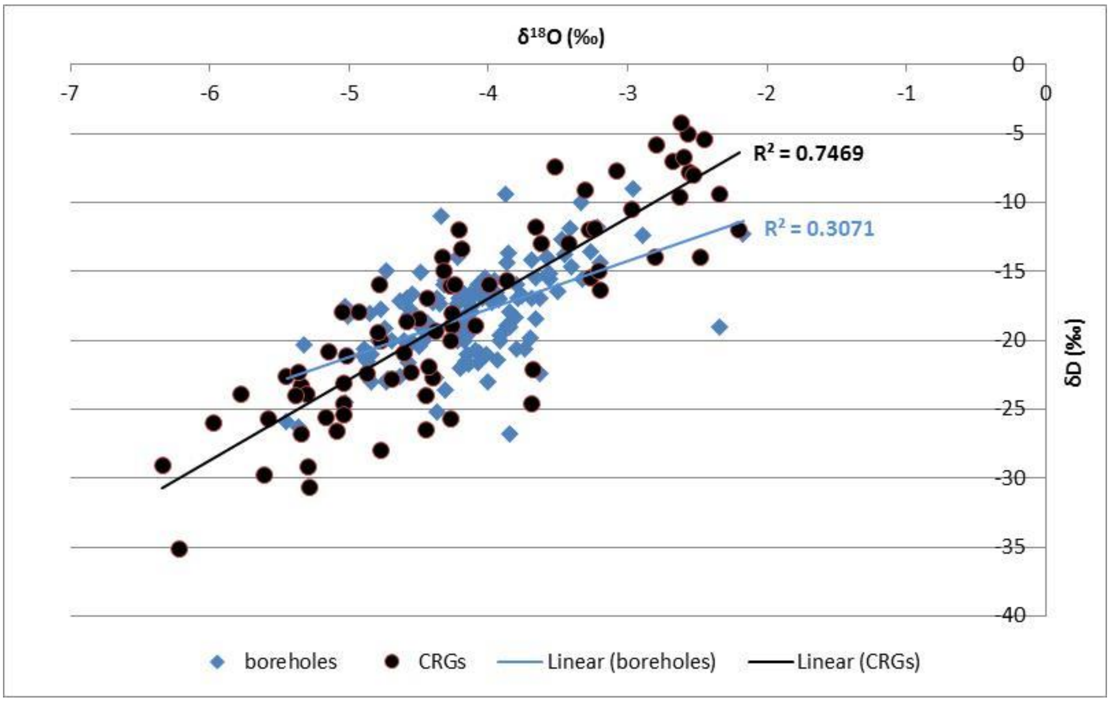


Figure 5.5 **Comparison between the isotope data collected from the TMGA boreholes and cumulative rainfall gauges (CRGs).**

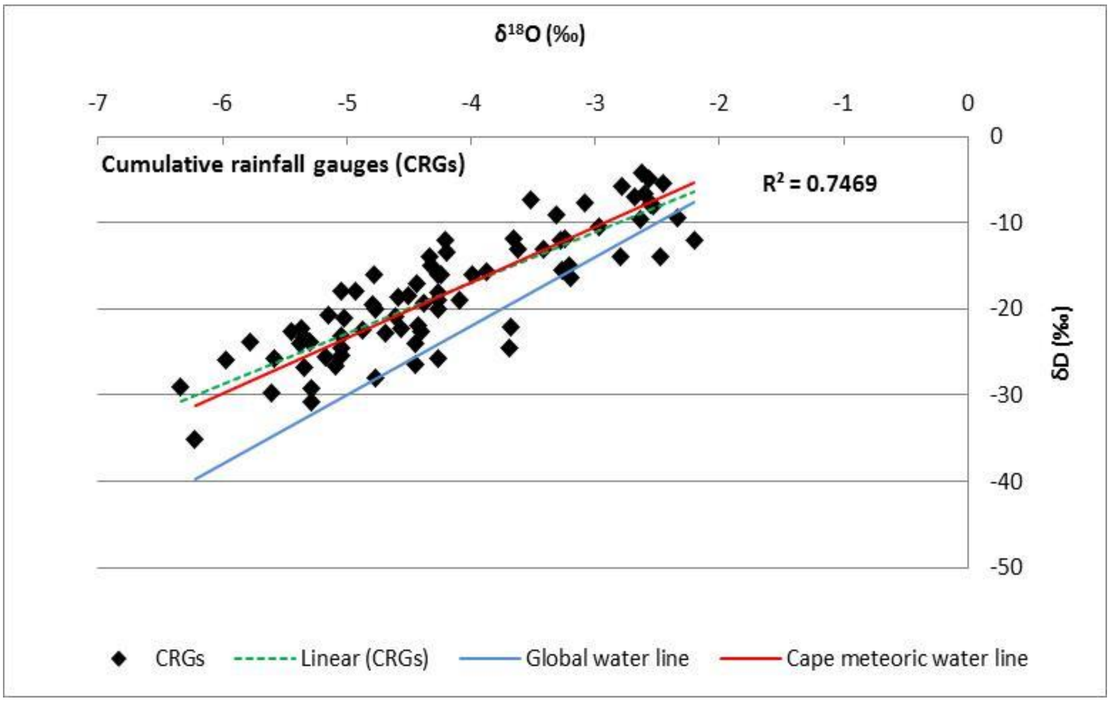


Figure 5.6 **Scatterplot of isotope data collected from the cumulative rainfall gauges (CRGs).**

6 AERIAL IMAGERY

6.1 Introduction

The objective of capturing aerial imagery of the TMGA ecosites and the surrounding area was to determine inter-annual changes in Normalised Differential Vegetation Index (NDVI) measured twice a year in March and November of each year. It is assumed that this may provide an early detection of stress in the wetland systems in the event of over-abstraction of groundwater, as well as long-term wetland shrinkage.

The aerial photographs were captured at 0.25 m and 1 m nominal spatial resolution in order to produce:

- RGB imagery for mapping of wetland boundaries and possibly vegetation communities of interest,
- Red (R) and near infra-red (NIR) imagery for NDVI analysis.

In October 2012, however, it was decided by the TMGAA that the high resolution images would be captured but not processed, as the resolution on these base images is too high for pixel to pixel comparison. The aerial images are included in the accompanying Data CD and summarised in Volume 3: Data Report, but are not presented here. The following sections describe the analyses performed on the images.

6.2 NDVI analysis

A comparison between images taken in March 2011 and March 2013 of some of the Kogelberg ecosites is provided in Figure 6.1, along with an image of the NDVI change analysis between these two periods. The NDVI values for all of the ecoseeps are provided in Figure 6.2.

Overall, the NDVI values calculated for the ecoseeps were low. Dense forest tends to vary between 0.6 and 0.8, shrub- and grassland between 0.2 and 0.3, and soils generally between 0.1 and 0.2 (Weier and Herring, 2000). Bare rock gives an NDVI below 0.1. The values calculated for the ecoseeps varied between 0.1 and 0.4, indicating reflectance from a range from rocky, open areas through to dense, shrubby fynbos. Comparison with the NDVI time series provided on the Wide Area Monitoring Information System (WAMIS) portal (http://wamis.meraka.org.za/time-series-viewer) using the Moderate-resolution Imaging Spectroradiometer (MODIS) instrument highlighted the relatively low NDVI values calculated for the ecoseeps (Figure 6.3).

It must be noted that the WAMIS data are provided at a much lower resolution, as an average NDVI over 9 pixels representing a land surface of approximately 250 x 250 m. Furthermore, the NDVI is calculated as an average over 16 days. Thus, the comparison should be limited to trends and patterns of change rather than absolute values.

6.2.1 Temporal variation

An increase in NDVI is an indication of an increase in plant greenness or productivity. The NDVI should, therefore, increase during the growth season (spring/summer). However, the values calculated for the TMG ecoseeps did not show clear seasonality. At some of the sites - B1_1, T3_Pal4, T6_1b, T6_4 and T8_2b – NDVI values were higher in March 2011 than in November 2011, but this was not the case in 2012. Rainfall was higher in winter 2012 at all sites (see Section 2), which may explain the increase in NDVI over 2012. However, at other sites – H8_3b, K_1, K_2b, K_5b and K_6 - the March (late summer) NDVI values were always higher than the November (spring) NDVI.

It is possible that NDVI values within a seep will not vary as much as dryland vegetation, due to the more consistent moisture in the soils. The soil moisture data presented and discussed in Section 7 do show that the ecoseeps were constantly wet, at least in some parts of the ecoseep. Another confounding factor was fire, which resulted in the vegetation being in an early successional stage with bare patches of soil. This lowered the NDVI considerably, as can be seen by the drop in NDVI after fire in most TSAs (Figure 6.3). Burnt areas show a slow return to previous NDVI values. Seasonal and inter-annual trends in NDVI measured for the TMG ecoseeps may only come clear over a longer monitoring period.

6.2.2 Recommendations

It is useful to note that, according to the WAMIS data, NDVI peaked in May - July, with lowest values in December - February. March lies on an upward trend, and November on a downward trend, with similar NDVI values for these months, rather than representing opposite seasonal extremes. This was also evident in the comparison between the NDVI values calculated for B1_1 and K_2b and the rainfall recorded at the rainfall gauges closest to these ecoseeps (Figure 6.4). There was relatively low rainfall during both months, and this may explain the lack of seaonality in the TMG NDVI values.

The problem with this is that it is impractical to take aerial photographs during winter, due to cloud cover. As a future consideration, the best result may be achieved by taking photographs in January/February at the NDVI peak, and again in September/October. An alternative would be to limit the anaylsis to inter-annual comparirons of NDVI. In this case, imagery should be captured during February or March each year, which is when producitivity is at its lowest. If draw-down in the Peninsula Aquifer affects plant productivity, then there should be a noticeable decrease in NDVI at this time of year. There is a good dataset of March imagery from the start of EPM1, for analysis.

Radiometric calibration of the imagery to obtain “true” reflectance or radiance values is another area which should be investigated further in order to improve change detection analysis. Due to daily and seasonal irradiance variations, image digital numbers (DNs) may vary for the same object photographed at different times. To some extent the difference component of the NDVI and radiometric normalisation during the change detection process accounts for scene illumination change, but thorough radiometric calibration will help to improve the situation and make the analysis more robust. This can be achieved in various ways from “flat field” calibration, which was attempted with the EPM2 imagery through the use of the white reflectance markers, to field-based spectral analysis (through the use of an imaging spectrometer) to determine true object scene reflectance values, with which to perform image radiometric calibration. Calibration could be performed within the wetter and drier areas of each seep, now that those areas have been identified through the soil moisture data analysis (see Section 7).

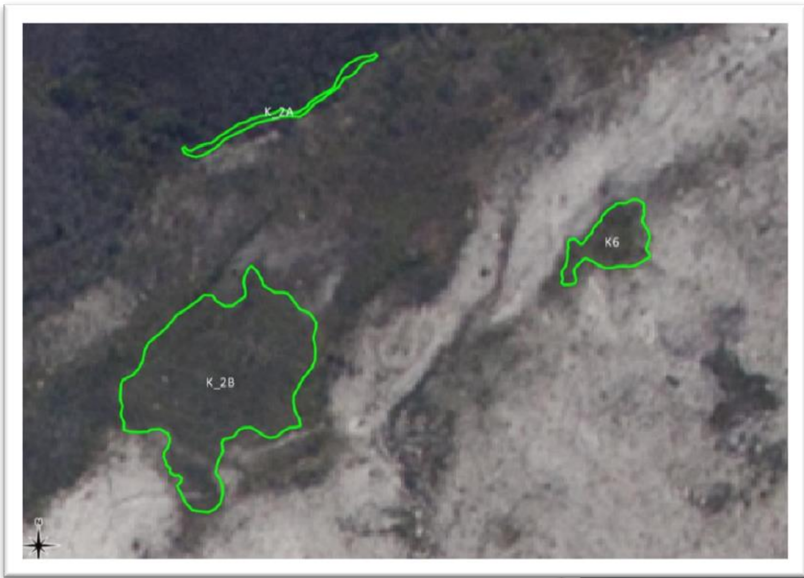
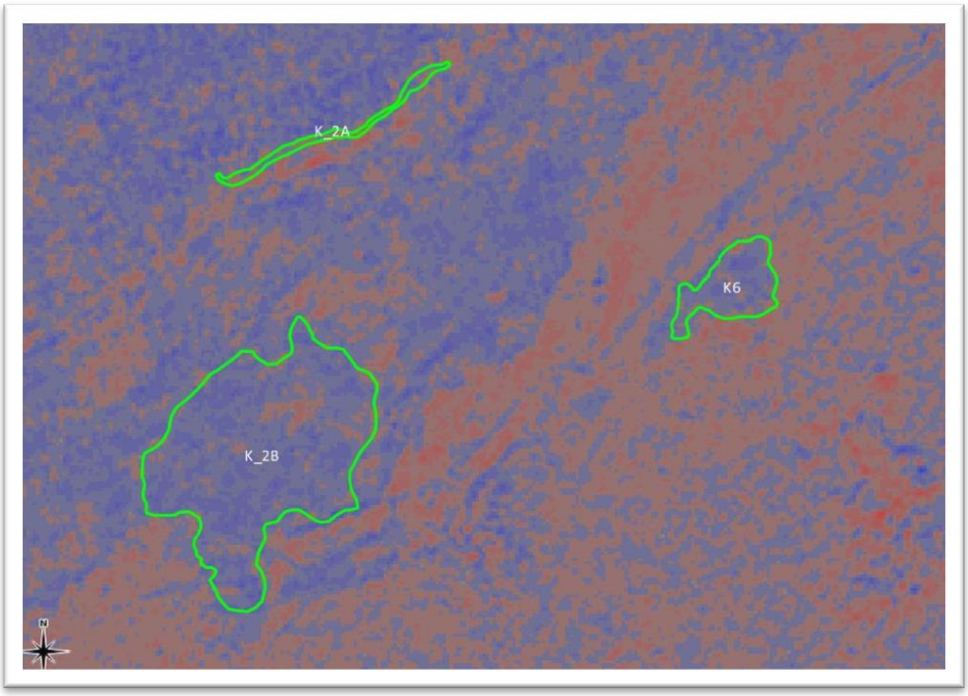


Figure 6.1. **March 2011 (top) and March 2013 (right) low resolution imagery of K_2a, K_2b, and K_6. The area burnt in March 2011 and shows slow recovery of the vegetation. The image below is the NDVI change analysis between March 2011 and March 2013, where blue shows a decrease in NDVI, and red an increase.**



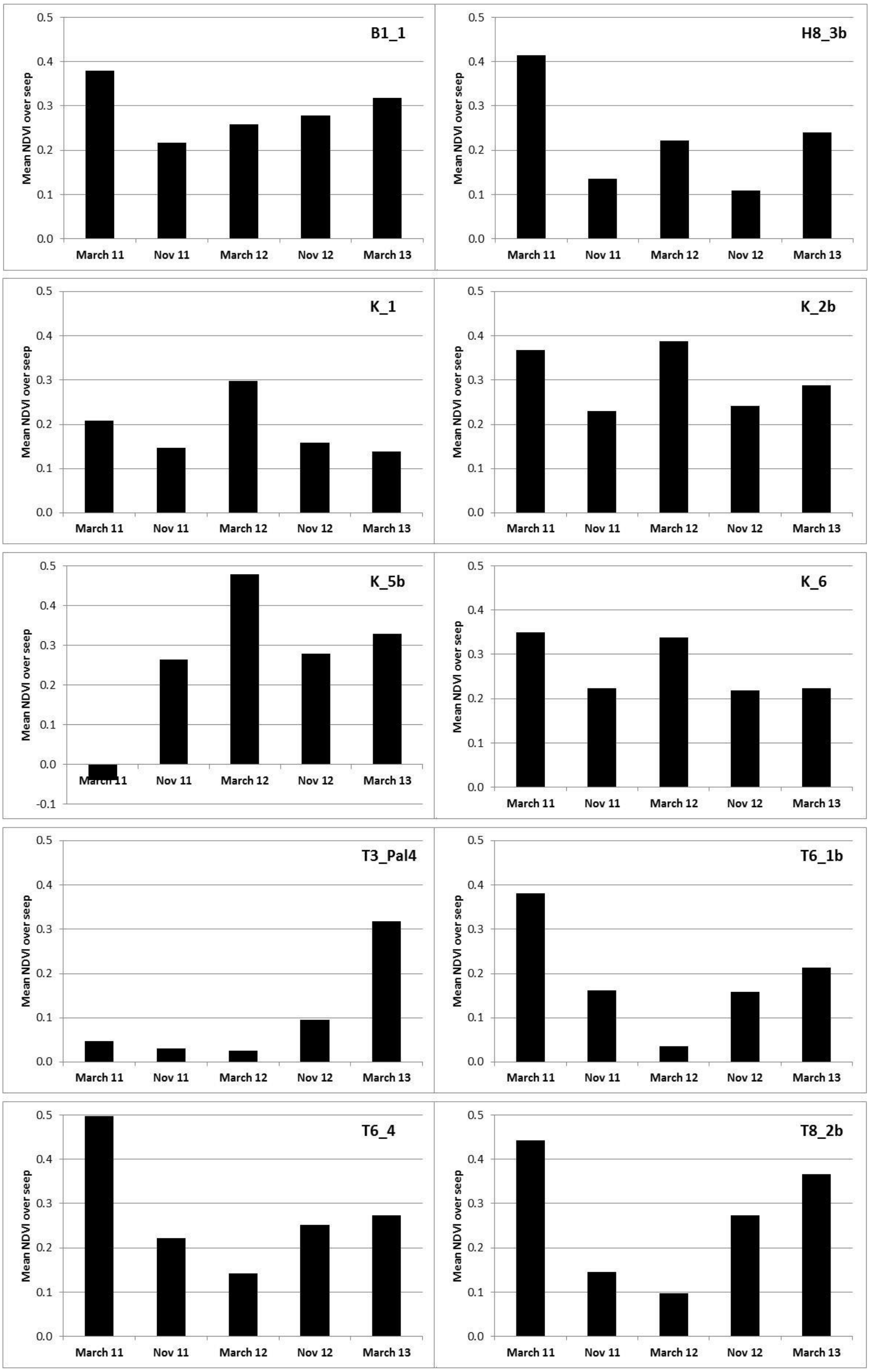


Figure 6.2 Mean NDVI calculated over the whole ecoseep, for the period March 2011 to March 2013.

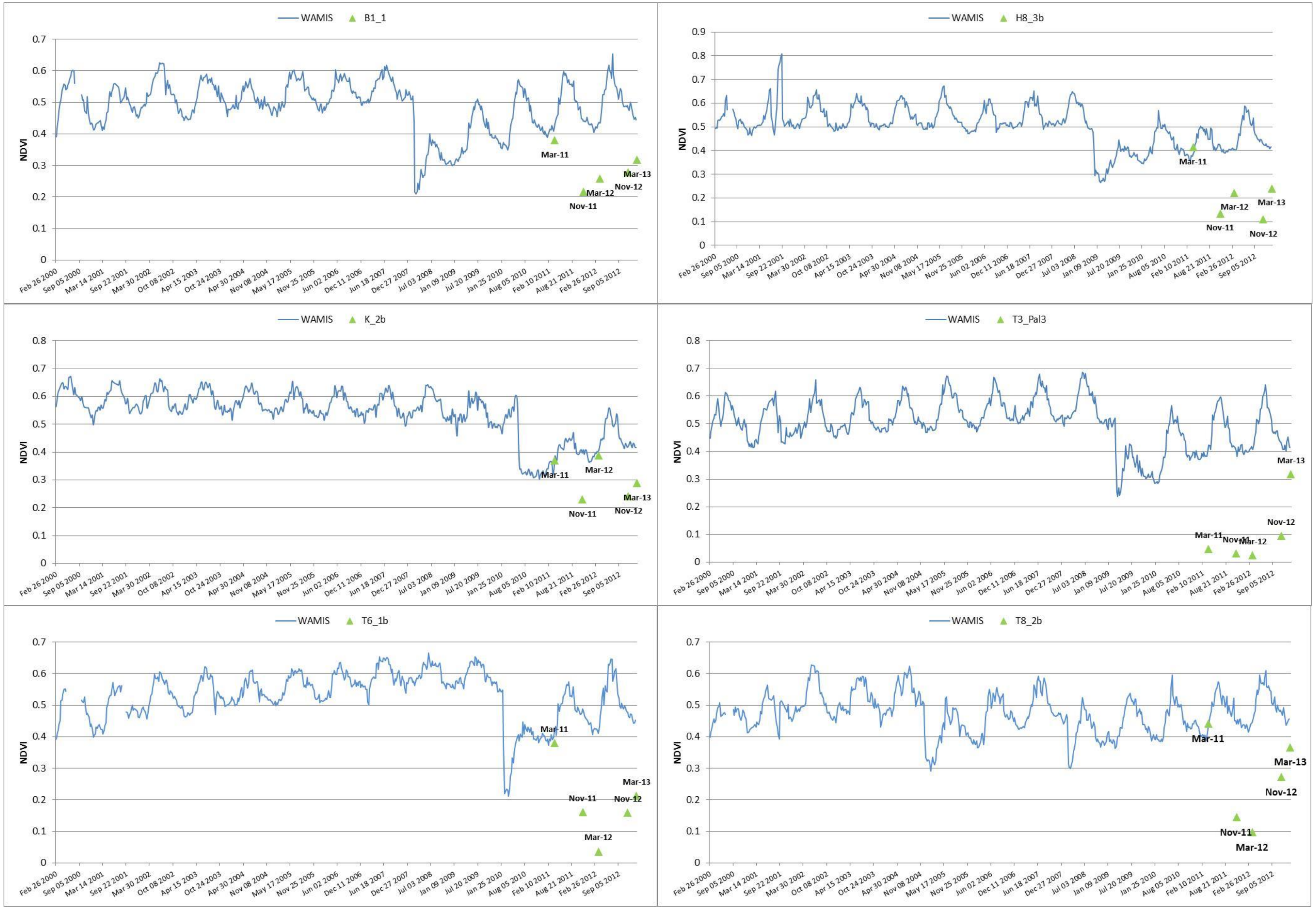


Figure 6.3 Comparison of the TMG NDVI values calculated for the ecoseeps in comparison with the low resolution NDVI time series for each TSA from the Wide Area Monitoring Information System (WAMIS) portal's time series viewer. The WAMIS data are provided for a land surface of approximately 300 m x 300 m.

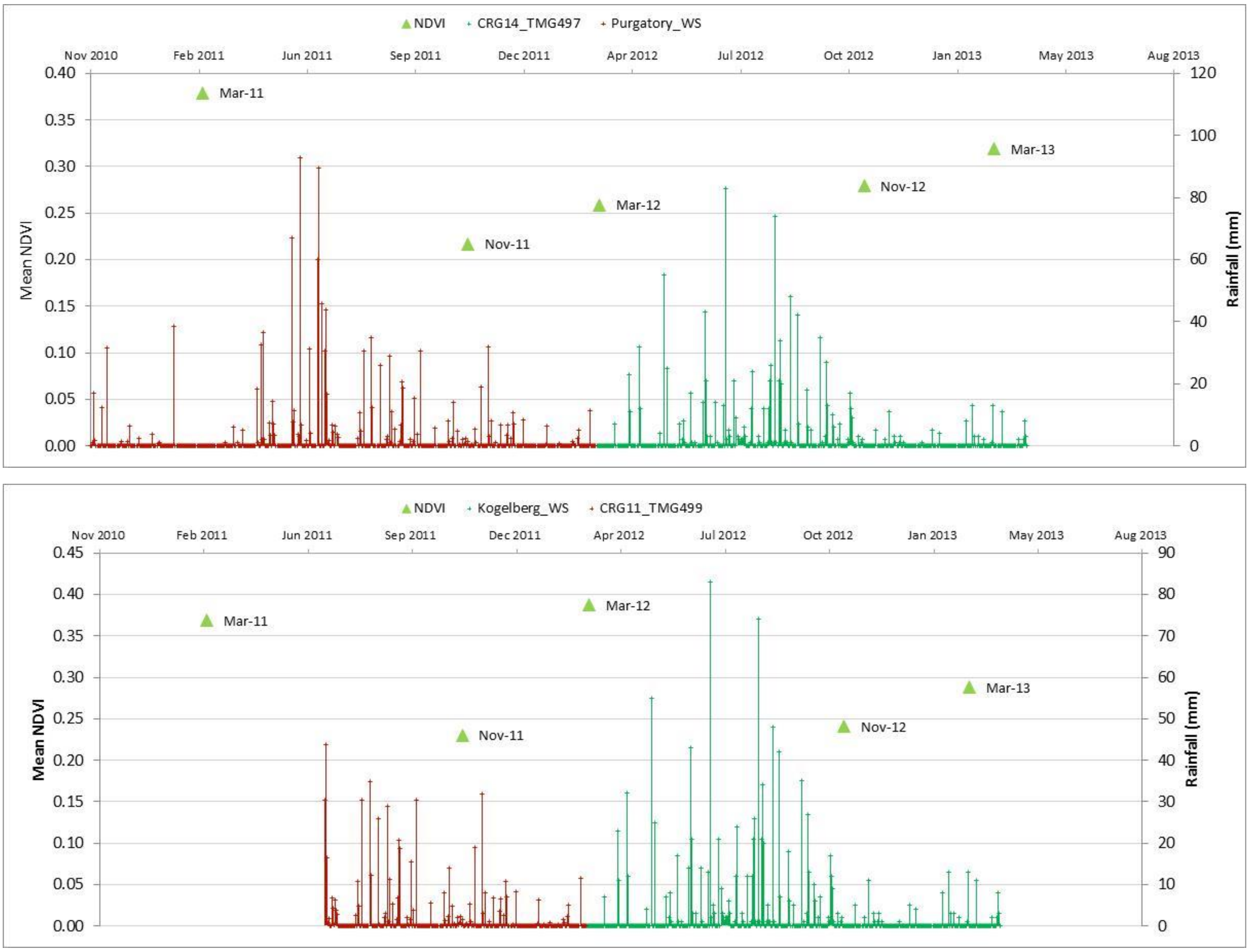


Figure 6.4 Rainfall compared against the mean NDVI calculated for B1_1 (top) and H8_3b (bottom).

7 SOIL MOISTURE

7.1 *Introduction*

The monitoring objectives for the collection and analysis of soil moisture data during EPM2 were to describe annual cycles in this parameter at each ecoseep, and the variability of the soil moisture regime (i.e. intra- and inter-annual wetting and drying cycles) of the seep, and, once abstraction has begun, to detect changes in the regime that may be related to the use of the Peninsula Aquifer.

Soil moisture is measured monthly at 10 cm-depth intervals to a maximum depth of 1 m at a number of monitoring points along each of the three transects across the ecoseeps. The data are presented as:

- Monthly time series of volumetric soil moisture; and
- Monthly time series of degree of saturation.

The following sections present the results of the analysis of 25 months of soil moisture data, collected from April 2011 to April 2013, at the nine ecoseeps being monitored in EPM2. The methods used for the analysis are presented in Volume 2: Method Statements.

7.2 *Results of Analysis*

7.2.1 Identifying soil seasons

The residuals calculated from the STARS regime shift analysis for the soil moisture data are shown in Figure 7.1, which displays a fairly consistent shift from a dry soil season to a wet soil season in June of 2011 and 2012, and a shift from dry to wet roughly in December each year. The shift is slightly clearer in 2011 than in 2012. Thus, it was determined that the wet soil season extends from June to November, and the dry soil season from December to May.

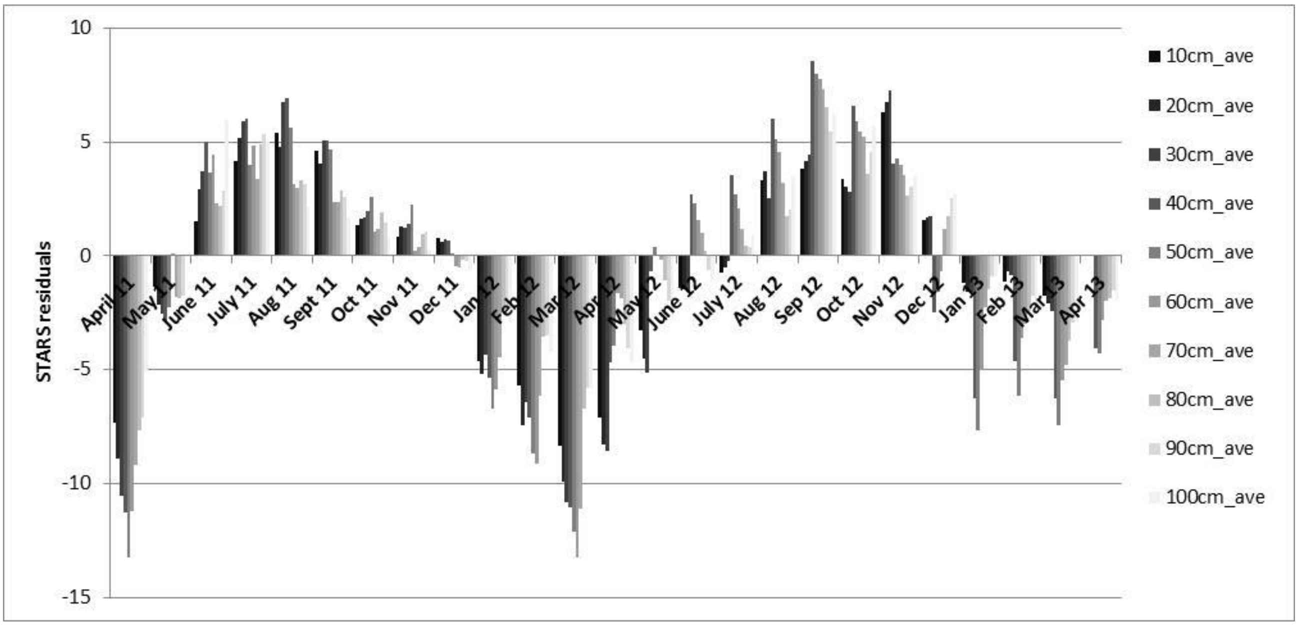


Figure 7.1 Residuals from the STARS regime shift analysis, graphed separately for each depth interval and averaged across all of the ecoseeps. Probability = 0.1, cut-off length = 3 months, Huber parameter = 1; using IPN4; subsample size = 3; shift detection: after pre-whitening.

7.2.2 Monitoring temporal shifts in soil moisture and links with groundwater level and rainfall

7.2.2.1 Ecoseep B1_1

The soils are deep in this ecoseep, and so most monitoring access tubes extend to 1 m. The ecoseep has a perennially wet core, surrounded by a seasonally to intermittently wet outer zone[5] (see Figure 7.2). On Transect 1, SM3, 4 and 5 remained saturated[6] throughout the monitoring period, while the soils on the edges of the ecoseep were drier and showed a distinctly seasonal wetting/drying pattern. On Transect 2, SM3 remained close to saturation throughout the period, while the remaining points showed seasonal wetting and drying patterns. On Transect 3, SM2, 3 and 4 reached saturation only in the wet season, drying out in summer.

This observation was supported by the data from the piezometers – P1 in the upper portion of the seep logged water levels that never dropped below 0.5 m, while those at P2 dropped seasonally below 0.5 m (Section 3.1; Figure 7.3 and Figure 7.4). The soil moisture monitoring point closest to P1, SM5 on Transect 1, remained constantly wet throughout the monitoring period (Figure 7.3), especially below 10-cm depth. The soils on the surface at this point showed more variation in water content, particularly during the dry season of 2011/2012, than the deeper layers. Data from the soil moisture monitoring point closest to P2, SM3 on Transect 3, echoed the seasonal wetting and drying cycle logged at P2 at all soil depths (Figure 7.4).

Thus, it seems that water emerges in the middle of Transects 1 and 2, keeping this core part of the ecoseep saturated or even inundated throughout the year, while Transect 3 is more seasonal (see Volume 1: Monitoring Framework and Protocol for a detailed description of the site). In September 2012, the seep was saturated across the whole area, more evenly so than in September 2011 (Figure 7.2).

As a whole, the seep was driest at the surface, becoming increasingly wet with depth, in both 2011/12 and 2012/13 (Figure 7.5). The rainfall in this month in 2012 was higher than in 2011 (e.g. Figure 7.3), and this resulted in wetter means over 2012/13 (Figure 7.5).

The PCA of soil moisture variables showed that a cumulative total of 88% of the variation between the soil moisture monitoring points was explained by the first three axes. The spread of points along PC1 (58% of the variation) was driven largely by the variation in soil moisture during the dry season at 40 – 50-cm depth (L2_Dsd), during the wet season at 20 – 30-cm depth (L1_Wsd), and in the dry season below 50 cm (L3_Dsd) (Table 7.1 and Figure 7.6). PC2 was driven primarily by the dry season maximum at 20 – 30-cm depth (L1_Dmax), and to a lesser degree by the variation in soil moisture at the surface during the dry season (L0_Dsd). PC3 was clearly driven by the wet season minimum below 50-cm (L3_Wmin) (Table 7.1).

Significant differences were found at all soil depths between the intermittently, seasonally and perennially saturated monitoring points ($p \leq 0.05$). The differences between the monitoring points at depths greater than 30 cm (L2 and L3) were found to be the most significant (Figure 7.7). The most important driver of these differences at depth was found to be the dry season variation in soil moisture (L3_Dsd) (Figure 7.8). The latter was considerably lower at the perennially and intermittently saturated points.

Thus, at B1_1 the variation in soil moisture and the extremes within each season are all important variables, and this seems to be the case at all soil depths. Soil moisture at depths below 20 cm, especially in the top portion of the ecoseep close to P1, were more constantly wet during the monitoring period, and showed significant differences between hydroperiod classes, especially at depths below 50 cm.

[5] *Soil hydroperiod is defined as follows: perennial =*

[6] *A soil that has an s-value or degree of saturation greater than 0.9 is considered to be saturated for this study.*

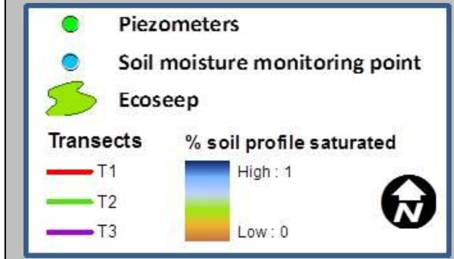
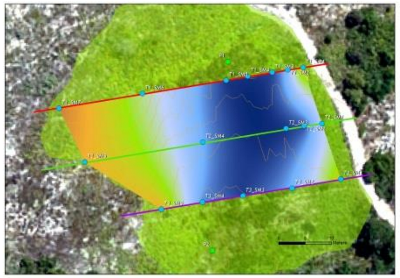
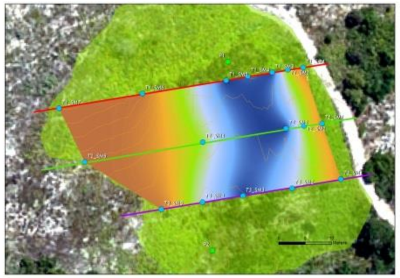
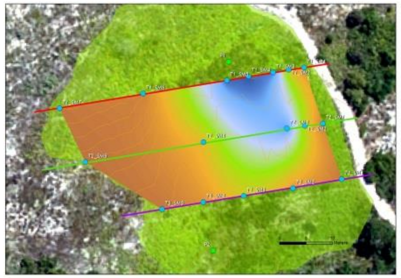
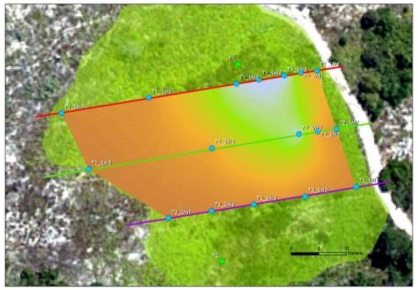
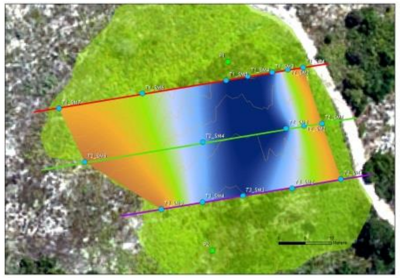
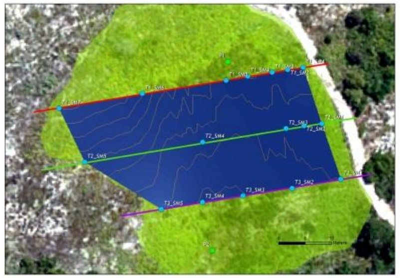
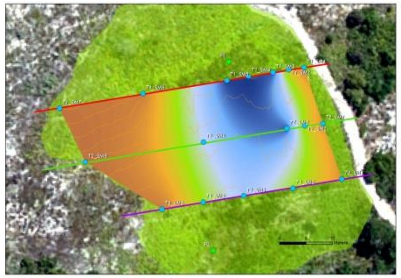
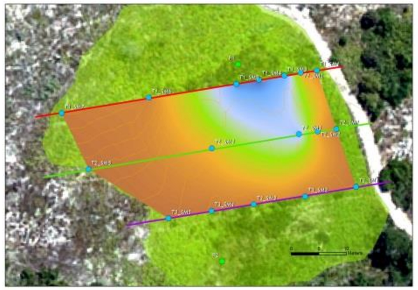
	March	June	September	December
2011				
2012				
2013				

Figure 7.2 Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at B1_1. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).

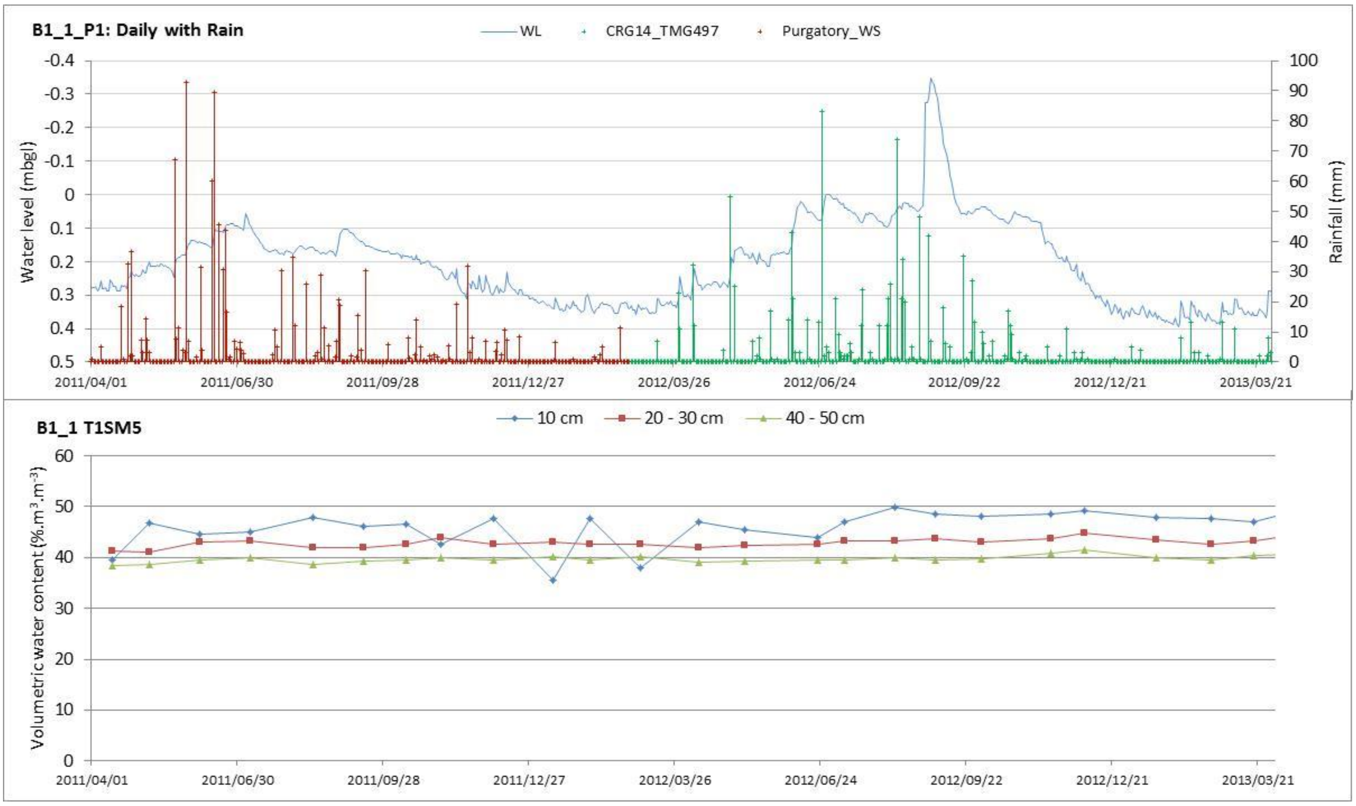


Figure 7.3 **Comparison between the rainfall and groundwater level logged in P1 at B1_1 (top) and the volumetric soil water content (bottom) monitored at SM5 on Transect 1.**

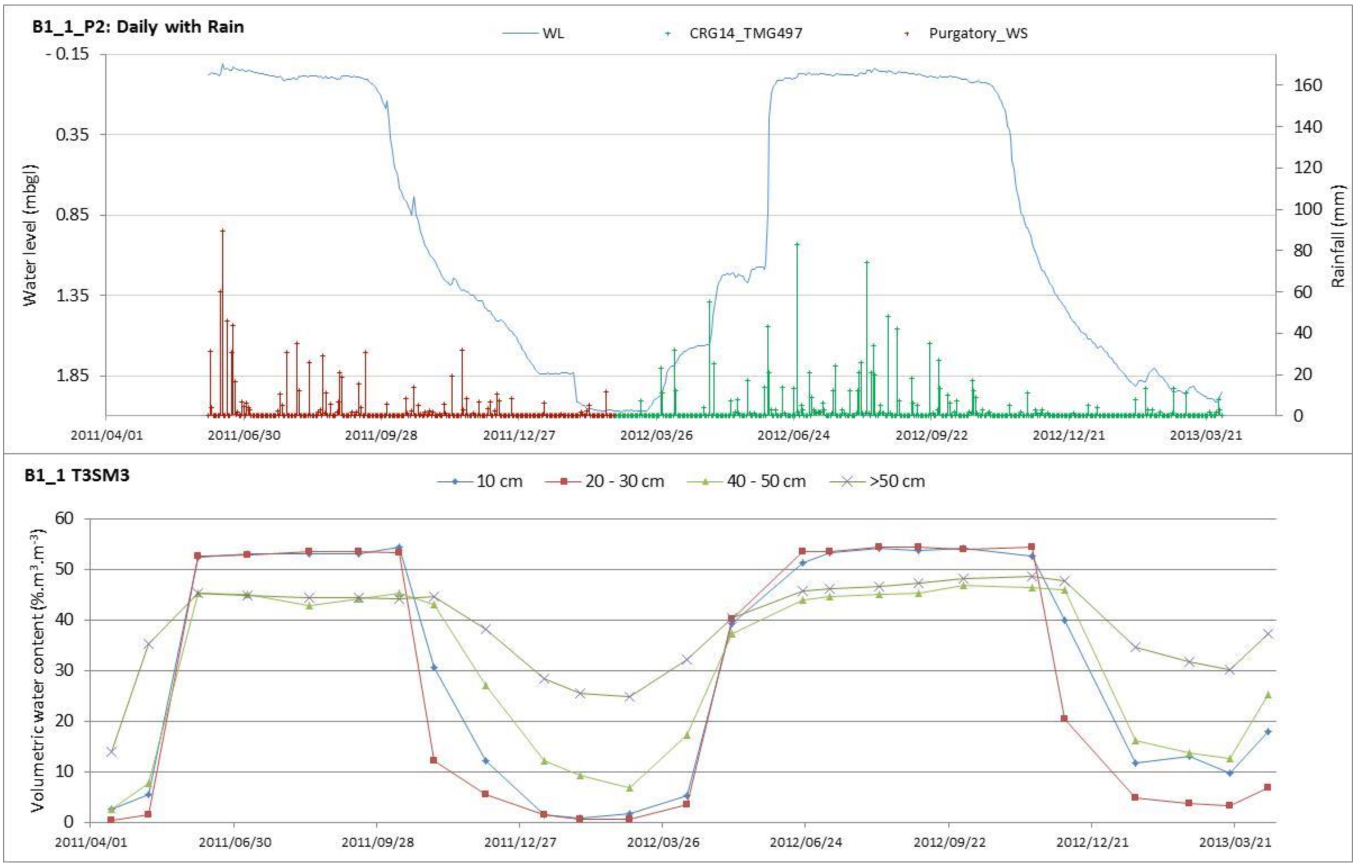


Figure 7.4 **Comparison between the rainfall and groundwater level logged in P2 at B1_1 (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 3.**

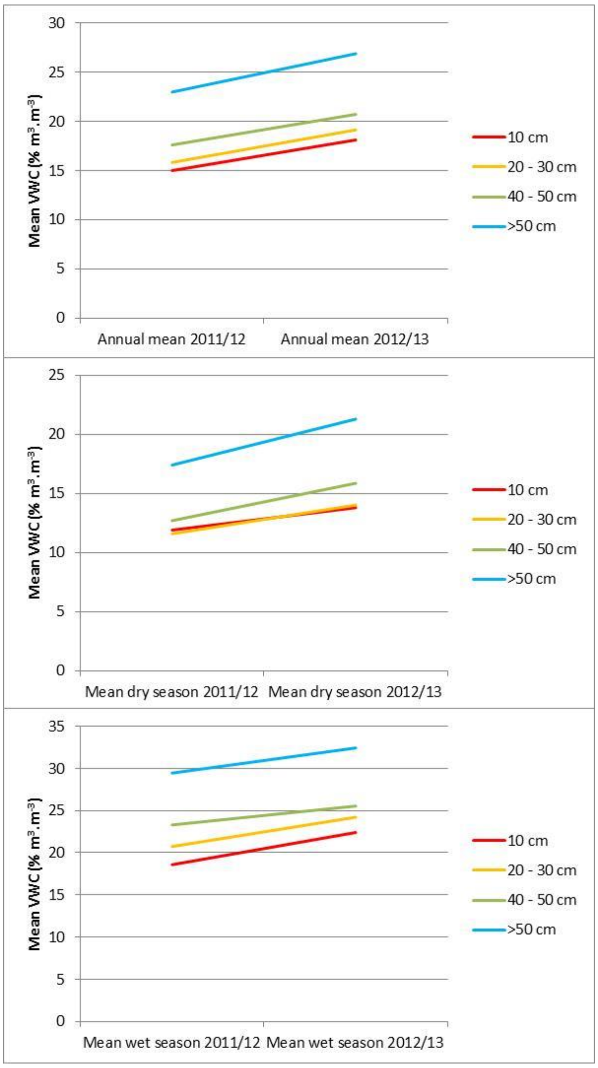


Figure 7.5 **Mean volumetric water content (VWC) averaged across B1_1 within each depth category, and expressed as annual, dry season and wet season means, for 2011/12 and 2012/13.**

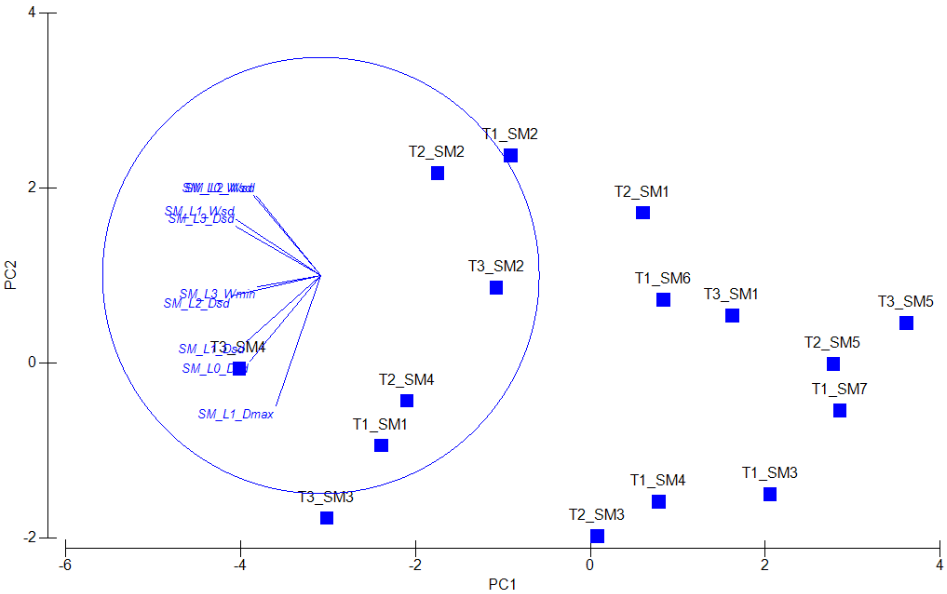


Figure 7.6 **Principle Components Analysis of a subset of nine soil moisture variables for B1_1. The blue vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 79% of the variation).**

Table 7.1 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for B1_1. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (58%)	PC2 (21%)	PC3 (9%)
L0_Dsd	-0.324	-0.392	0.018
L0_Wsd	-0.307	0.366	0.159
L1_Dsd	-0.341	-0.303	-0.472
L1_Wsd	**-0.390**	0.258	-0.197
L1_Dmax	-0.206	**-0.600**	0.205
L2_Dsd	**-0.409**	-0.094	-0.202
L2_Wsd	-0.294	0.364	0.025
L3_Dsd	**-0.389**	0.225	-0.034
L3_Wmin	-0.290	-0.052	**0.793**

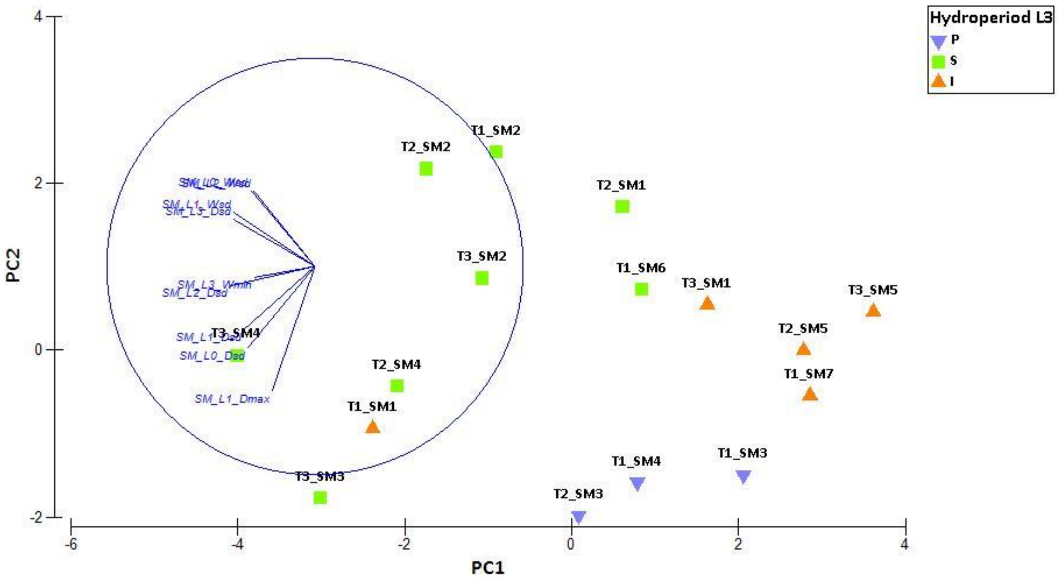


Figure 7.7 PCA of soil moisture variables at B1_1, with the hydroperiod classes at a soil depth greater than 50 cm (L3) shown as symbols.

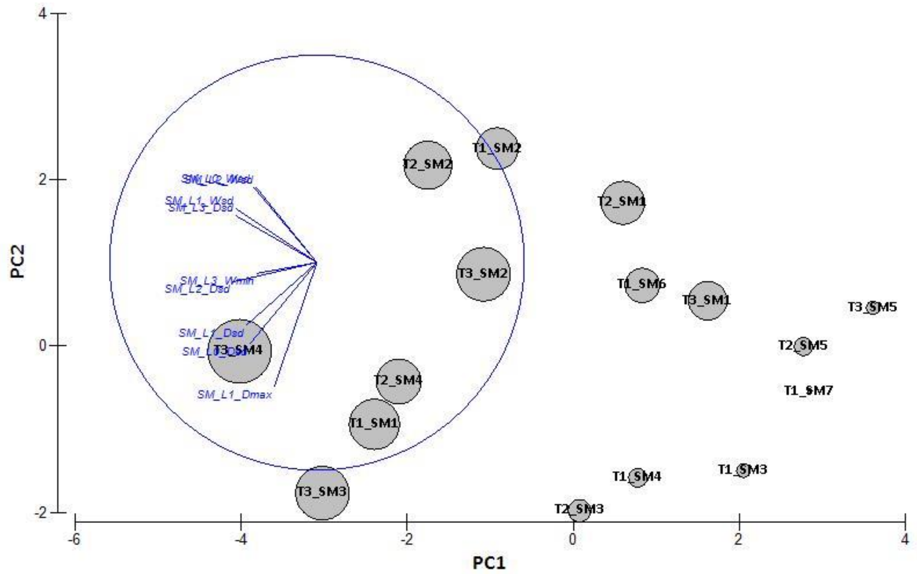


Figure 7.8 PCA of soil moisture variables at B1_1, with the variation in soil moisture in the dry season at more than 50-cm depth represented as bubbles, where the larger the bubble the greater the variation. The perennially and intermittently saturated monitoring points show far less variation in the dry season than the seasonal points.

7.2.2.2 Ecoseep H8_3b

The soils are deep at this ecoseep, and most access tubes extend to between 0.9 m and 1.0 m. During the monitoring period this ecoseep was visibly wetter towards the lower, Transect 3, where soils remained saturated or close to saturation throughout the monitoring period (Figure 7.9). Most soil moisture monitoring points on Transects 1 and 2 showed a seasonal wetting pattern, demonstrating the probable influence of rainfall patterns on the top and middle portions of the seep (Figure 7.9). The almost constant saturation of Transect 3 could be the result of either topographically driven interflow or groundwater from the Skurweberg Formation (see Volume 1: Monitoring Framework and Protocol for the setting of the site).

The water levels measured in the three piezometers at H8_3b showed the same pattern: water levels at the lower P3 remained within 15 cm of the surface (Section 3.1). The soil moisture monitoring points close to P2 and P3 (P1 is some distance from the monitoring points and so is not compared here) echo this pattern, where SM3 on Transect 2 dried out seasonally at all soil depths towards the end of summer in 2011 and 2012 (Figure 7.10), but SM5 on Transect 3 remained at or near saturation (Figure 7.11). The higher rainfall of winter 2013 led to this ecoseep remaining wetter into March of that year, compared with 2012 (Figure 7.9, Figure 7.10 and Figure 7.11). Unlike at B1_1, there was little spatial variation in soil moisture content across the site at any time, with the exception of March 2012, when there was a considerable difference between the upper and lower parts of the seep.

At H8_3b the soils in the top 10 cm (L0) were drier and more variable than the other depth layers (e.g. Figure 7.10, Figure 7.11 and Figure 7.12). Unlike B1_1, this seep does not steadily increase in wetness with depth, as the 40 – 50-cm layer was, on average, drier than the upper layers, in both the wet and dry seasons (Figure 7.12). This may indicate that this soil layer drains more readily, such as occurs in sand with no organic matter.

Interestingly, although most soil layers were wetter in 2012/13 than in 2011/12, this was not the case for the deepest soil layers (> 50 cm deep) that showed little inter-annual variation (Figure 7.12). This points towards a constant, deep source of water for the seep - this site is likely to be fed by the Skurweberg Aquifer (see Volume 1: Monitoring Framework and Protocol). Overall, the seep was wetter in 2012/13 than in 2011/12; the dry season showed a slightly steeper increase between years (Figure 7.12). Thus, the higher rainfall of winter 2012 and overall increased wetness of the seep during the wet season persisted into the dry season.

According to the PCA, a cumulative total of 91% of variation was explained by the first three axes. Along PC1, the driving variables were the wet season maximum below 50-cm depth (L3_Wmax), followed by a combination of the dry season maximum at 40 – 50-cm depth (L2_Dmax), the duration of saturation below 50 cm ($L3\_Sat_{dur}$), and the wet season minimum also below 50 cm (L3_Wmin) (Table 7.2, Figure 7.13). Thus, this axis was determined primarily by deep soil (40 cm and below) extremes, and the duration of saturation. PC2 was driven by the dry season variation at the surface (L0_Dsd), and the wet season variation below 50 cm (L3_Wsd). PC3 combined the dry season maximum at 40 – 50 cm (L2_Dmax), and the wet season minimum below 50 cm (L3_Wmin), so was similar to PC1 (Table 7.2).

There were only significant differences ($p \leq 0.05$) between hydroperiod classes below 30 cm (i.e. at L2 and L3) (Figure 7.14). In the shallower soil layers, there were only seasonally and intermittently saturated monitoring points, whereas in the soils deeper than 30 cm, there were only seasonally and perennially saturated points. The monitoring points below 50 cm separated along a gradient of wet season variation (Figure 7.15). Thus, while the dissimilarities between soil moisture monitoring points at H8_3b were minimal, these were driven largely by seasonal extremes, with some influence of wet season variation. Differentiation between points was more significant in the deeper soils.

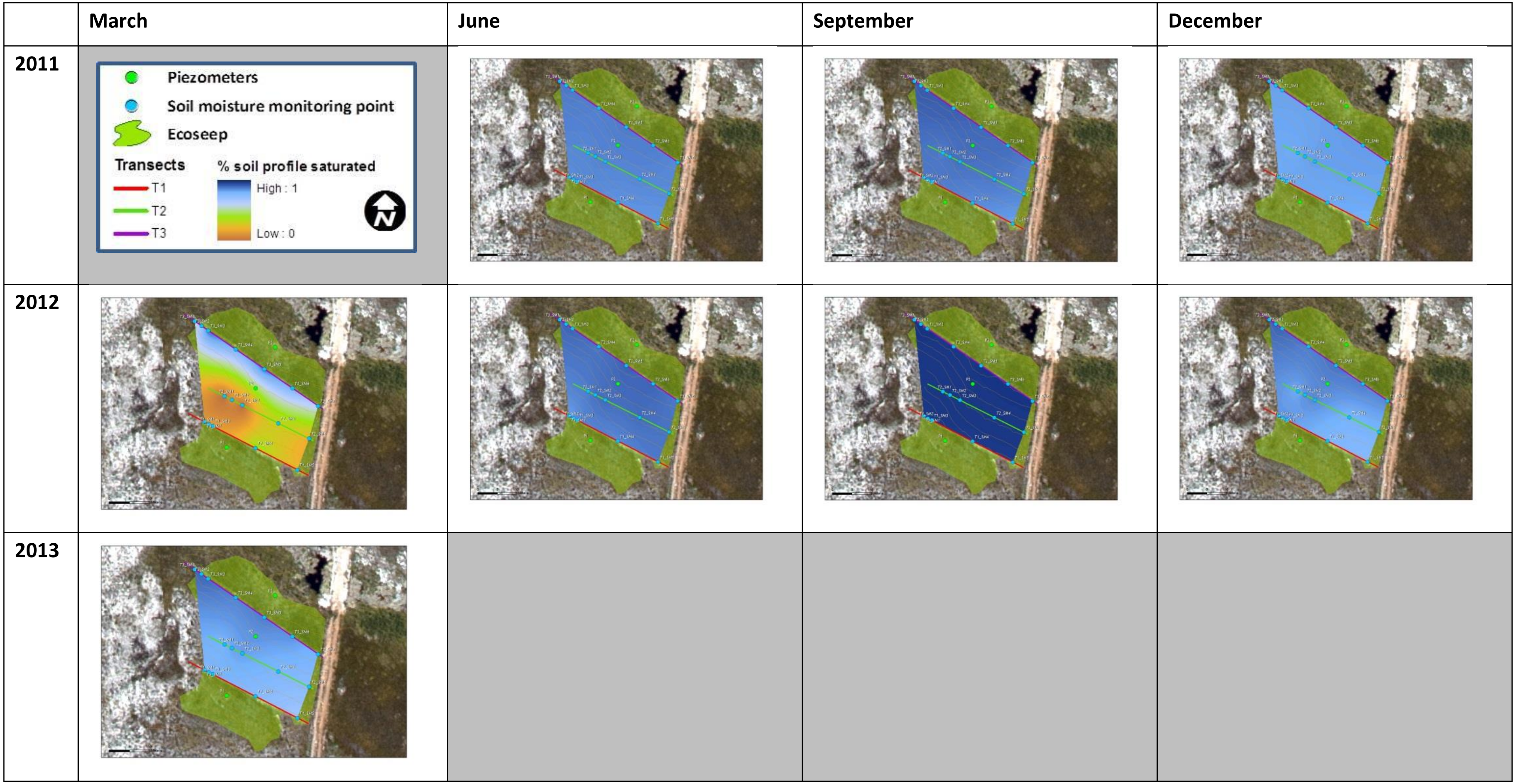


Figure 7.9 **Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at H8_3b. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).**

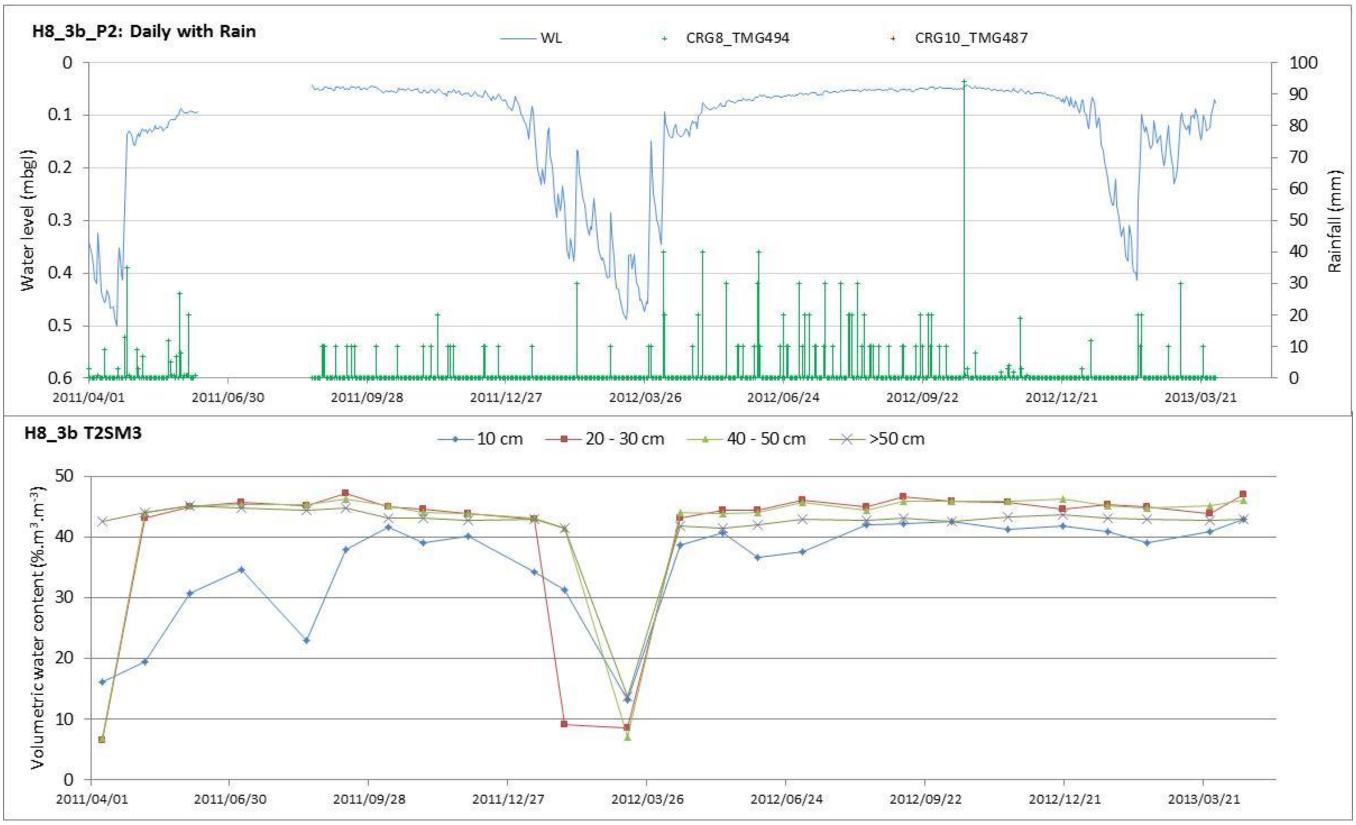


Figure 7.10 Comparison between the rainfall and groundwater level logged in P2 at H8_3b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 2.

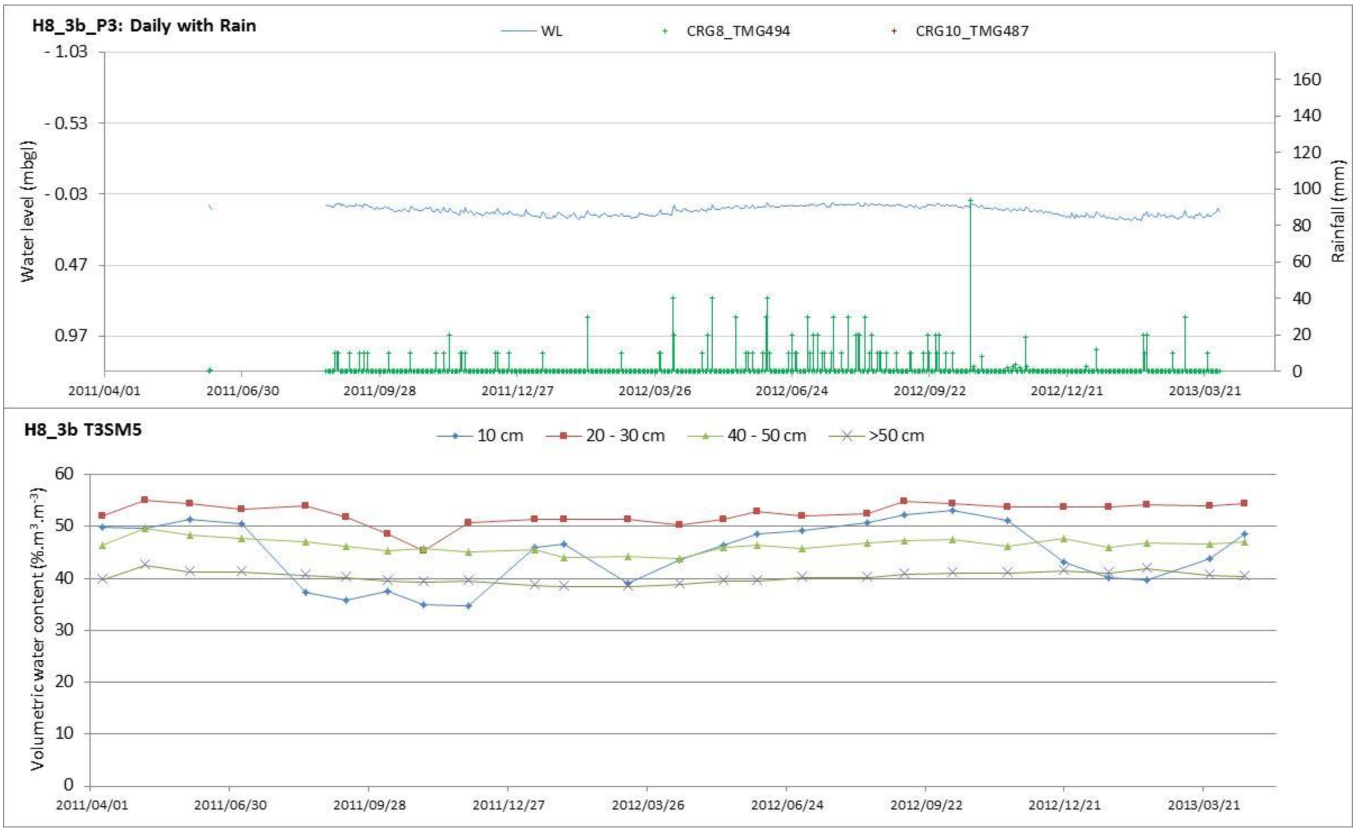


Figure 7.11 Comparison between the rainfall and groundwater level logged in P3 at H8_3b (top) and the volumetric soil water content (bottom) monitored at SM5 on Transect 3.

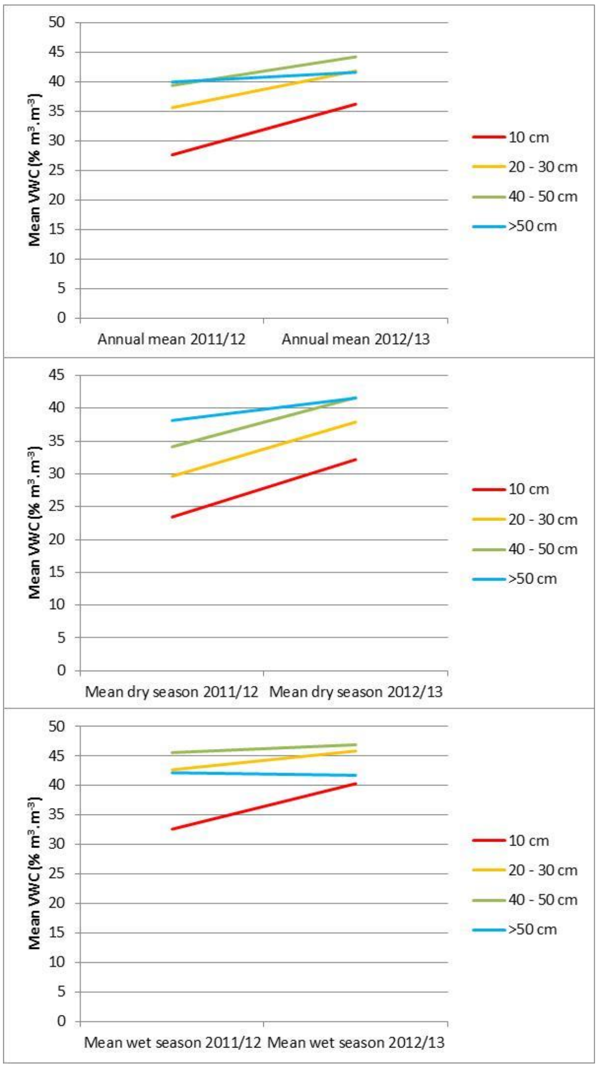


Figure 7.12 Mean volumetric water content (VWC) averaged across H8_3b within each depth category, and expressed as annual, dry season and wet season means, for 2011/12 and 2012/13.

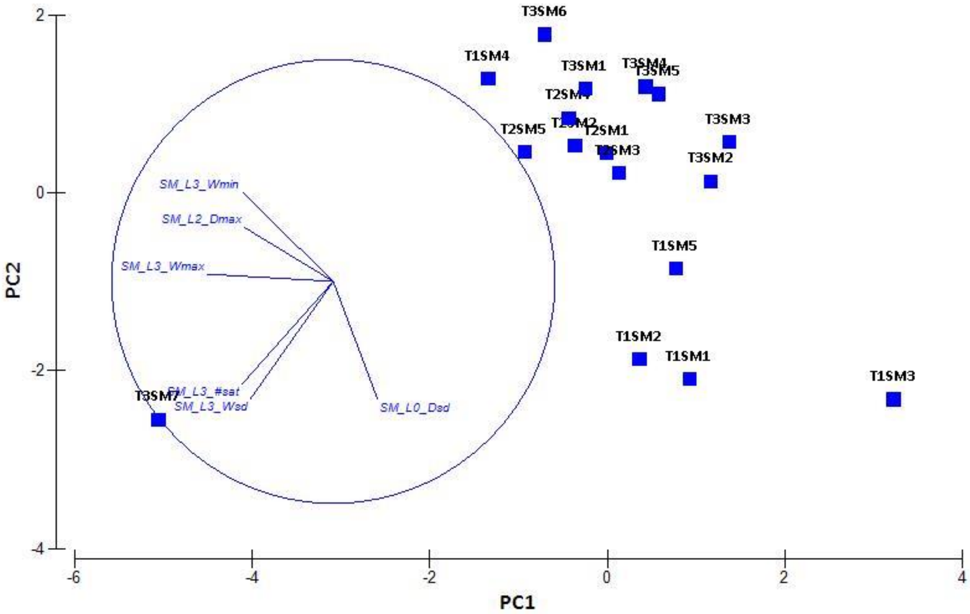


Figure 7.13 Principle Components Analysis of a subset of six soil moisture variables for H8_3b. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 80% of the variation).

Table 7.2 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for H8_3b. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (47%)	PC2 (33%)	PC3 (12%)
L0_Dsd	0.200	**-0.533**	-0.340
L2_Dmax	**-0.400**	0.243	**0.652**
L3_Satdur	**-0.411**	-0.462	-0.041
L3_Wsd	-0.374	**-0.530**	0.254
L3_Wmin	**-0.411**	0.402	**-0.531**
L3_Wmax	**-0.568**	0.033	-0.333

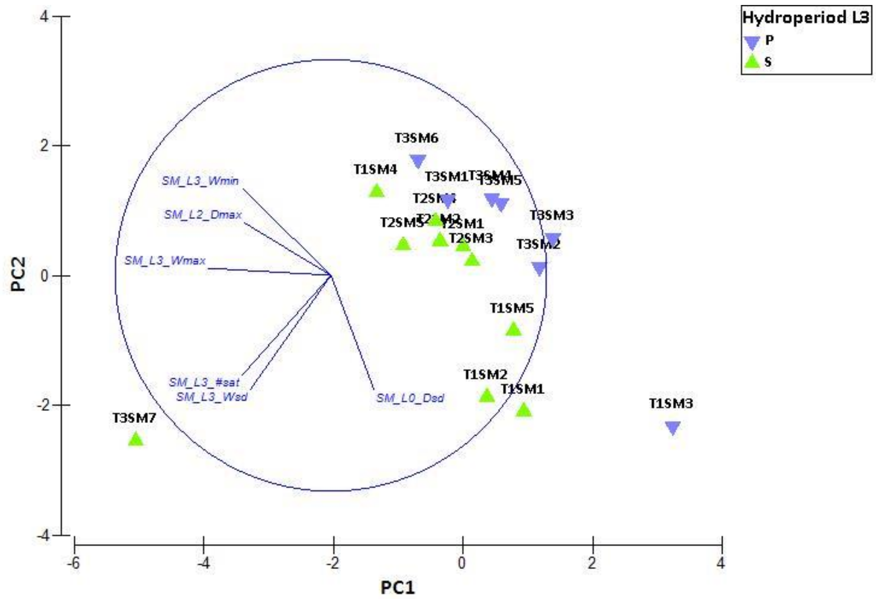


Figure 7.14 PCA of soil moisture variables at H8_3b, with the hydroperiod classes at a soil depth greater than 50 cm (L3) shown as symbols.

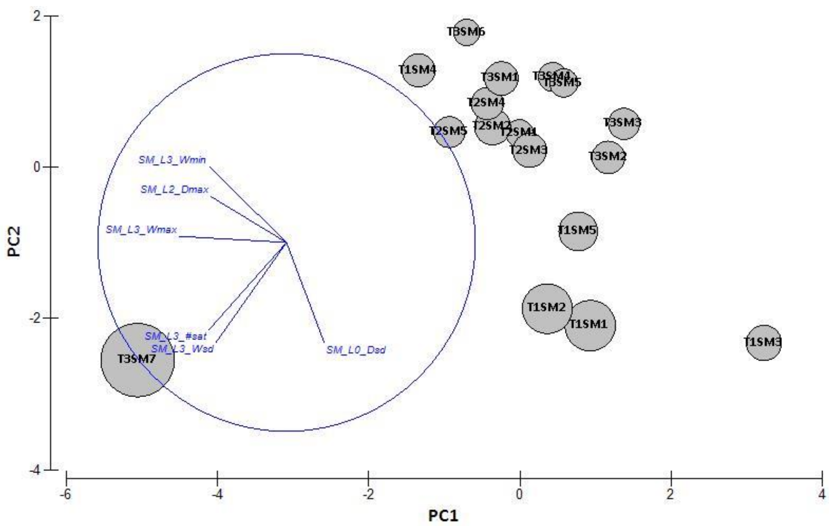


Figure 7.15 PCA of soil moisture variables at H8_3b, with the variation in soil moisture in the wet season at more than 50-cm depth represented as bubbles, where the larger the bubble the greater the variation. The seasonally saturated monitoring points (see Figure 7.14) show more variation in the wet season.

7.2.2.3 Ecoseep K_2b

With one exception, the soil moisture access tubes reach 1 m at K_2b. There was a marked seasonality in the soil moisture regime at this ecoseep, with the site reaching maximum saturation in September, and drying out by March of each year (Figure 7.16). The wettest portion of the site was around SM2 and SM3 on Transect 3.

Variations in soil moisture closely matched the logged water levels in the piezometers. The monitoring point closest to P1, SM3 on Transect 1, showed a markedly seasonal pattern of wetting and drying at all soil depths similar to that recorded at P1, where water levels dropped to below 1 mbgl by January of each year (Figure 7.17). Water levels at P2 were more constant, but still showed a drop to just below 0.5 mbgl towards the middle and end of summer of each year – and, similarly, soil moisture at SM3 on Transect 3 remained relatively constant, especially below 50 cm (Figure 7.18).

Soil moisture in the shallower soils was more variable and at a much lower content than the deeper soils (Figure 7.19). While the higher rainfall in 2012 led to an increase in mean VWC in all depth categories below 10 cm, the surface soil layer was drier in 2011/12. This was due to a decrease in the dry season mean between years at this depth. This was different to both B1_1 and H8_3b where mean VWC increased between years. This emphasises the seasonality of this site, and the independence of both the seasons and the soil depth categories. This highlights the importance of monitoring both the dry and wet season regimes at different depths, as the one may be more sensitive to changes in rainfall or groundwater input than the other.

In summary, K_2b was wetter and more constantly so at depth, and particularly towards the bottom of the site. This may be an indication of the influence of groundwater or interflow coming closer to the surface in this portion. The seep flattens out somewhat as it joins the valley floor of the Oudebosch valley, and it is likely that interflow and possibly deeper groundwater comes close to the surface at this point.

The PCA of soil moisture variables at K_2b showed that 66% of the variation between monitoring points was explained by the first three axes (Table 7.3 and Figure 7.20). Along PC1, the spread was driven largely by the dry season maximum at 40 – 50 cm (L2_Dmax), followed by a combination of the dry and wet season variation at 20 – 30 cm (L1_Dsd, L1_Wsd) (Table 7.3). Along PC2, dry season variation at 40 – 50 cm (L2_Dsd) was driving the separation between monitoring points, and along PC3, it was the wet season variation below 50 cm (L3_Wsd). Thus, at this site the variation in soil moisture in both the wet and dry seasons was a driving factor.

There were significant differences ($p \leq 0.05$) between intermittently and seasonally saturated points in the surface soils (there were no perennially inundated soils in this layer), along a gradient of dry season minimum water content (and Figure 7.22). The seasonally saturated monitoring points below 50-cm depth were also significantly different from those that are perennially saturated, along a gradient of dry season variation (and Figure 7.22). There were no intermittently saturated soils below 30 cm. The duration of saturation over the year increased from the surface of the soil into the deeper soils, indicating a deep water source that keeps the ecoseep wet or even saturated at depth all year round.

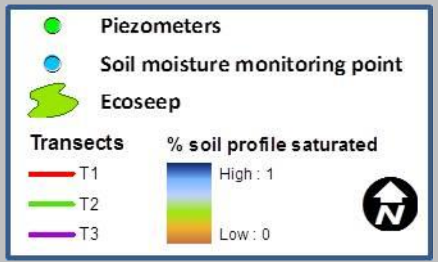
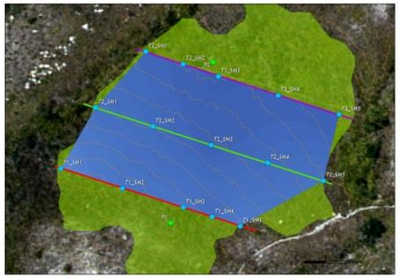
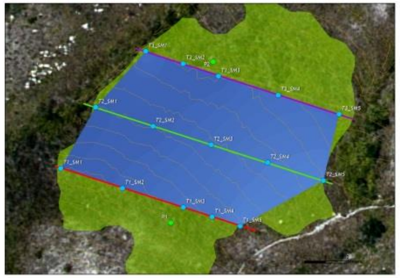
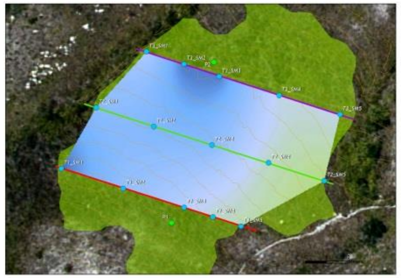
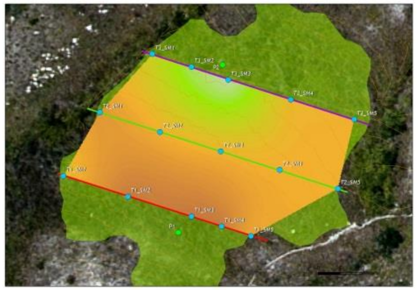
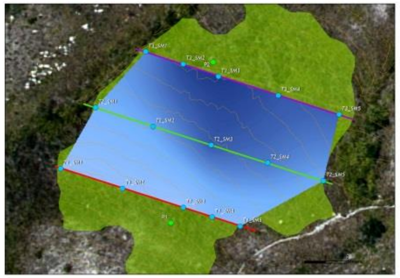
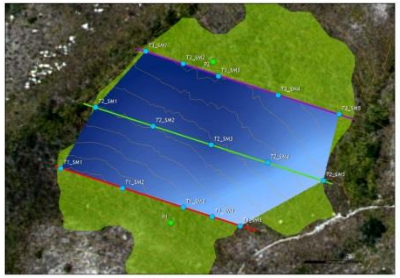
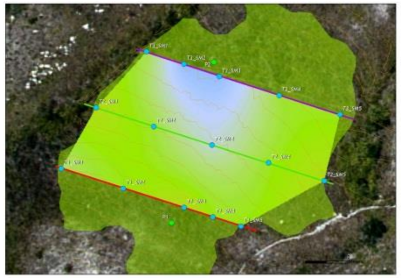
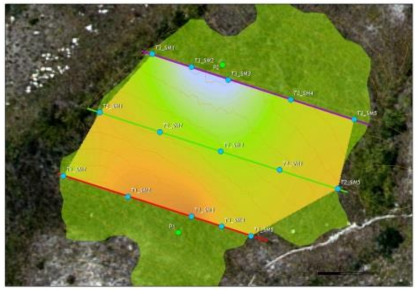
	March	June	September	December
2011				
2012				
2013				

Figure 7.16 Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at K_2b. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).

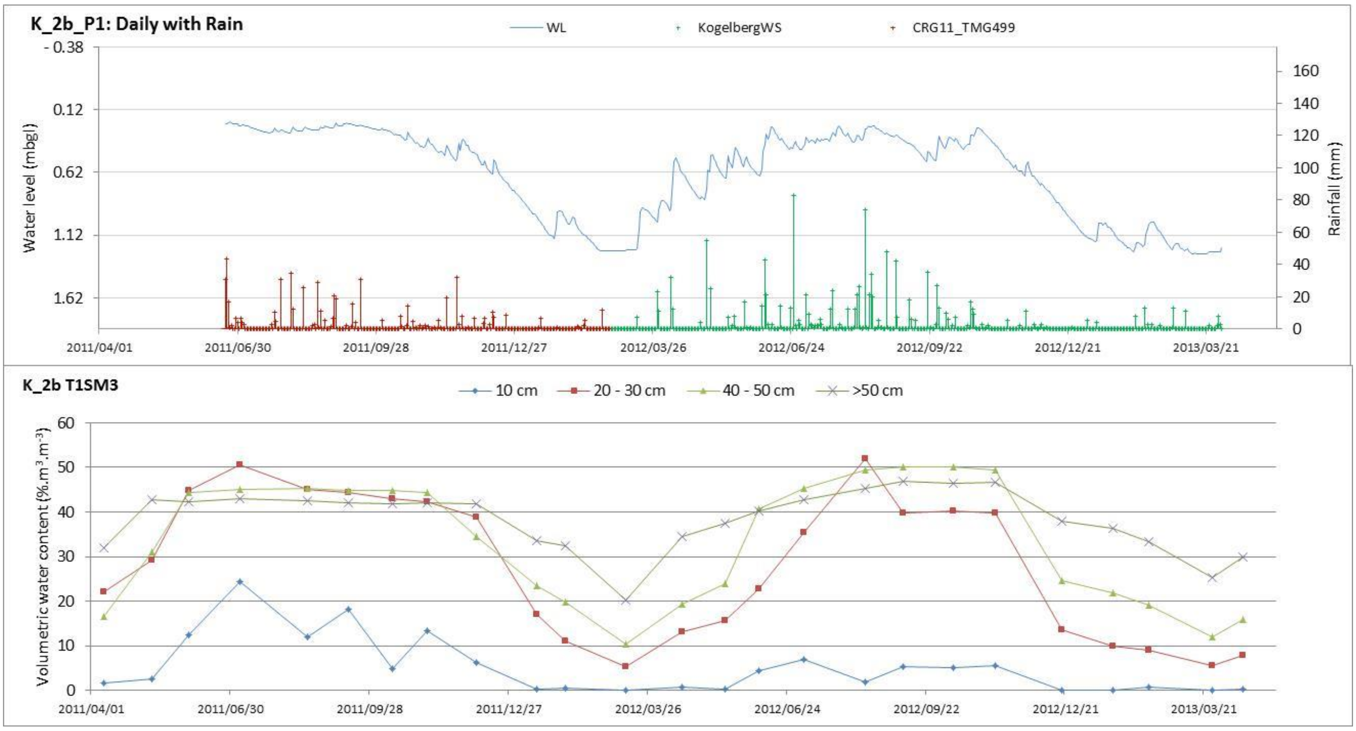


Figure 7.17 Comparison between the rainfall and groundwater level logged in P1 at K_2b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 1.

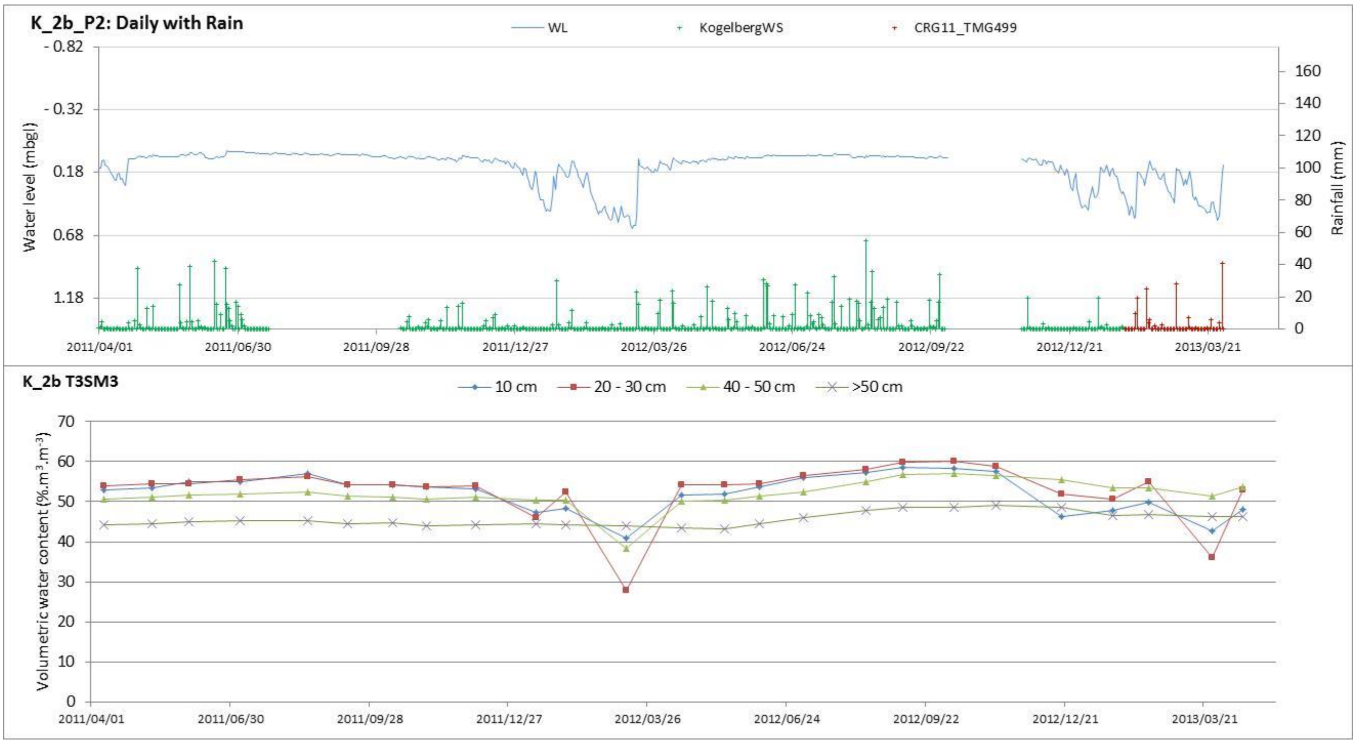


Figure 7.18 Comparison between the rainfall and groundwater level logged in P2 at K_2b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 3.

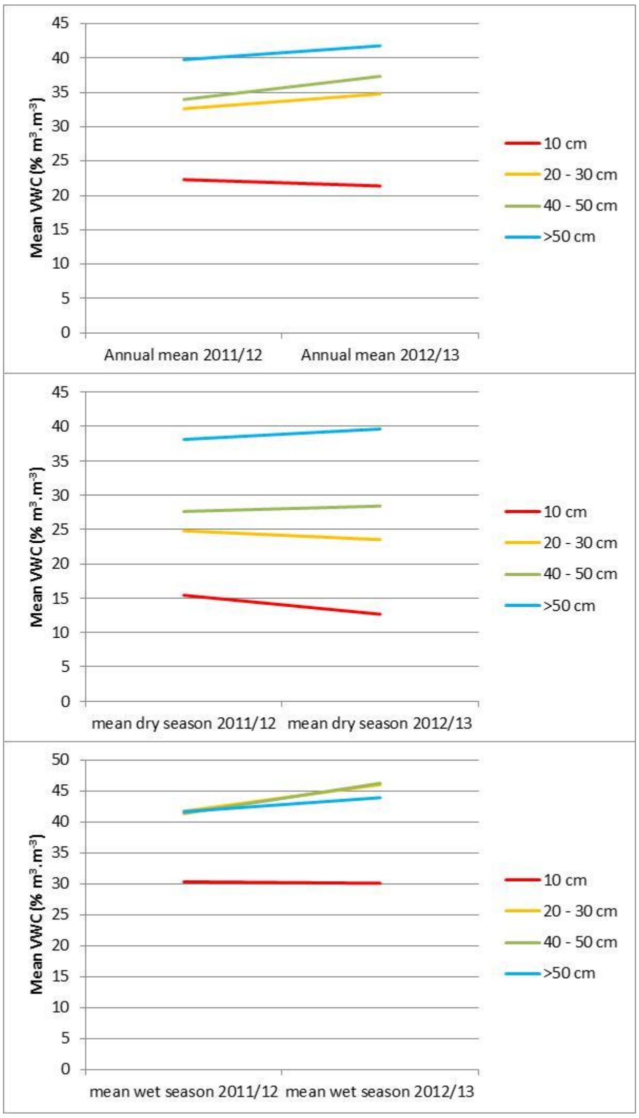


Figure 7.19 Mean volumetric water content (VWC) averaged across K_2b and all soil depths, expressed as annual means, and dry season and wet season means, for 2011/12 and 2012/13.

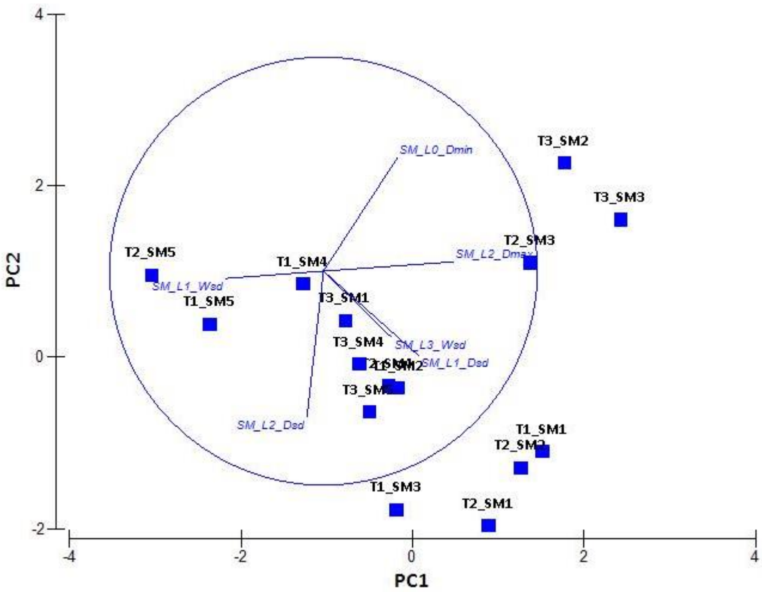


Figure 7.20 Principle Components Analysis of a subset of six soil moisture variables for K_2b. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 66% of the variation).

Table 7.3 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for K_2b. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

<table>
<tr><th colspan="3">Variable</th><th>PC1 (40%)</th><th>PC2 (26%)</th><th>PC3 (22%)</th></tr>
<tr><td colspan="3">L0_Dmin</td><td>0.344</td><td>0.527</td><td>0.363</td></tr>
<tr><td colspan="3">L1_Dsd</td><td>0.445</td><td>-0.395</td><td>-0.311</td></tr>
<tr><td colspan="3">L1_Wsd</td><td>-0.456</td><td>-0.034</td><td>0.583</td></tr>
<tr><td colspan="3">L2_Dsd</td><td>-0.078</td><td>-0.682</td><td>0.157</td></tr>
<tr><td colspan="3">L2_Dmax</td><td>0.606</td><td>0.043</td><td>0.153</td></tr>
<tr><td>L3_Wsd</td><td>0.320</td><td>-0.312</td><td colspan="3">0.620</td></tr>
</table>

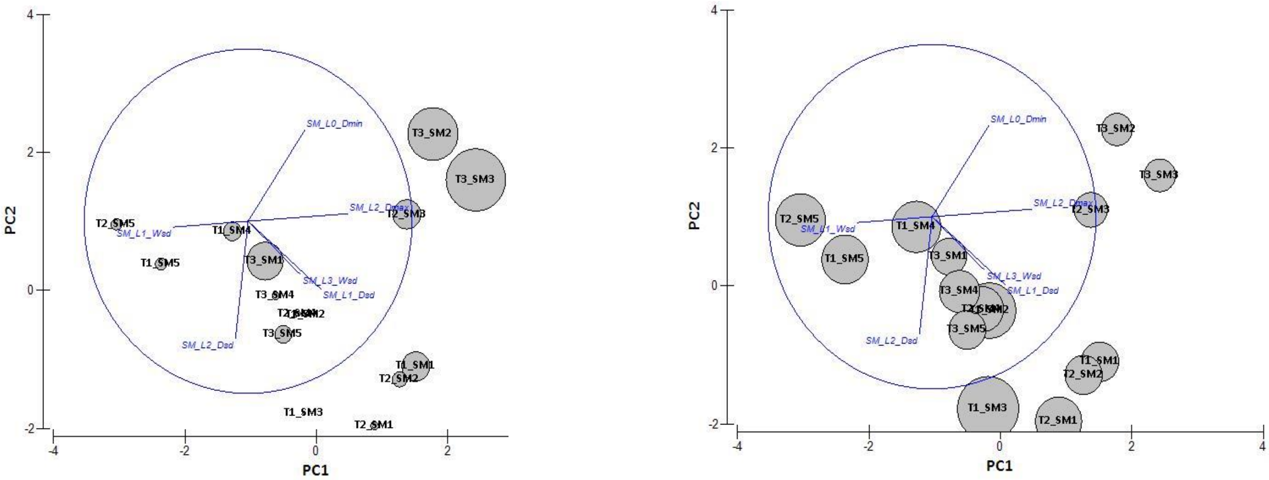


Figure 7.21 PCA of soil moisture variables at K_2b, with the hydroperiod classes in surface soils (L0, left) and at depths greater than 50 cm (L3, right) shown as symbols.

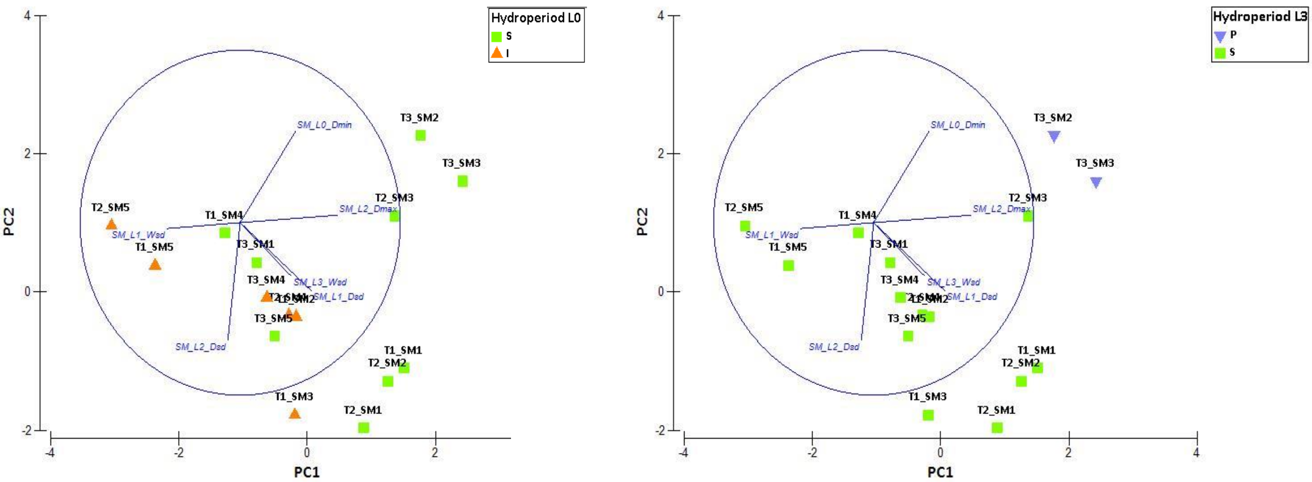


Figure 7.22 PCA of soil moisture variables at K_2b, with the dry season minimum at the surface (L0) (left) and the dry season variation below 50-cm depth (L3) (right) represented as bubbles, where the larger the bubble the higher the minimum or greater the variation.

7.2.2.4 Ecoseep K_5b

The soils in this ecoseep are shallow, with most access tubes reaching to between 20 and 40 cm, with the exception of two points on Transect 3 that are 50 cm deep. Most of the monitoring points were seasonally saturated at all depths, with very few of them remaining saturated for very long. The wettest portions of the site were up on Transect 1, around SM4 and SM5 (Figure 7.23), and on Transect 3 at SM3. Generally, there was little spatial variation in saturation of the soil profiles across the site in most months, except for March 2013, when portions of the seep were clearly drier than others.

In the top portion of the seep, soil moisture was more variable than the groundwater levels monitored in the upper piezometer P1, where water levels dropped to almost 0.70 mbgl in late January 2013, but then recovered more or less in February 2013. Soil moisture measured nearby at SM2 on Transect 1 continued to drop in March and into April 2013, despite the rainfall in February and March 2013 (Figure 7.24). At P2, water levels remained near the ground surface throughout the monitoring period, while soil moisture measured at SM3 on Transect 3 also remained fairly constant, especially at 20 – 30-cm depth (Figure 7.25). The deeper soil layers were wetter than the surface layer at both points. This may indicate the influence of groundwater or at least interflow, entering this seep, which is likely to be fed by the Peninsula Aquifer.

There was no inter-annual comparison of wet and dry season means at this site, as there is only one year of monitoring data.

Statistical analysis of the soil moisture data at this site was limited to the surface (L0) and shallow (20 – 30 cm) depth layers, as there were numerous gaps in the data measured below 30 cm. The PCA of soil moisture variables revealed that 89% of the spatial variation between monitoring points could be explained by the first three axes (Table 7.4). Along PC1, this variation was driven largely by the dry season minimum (L0_Dmin) (see also Figure 7.26) and maximum (L0_Dmax), and wet season minimum in the surface soils (L0_Wmin), while both PC2 and PC3 showed gradients of dry and wet season variation (Dsd and Wsd) in soil moisture in L0 and L1 (Table 7.4).

There were no significant differences between soil moisture monitoring points placed in the three hydroperiod classes, but this is probably due to the fact that almost all points were seasonally saturated, with very few being classified as either intermittently or perennially saturated. Despite the lack of significant differences between hydroperiod categories and uniform seasonality across the site, the soil moisture monitoring points did separate along a gradient of dry season minimum VWC, as shown in Figure 7.27.

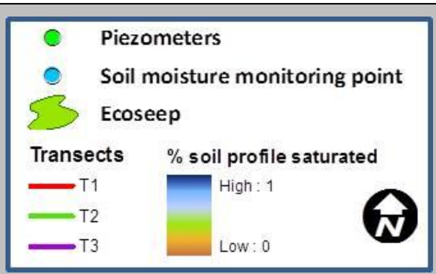
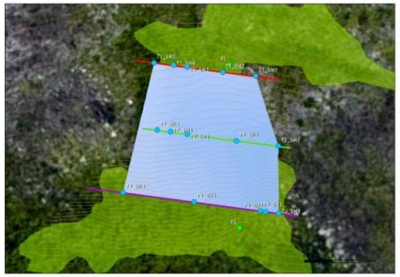
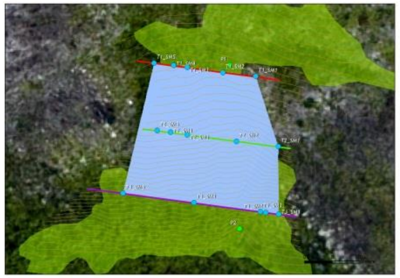
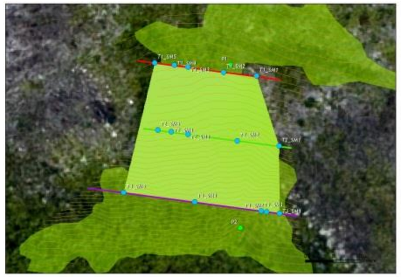
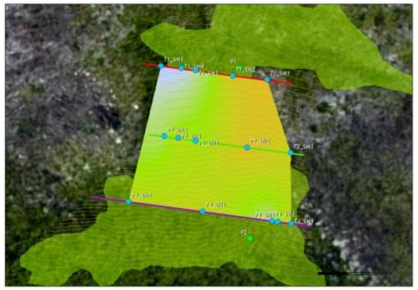
	March	June	September	December
2011				
2012				
2013				

Figure 7.23 **Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from June 2012, when monitoring commenced at K_5b. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).**

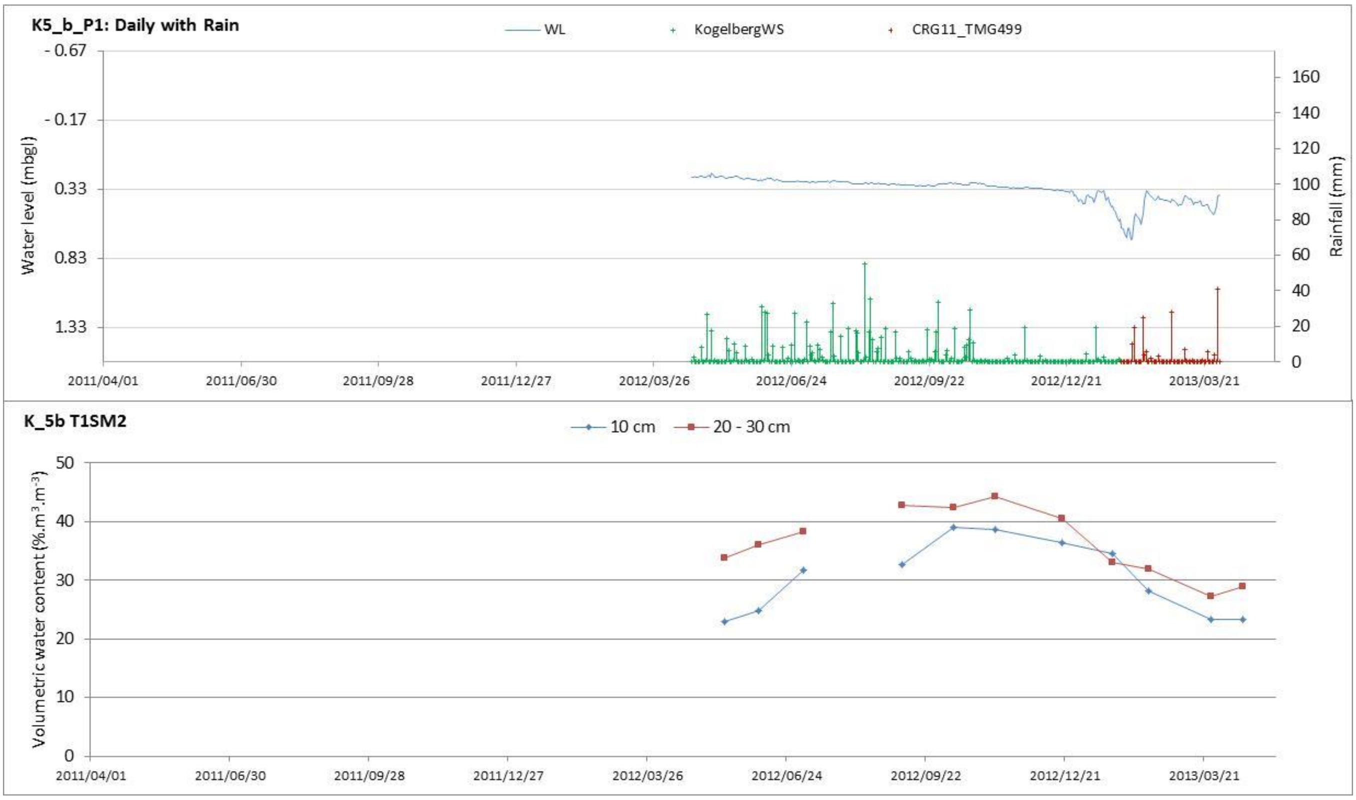


Figure 7.24 Comparison between the rainfall and groundwater level logged in P1 at K_5b (top) and the volumetric soil water content (bottom) monitored at SM2 on Transect 1.

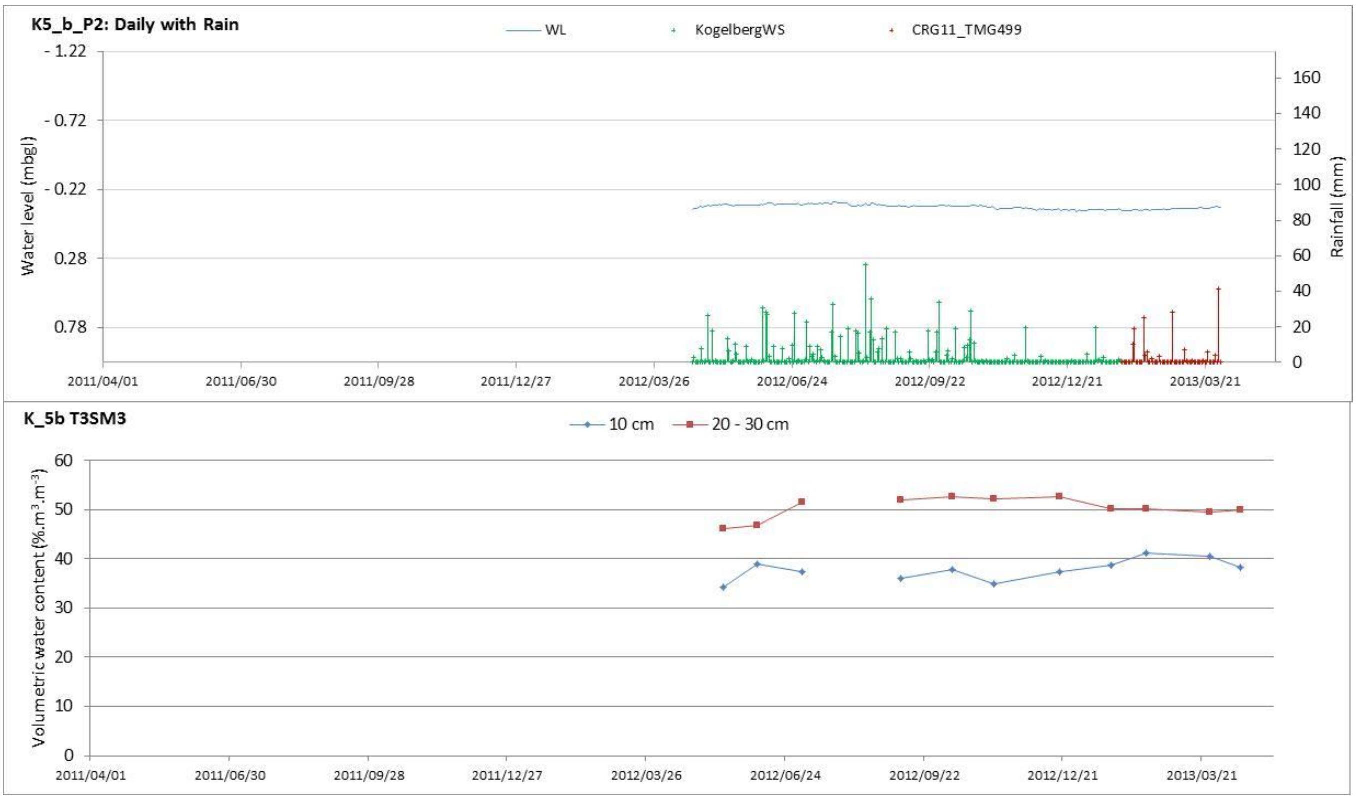


Figure 7.25 Comparison between the rainfall and groundwater level logged in P2 at K_5b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 3.

Table 7.4 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for K_5b. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (50%)	PC2 (23%)	PC3 (16%)
L0_Wsd	-0.038	**-0.493**	**0.805**
L0_Dmin	**0.561**	-0.131	-0.103
L0_Wmin	**0.565**	-0.081	-0.01
L0_Dmax	**0.566**	-0.101	0.075
L1_Dsd	0.061	**0.597**	**0.574**
L1_Wsd	0.201	**0.606**	0.08

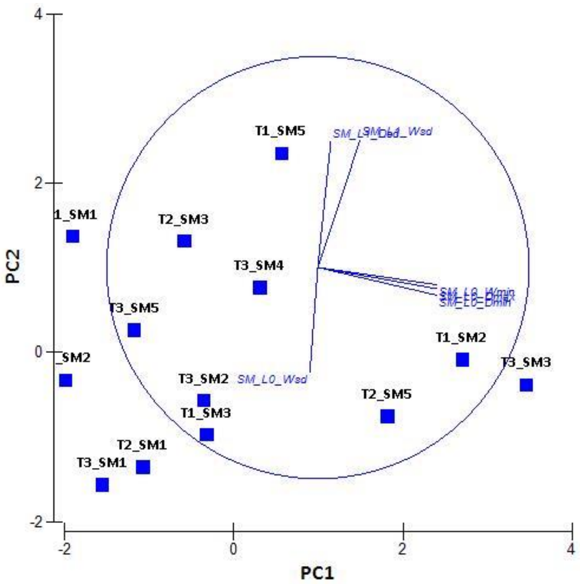


Figure 7.26 Principle Components Analysis of a subset of six soil moisture variables for K_5b. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 73% of the variation).

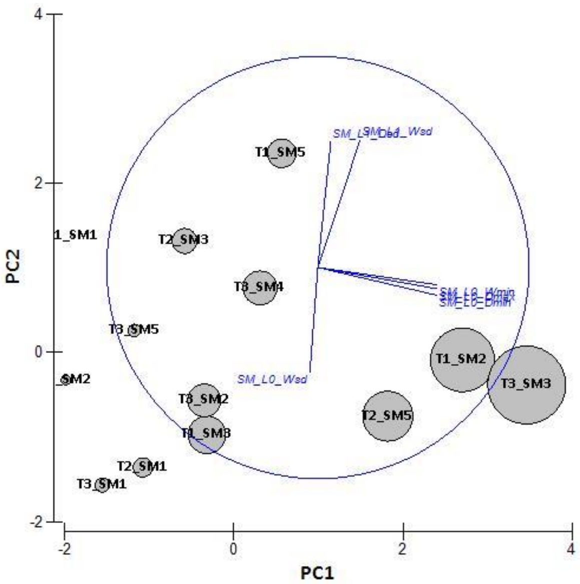


Figure 7.27 PCA of soil moisture variables at K_5b, with the dry season minimum at the surface (L0) represented as bubbles, where the larger the bubble the higher the minimum. This variable varies considerably across the ecoseep.

7.2.2.5 Ecoseep K_6

The soils of this ecoseep are shallow, with most access tubes reaching between 20 and 40 cm below the ground surface. SM3 on Transect 1 is the only deeper monitoring point, reaching 70 cm. The ecoseep remained relatively dry throughout the monitoring period, wetting up only in September 2012, and drying out again by December 2012 (Figure 7.28). This is in contrast with many of the other ecoseeps that remained fairly wet into November, and sometimes December. According to the duration of saturation at each monitoring point over a 365-day period, most of the seep was seasonally saturated between 10 and 30 cm, with few perennially or intermittently saturated points. The only perennially saturated points were below 30 cm at SM2 on Transect 3, and the deep point at SM3 on Transect 1. The wettest soil profiles were SM2 and SM3 on both Transect 1 and 3, with Transect 1 remaining wet for slightly longer than Transect 3 (Figure 7.28).

The water levels logged in the piezometers P1 and P2 showed a similar pattern, with levels dropping in late November and December 2012 to below 1 mbgl (Figure 7.29 and Figure 7.30). The deeper soil layers at SM3 on Transect 1 remained wetter than the surface layer, possibly showing the influence of interflow that kept the deeper soils wetter (although not saturated) while the soil surface dried out. There does not seem to be a perennial subsurface water source keeping the seep soils saturated, and water levels and soil moisture seemed responsive to rainfall patterns. It is also apparent that P2 does not lie in the wettest part of the lower seep.

An inter-annual comparison of wet and dry season means was not possible for this site, as there is only one year of monitoring data.

Statistical analysis of the soil moisture data at this site was limited to the surface (L0) and shallow (L1) depth layers, due to numerous gaps in the dataset below 30 cm. The subset of six soil moisture variables selected for the PCA for K_6 separated into two groups – the one lies along PC1, which was driven by seasonal extremes (wet minimum and maximum, and dry maximum) in the 20 – 30 cm layer (L1_Wmin, L1_Wmax, and L1_Dmax) while the other group lies along PC2, which was driven primarily by the wet season variation (L0_Wsd) and dry season minimum in the top 10 cm (L0_Dmin) and the wet season variation at 20 – 30 cm (L1_Wsd) (Figure 7.31 and Table 7.5). The wet season variation in the 20 – 30 cm soil layer (L1_Wsd) was the main gradient along PC3 (Table 7.5).

There were no significant differences between seasonally, intermittently or perennially saturated monitoring points, at any depth. This was due to the predominance of seasonal saturation across all the seep, and so the statistical comparison was weak. However, an overlay of the wet season maximum at 20 – 30–cm depth (L1_Wmax) clearly shows the variation in wetness across the ecoseep (PC1) during this season (Figure 7.32).

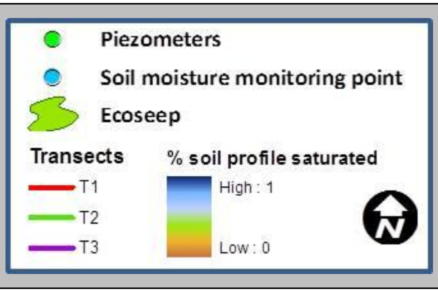
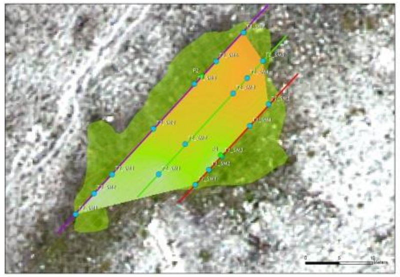
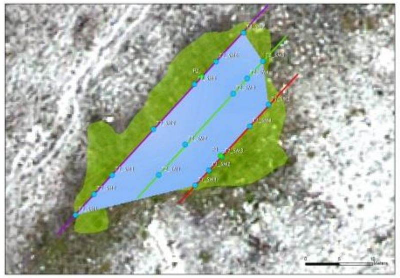
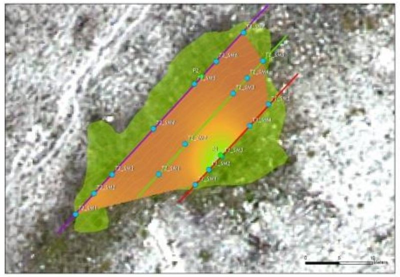
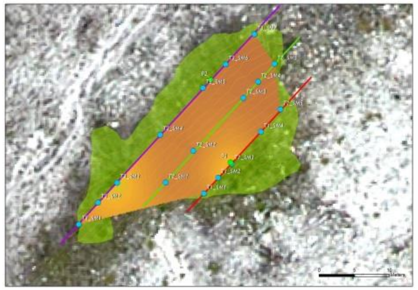
	March	June	September	December
2011				
2012				
2013				

Figure 7.28 **Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from June 2012, when monitoring commenced at K_6. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).**

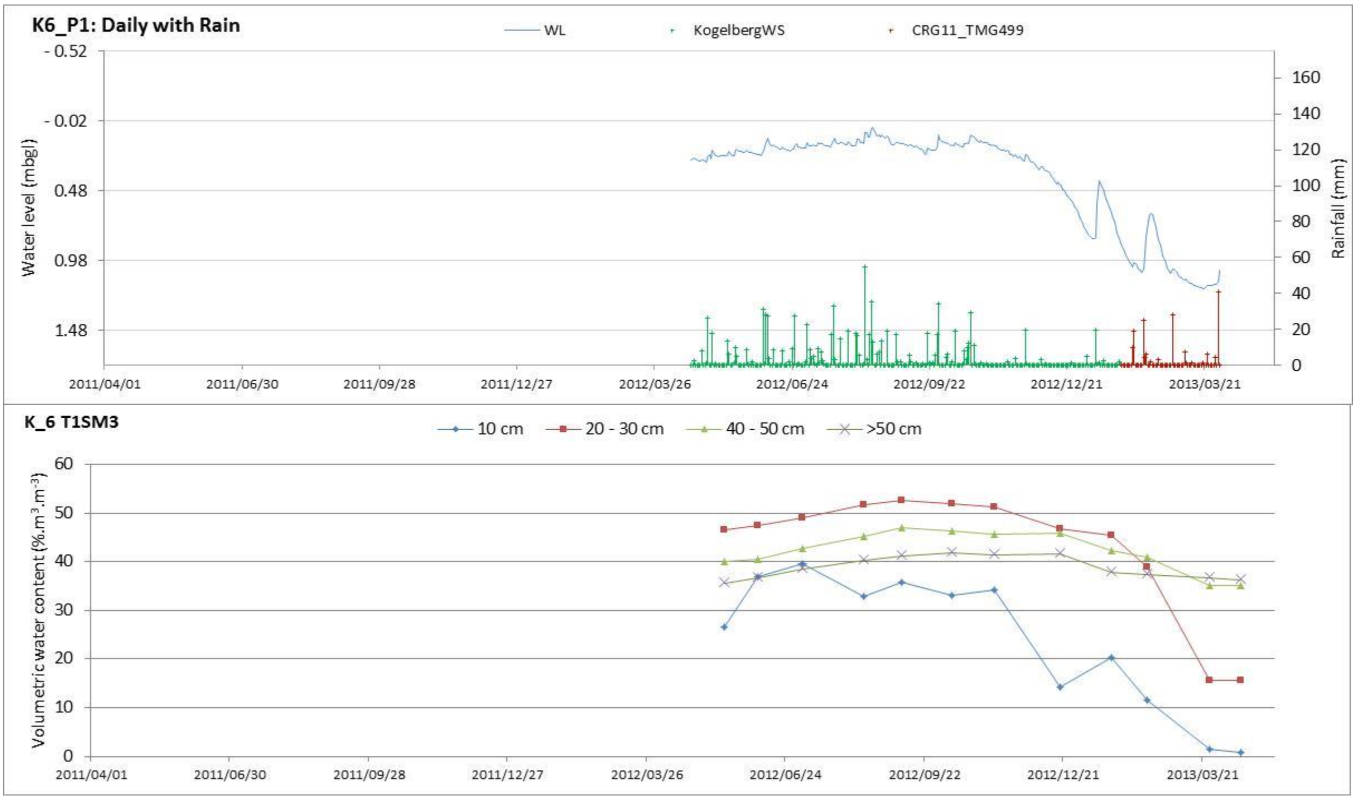


Figure 7.29 Comparison between the rainfall and groundwater level logged in P1 at K_6 (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 1.

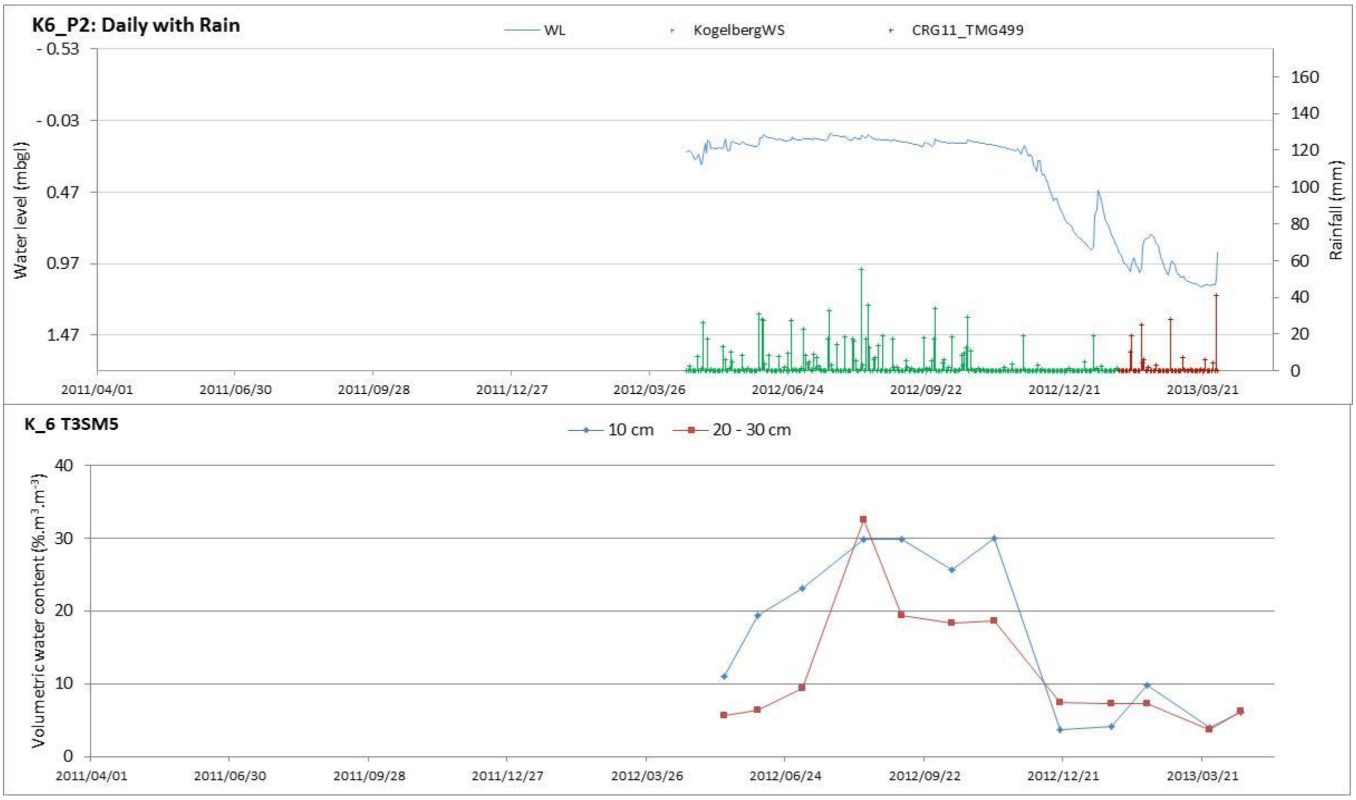


Figure 7.30 Comparison between the rainfall and groundwater level logged in P2 at K_6 (top) and the volumetric soil water content (bottom) monitored at SM5 on Transect 3.

Table 7.5 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for K_6. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (53%)	PC2 (26%)	PC3 (15%)
L0_Wsd	-0.285	**0.539**	0.379
L0_Dmin	-0.325	**0.478**	0.390
L1_Wsd	-0.194	**0.475**	**-0.778**
L1_Wmin	**-0.509**	-0.312	0.060
L1_Dmax	**-0.483**	-0.382	0.091
L1_Wmax	**-0.532**	-0.109	-0.296

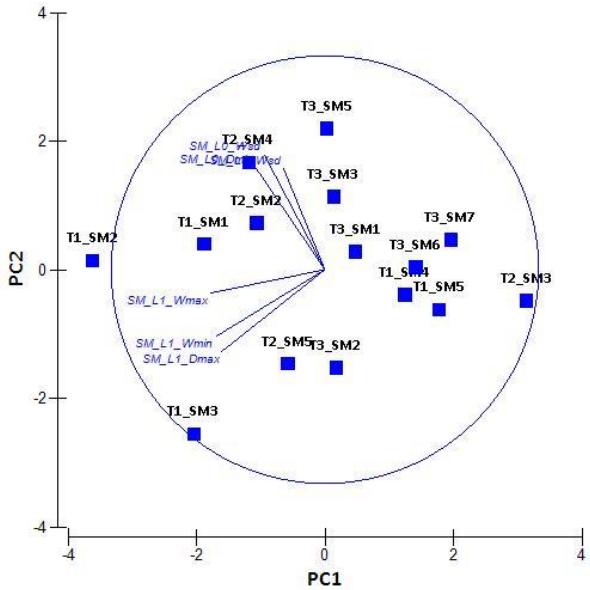


Figure 7.31 Principle Components Analysis of a subset of six soil moisture variables for K_6. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 79% of the variation).

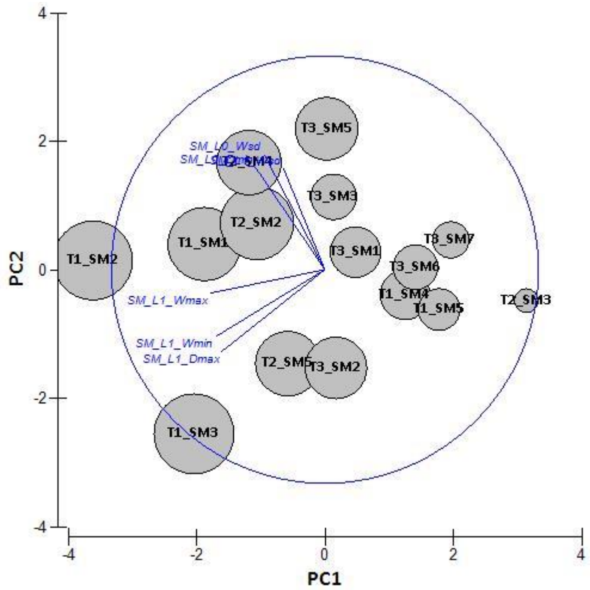


Figure 7.32 PCA of soil moisture variables at K_6, with the wet season maximum at 20 – 30 cm (L1) represented as bubbles, where the larger the bubble the higher the maximum. This variable varies considerably across the ecoseep, and shows that points along Transect 1 were wettest.

7.2.2.6 Ecoseep T3_Pal4

The soils in this ecoseep are rocky and shallow, with most access tubes reaching 30 - 40 cm, and only one, SM2 on Transect 3, reaching 90 cm. On Transects 1 and 3 some points remained close to saturation throughout the year, especially those situated at the start of each transect (i.e. SM1, SM2 and SM3), close to the stream to the north of the seep. The northern side of the seep remained constantly wetter than the remainder of the seep during the latter half of 2012, and into March 2013 (Figure 7.33).

This ecoseep is likely to be fed by groundwater from the Skurweberg Formation, and it may be that the groundwater emerges in the top northern portion of the site, keeping these parts of the ecoseep wet, and seeping as interflow to the lower portions of the seep along the northern edge of the seep and into the adjacent stream. The remainder of the seep remained fairly dry throughout the monitoring period (Figure 7.33).

The groundwater level data from P1 and P2 corroborated this observation – water levels logged at P1 remained within approximately 0.2 m of the ground surface with little variation (Figure 7.34), while those in P2 were generally below 0.8 mbgl and showed a distinctly seasonal pattern (Figure 7.35). Similarly, the soil moisture monitoring point close to P1 (SM1 on Transect 1) showed more constant VWC below 30 cm, with the shallower layers being more variable and wetter than the deeper layers during winter. At SM1 on Transect 3, close to P2, the deeper layers were always wetter than the shallower layers, and more constantly so.

Across the whole seep, mean soil moisture increased substantially with depth, and the seep showed a consistent increase in wetness between years at all soil depths (Figure 7.36).

Statistical analysis of the soil moisture data at this site was limited to the surface (L0) and shallow (L1) depth layers, due to numerous gaps in the data measured below 30 cm. The PCA of a subset of five soil moisture variables showed that 95% of the variation between the monitoring points was explained by the first three axes (Table 7.6 and Figure 7.37). On PC1, the driving variables were all from the top 10 cm of soil (L0) – maxima for the wet and dry seasons (L0_Wmax, L0_Dmax), and also the variation in soil moisture over the wet season (L0_Wsd). On PC2, the driving variable was clearly the dry season variation in the 20 – 30-cm layer (L1_Dsd), and on PC3, it was the wet season variation in the same layer (L1_Wsd).

Overlays of the wet season maximum in L0, the variable with the highest Eigenvalue along PC1, and the dry season variation in L1, the highest Eigenvalue along PC2, illustrate the gradients of these variables across the site (Figure 7.38).

Significant differences ($p \leq 0.05$) were found between seasonal and intermittent points in the top 10 cm of soil (L0), and between seasonal and intermittent points at 20 – 30 cm (L1), with the most significant differences being at 20 – 30 cm (Figure 7.39. The three hydroperiod classes separated diagonally along a gradient of wet season variation at this depth (i.e. PC3 in Table 7.6), as illustrated in Figure 7.40.

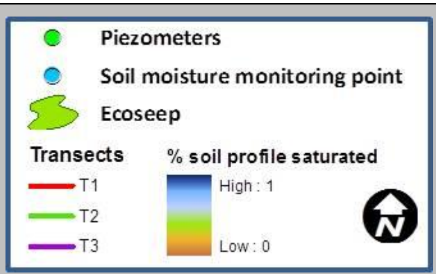
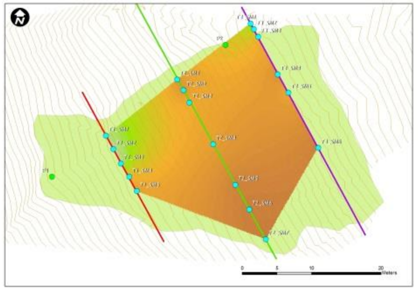
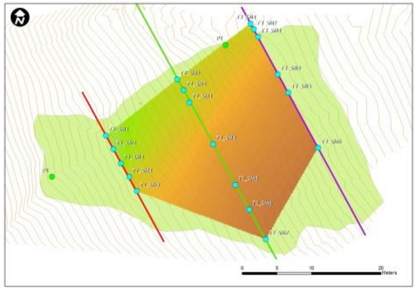
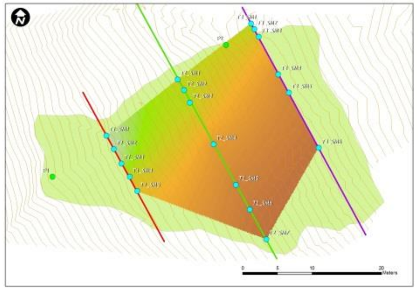
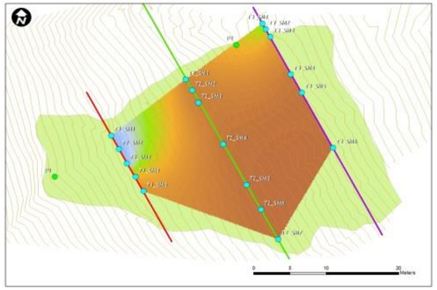
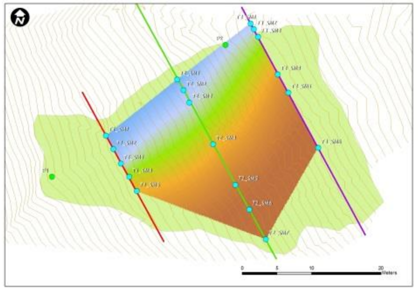
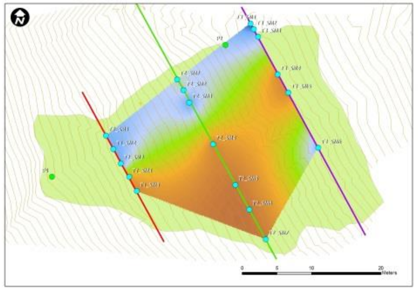
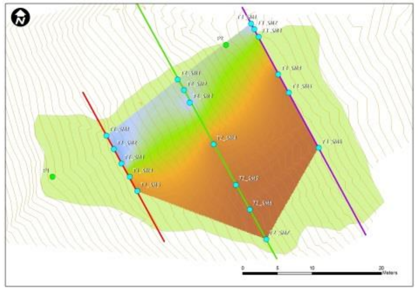
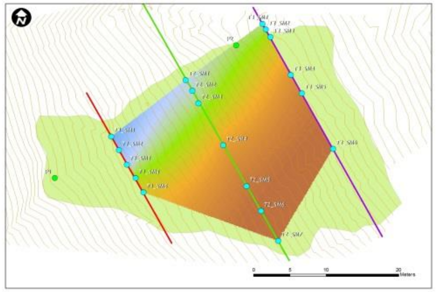
	March	June	September	December
2011				
2012				
2013				

Figure 7.33 Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at T3_Pal4. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).

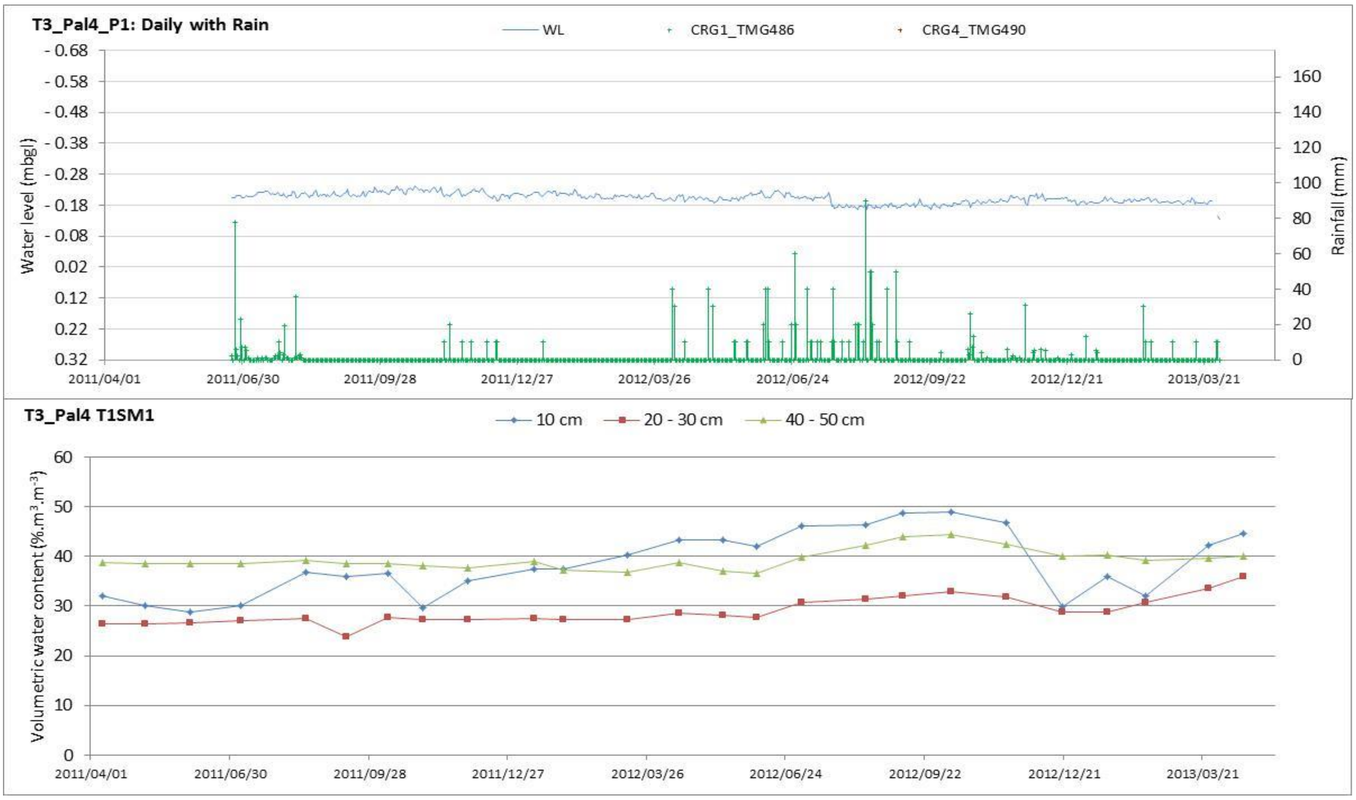


Figure 7.34 Comparison between the rainfall and groundwater level logged in P1 at T3_Pal4 (top) and the volumetric soil water content (bottom) monitored at SM1 on Transect 1.

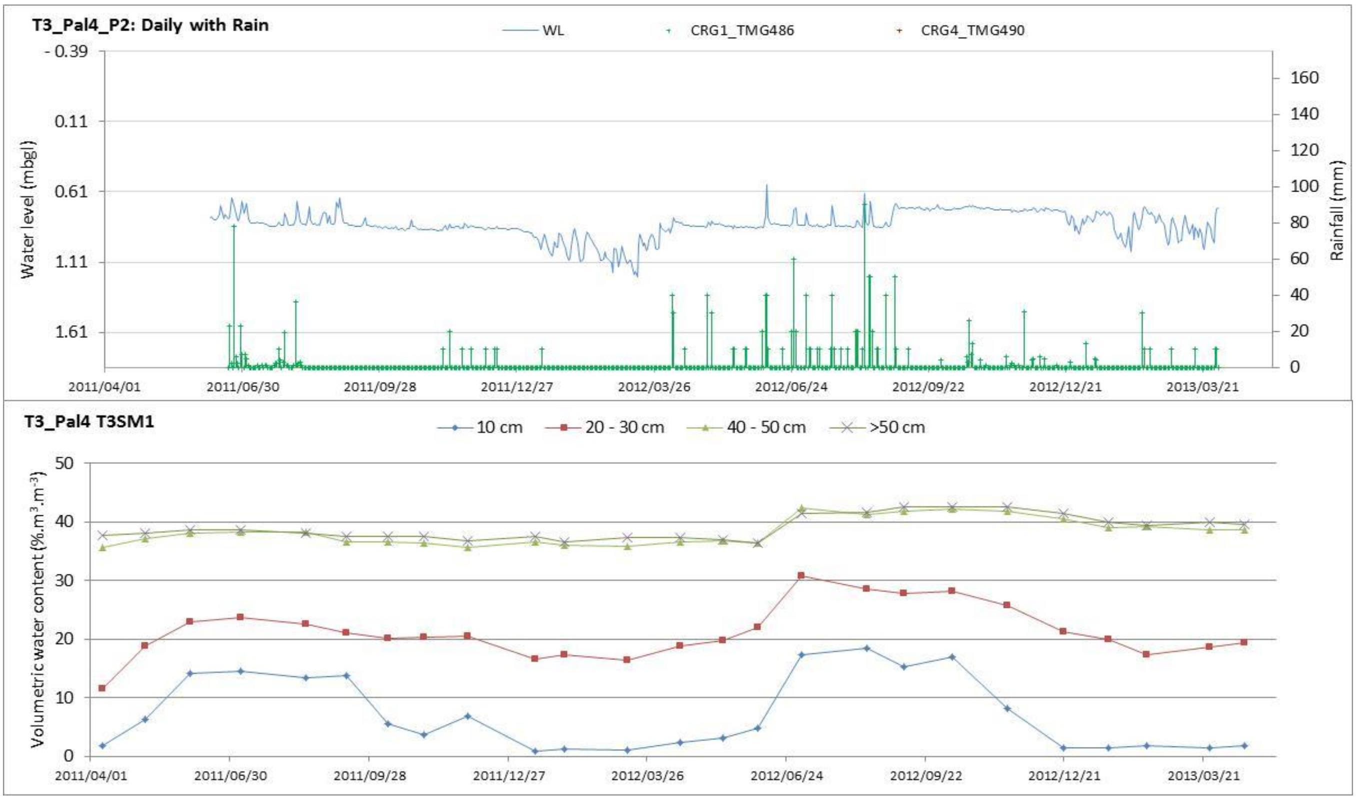


Figure 7.35 Comparison between the rainfall and groundwater level logged in P2 at T3_Pal4 (top) and the volumetric soil water content (bottom) monitored at SM1 on Transect 3.

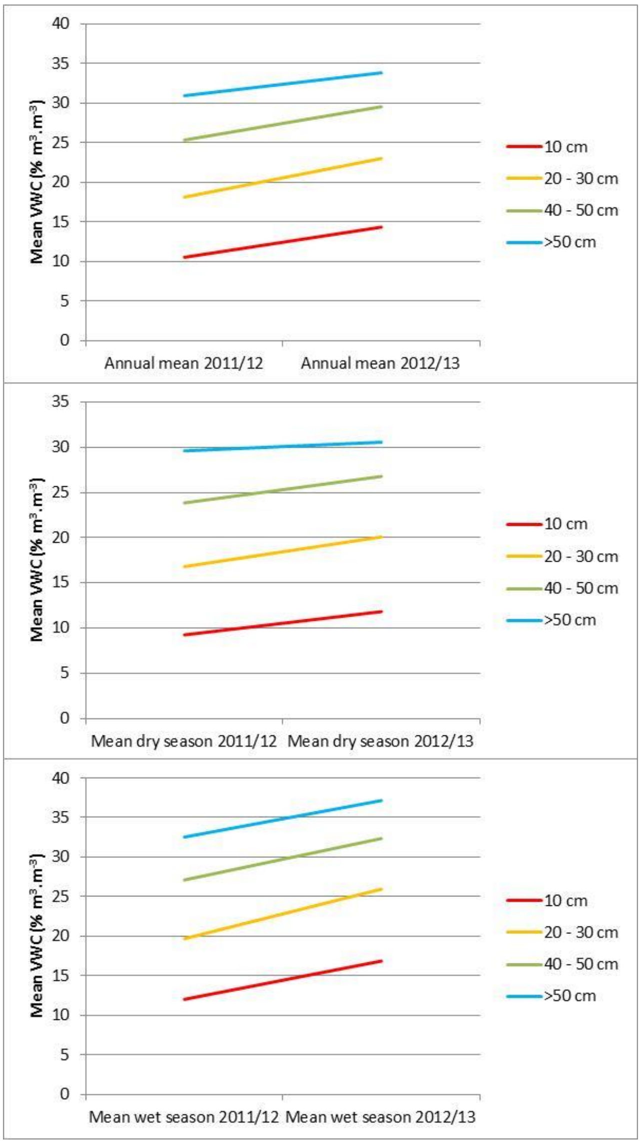


Figure 7.36 **Mean volumetric water content (VWC) averaged across T3_Pal4 and all soil depths, and expressed as annual means, and dry season and wet season means, for 2011/12 and 2012/13.**

Table 7.6 **The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for T3_Pal4. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.**

Variable	PC1 (60%)	PC2 (20%)	PC3 (15%)
L0_Wsd	**-0.520**	0.224	-0.324
L0_Dmax	**-0.504**	-0.377	-0.090
L0_Wmax	**-0.543**	-0.086	-0.28
L1_Dsd	0.250	**-0.852**	-0.288
L1_Wsd	0.345	0.271	**-0.852**

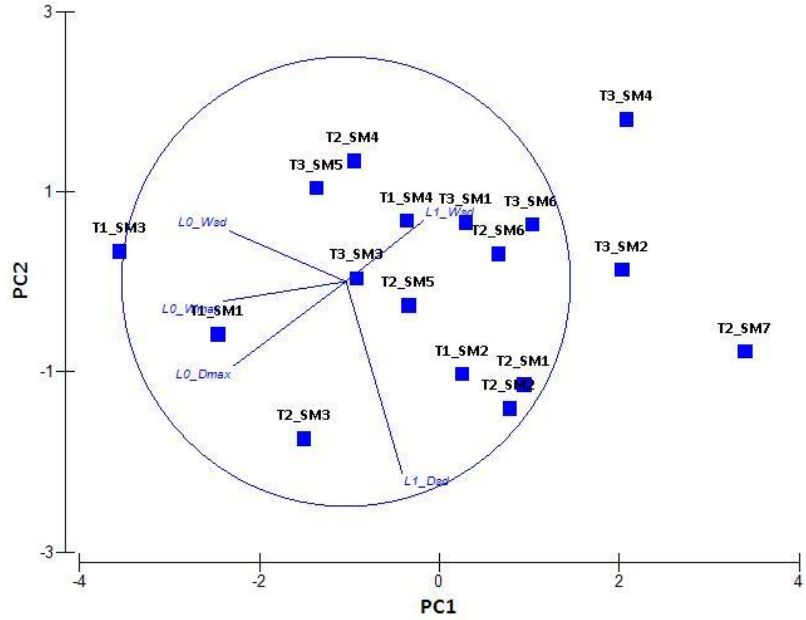


Figure 7.37 Principle Components Analysis of a subset of five soil moisture variables for T3_Pal4. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 80% of the variation).

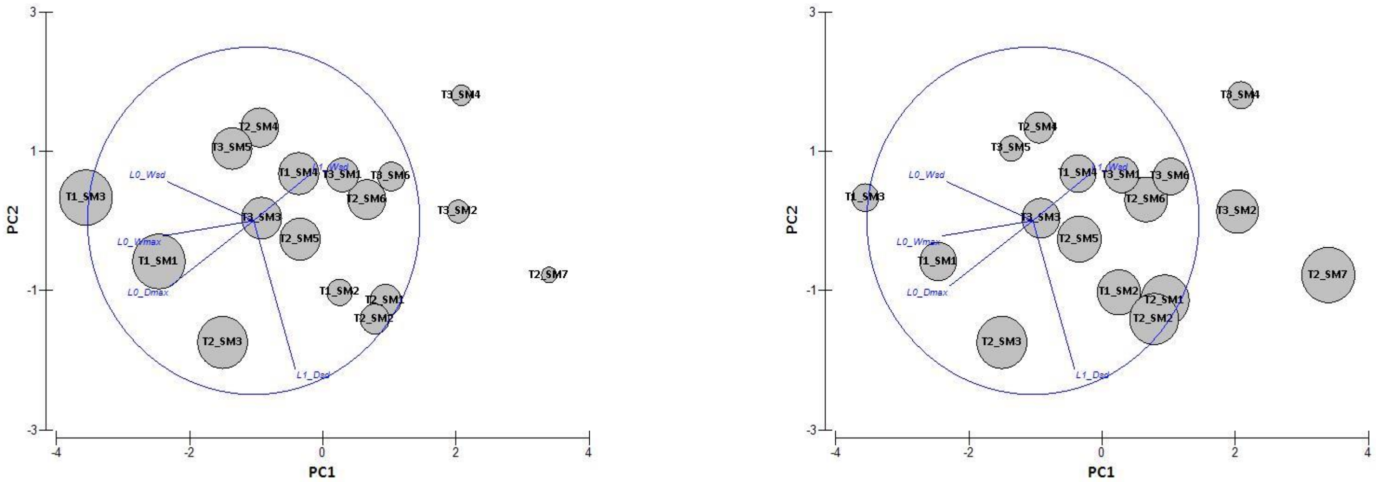


Figure 7.38 PCA of soil moisture variables at T3_Pal4, with the wet season maximum at 10 cm (L0) (left) and the dry season variation at 20 – 30 cm (L1) (right) overlain as bubbles, where the larger the bubble the higher the variable. These two variables returned the highest Eigenvalues on PC1 and PC2, respectively.

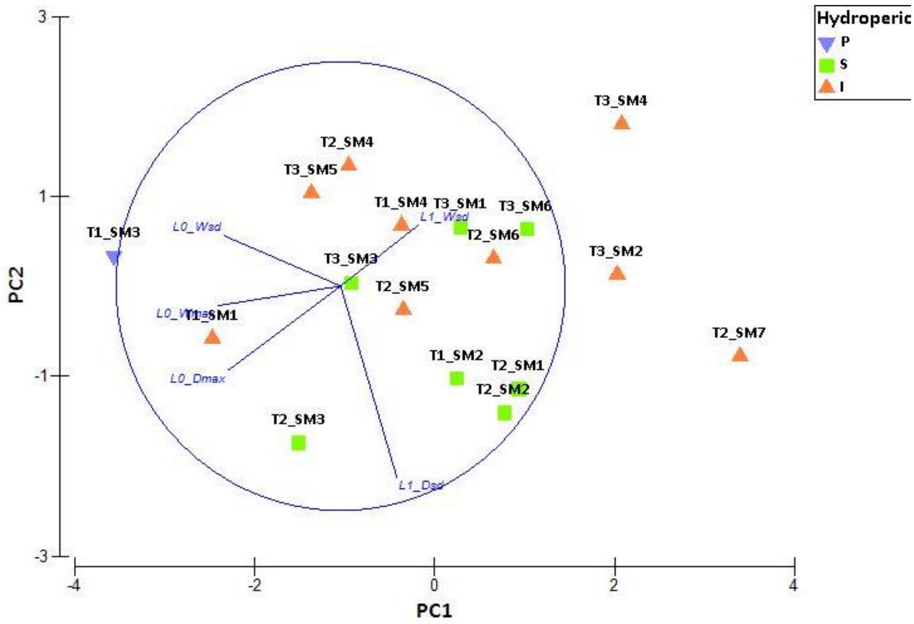


Figure 7.39 PCA of soil moisture variables at T3_Pal4, with the hydroperiod classes in soils 20 – 30 cm below ground shown as symbols.

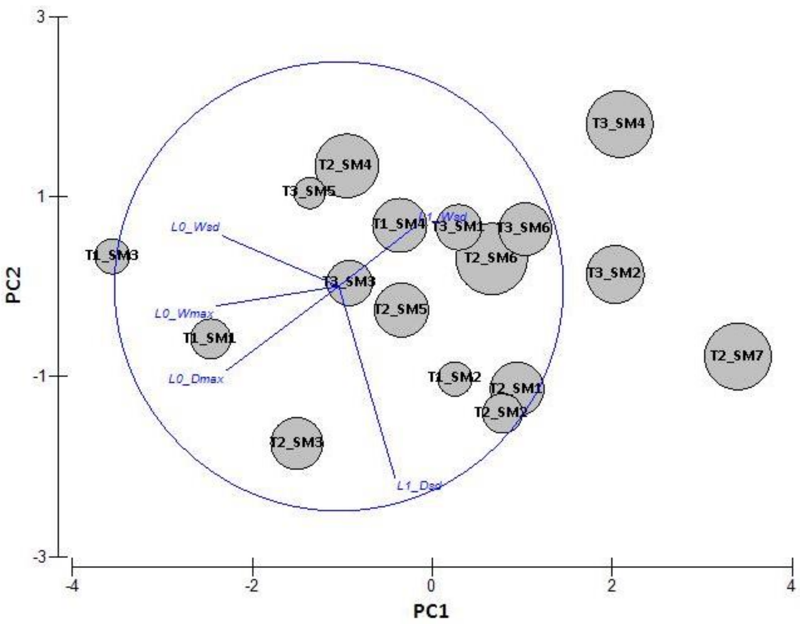


Figure 7.40 PCA of soil moisture variables at T3_Pal4, with the wet season variation at 20 – 30 cm (L1) shown as bubbles, where the larger the bubble the higher the variation.

7.2.2.7 Ecoseep T6_1b

The soil moisture access tubes at T6_1b range from 10 to 70 cm deep, but just over half the tubes are at depths shallower than 40 cm. During the drier months (illustrated by March 2012 and March 2013 (Figure 7.41) the seep had a distinctly wetter core, which extended across the middle of Transects 1 and 2, at SM2, SM3 and SM4 (Figure 7.41). The seep became uniformly wet during the late winter/early spring months of September in both 2011 and 2012.

The wetter core remained wet throughout the year, especially at 20 to 50 cm, as can be seen at SM3 on Transect 1 (Figure 7.42). Soil moisture in the top 10 cm was variable at this monitoring point, and appeared to respond directly to rainfall patterns. The water levels logged at P1 close to SM3 on Transect 1 showed a distinctly seasonal pattern, with levels hovering around 0.3 to 0.4 mbgl for most of the year, but dropping lower in December of each year (Figure 7.42).

P2, which lies close to SM3 on Transect 2, showed a different pattern in 2011 *versus* 2012 (Figure 7.43). In 2011, water level dropped to almost 1.3 mbgl, but did not drop at all in 2012. There was a substantial difference in the rainfall between years, but this should be read with caution, as these data were extracted from two different rainfall gauges. However, it is clear that the seep was definitely wetter in 2012/2013 than in 2011/2012 (Figure 7.41 and Figure 7.44). The shallow soil (top 10 cm) showed a steeper increase in soil moisture between years than did the deeper soils. This may be evidence of a more constant, deep source of water here.

This seep is likely to be fed by groundwater from the Peninsula Aquifer, which probably emerges in the top and middle portions of the site and then flows under the rocky area crossed by Transect 3 (see Volume 1: Monitoring Framework and Protocol for a full description of the site). The surface soils respond to rainfall, while the deeper soils below 10 cm are fed by a more constant flow of subsurface water.

Statistical analysis of the soil moisture data at this site was limited to the surface (L0) and shallow (20 – 30 cm) depth layers, due to numerous gaps in the data measured below 30 cm. A PCA of a subset of five soil moisture variables showed that the first three axes explained 77% of the variation between points (Table 7.7 and Figure 7.45). PC1 was driven primarily by the duration of saturation at 20 – 30 cm (L1_Sat$_{dur}$), followed by the wet season minimum (L1_Wmin) and wet season variation at the same depth (L1_Wsd) (Table 7.7). PC2 was driven by the dry season variation in the shallow soils (L1_Dsd), and the wet season variation in the top 10 cm (L0_Wsd). PC3 was also strongly driven by the latter variable (Table 7.7).

Table 7.7 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for T6_1b. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (50%)	PC2 (27%)	PC3 (16%)
L0_Wsd	-0.025	**0.649**	**0.713**
L1_Satdur	**0.619**	-0.053	0.106
L1_Dsd	-0.091	**-0.730**	0.488
L1_Wsd	**-0.517**	-0.139	0.371
L1_Wmin	**0.583**	-0.153	0.323

Significant differences ($p \leq 0.05$) were found between intermittently and perennially saturated points at 20 – 30 cm (L1) (Figure 7.46), which separated along a gradient of wet season minimum at this depth (Figure 7.47).

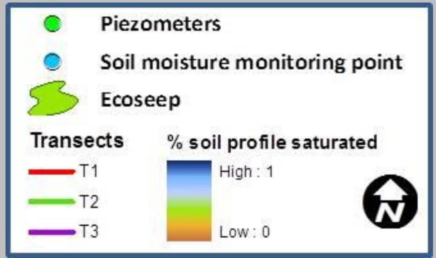
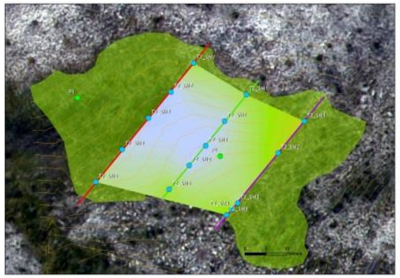
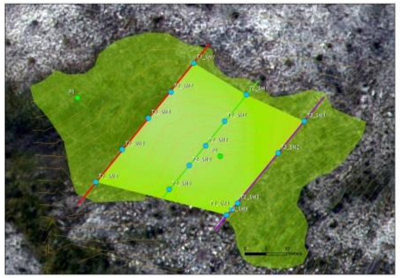
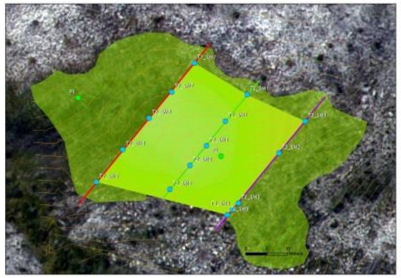
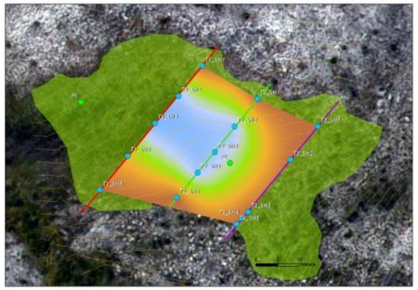
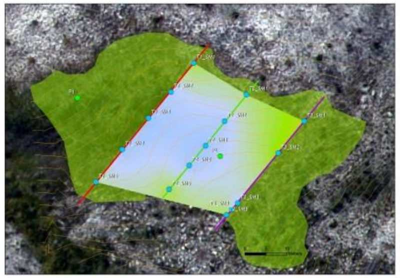
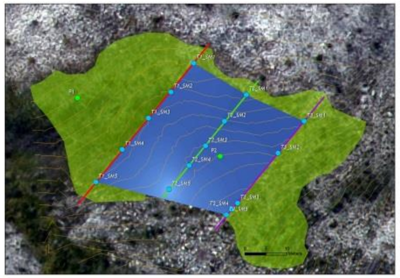
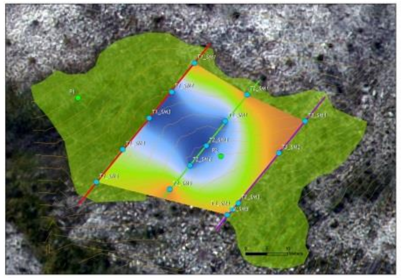
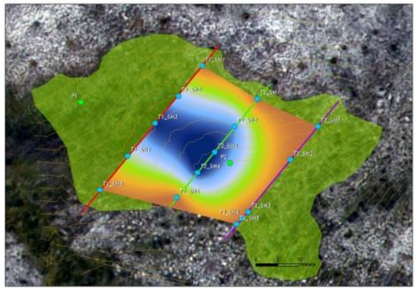
	March	June	September	December
2011				
2012				
2013				

Figure 7.41 Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at T6_1b. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).

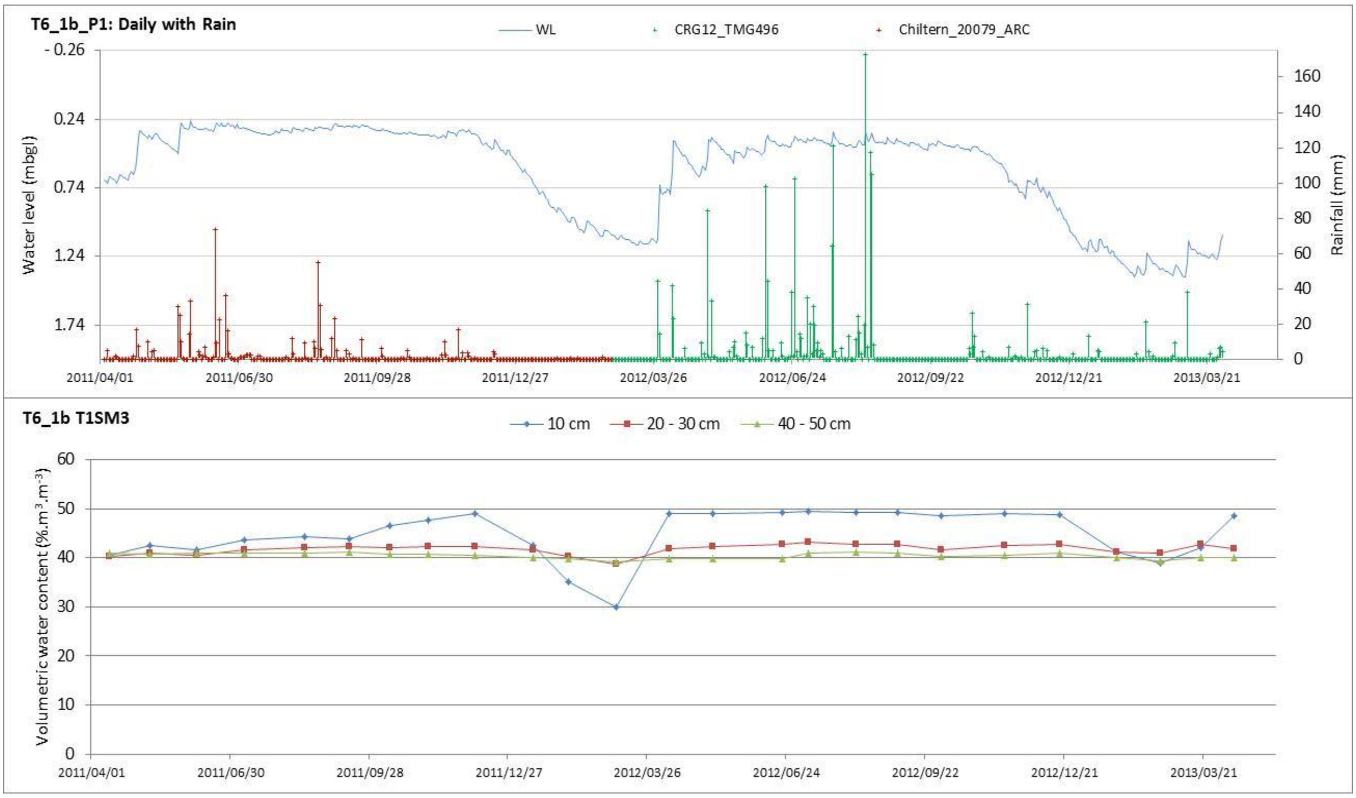


Figure 7.42 Comparison between the rainfall and groundwater level logged in P1 at T6_1b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 1.

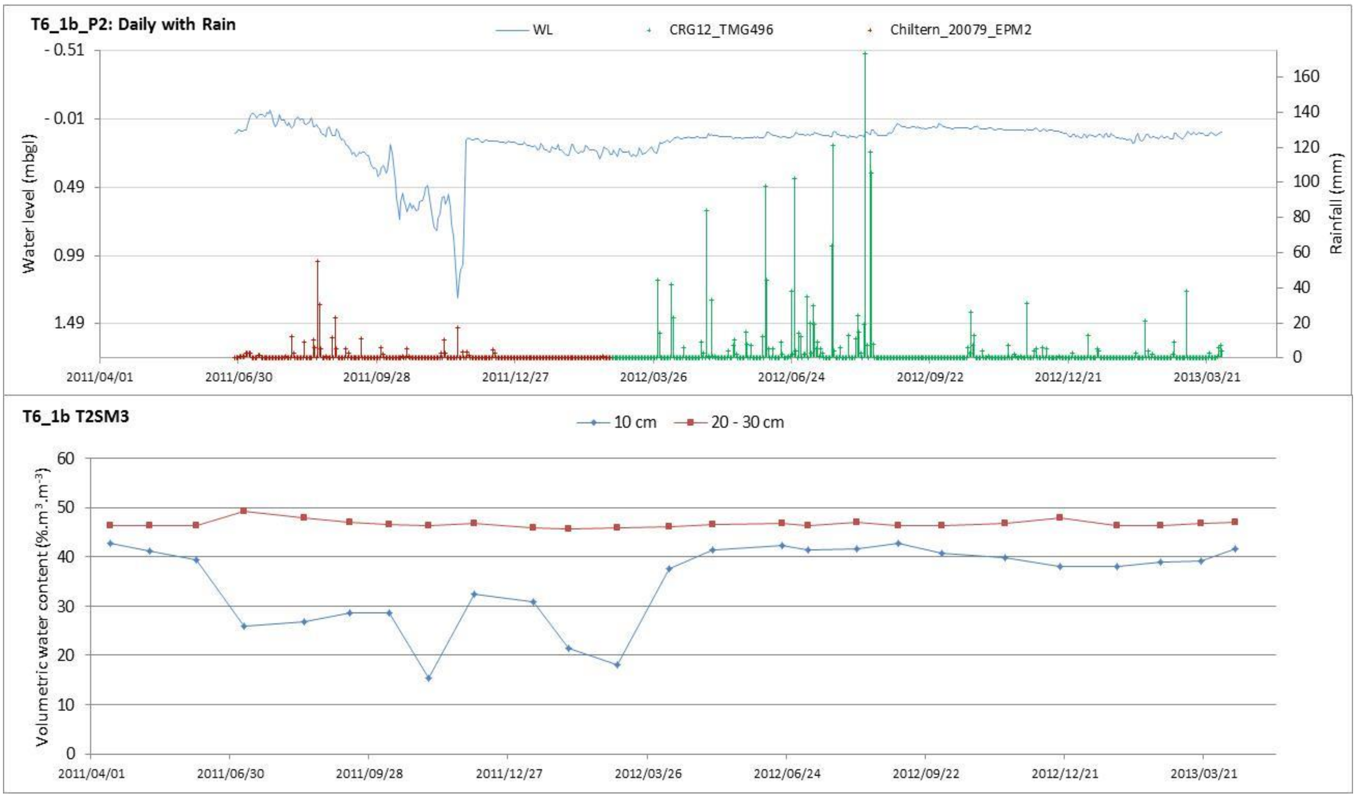


Figure 7.43 Comparison between the rainfall and groundwater level logged in P2 at T6_1b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 2.

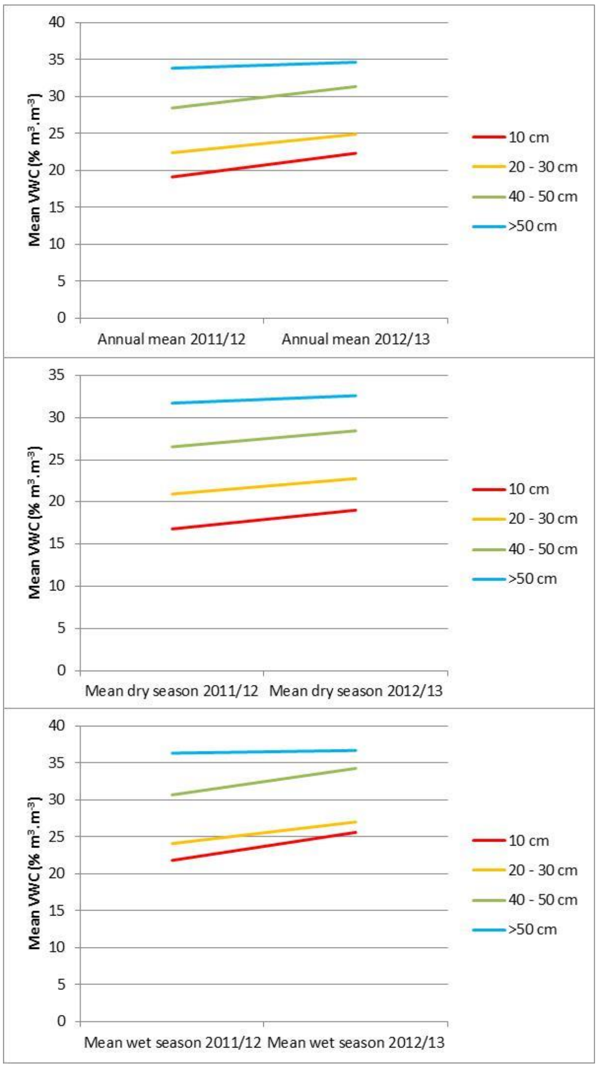


Figure 7.44 Mean volumetric water content (VWC) averaged across T6_1b and all soil depths, and expressed as annual means, and dry season and wet season means, for 2011/12 and 2012/13.

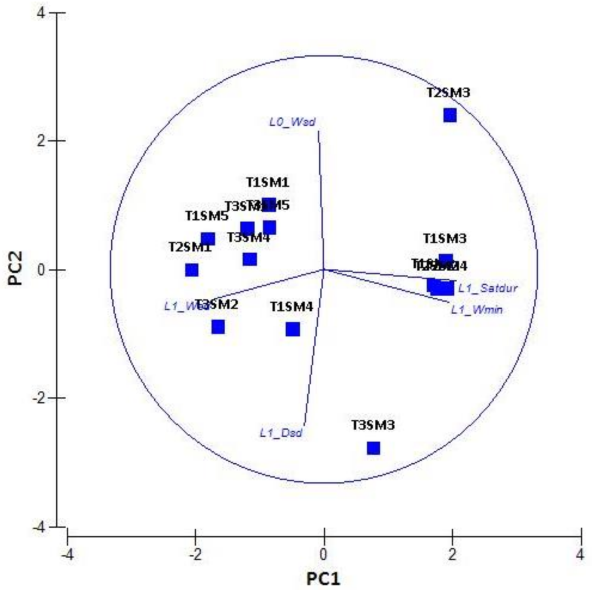


Figure 7.45 Principle Components Analysis of a subset of five soil moisture variables for T6_1b. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 77% of the variation).

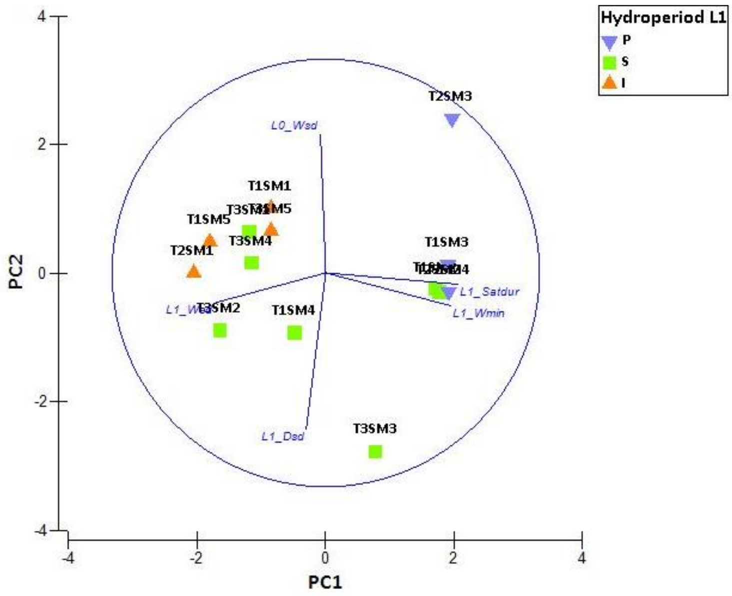


Figure 7.46 PCA of soil moisture variables at T6_1b, with the hydroperiod classes in soils 20 – 30 cm below ground (L1) shown as symbols.

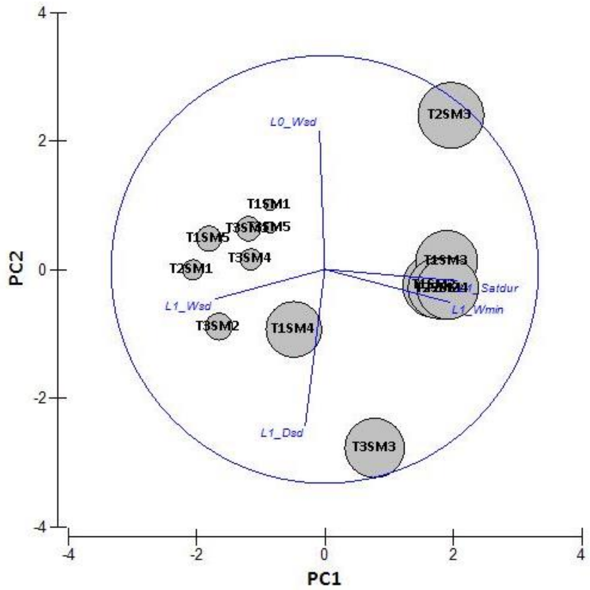


Figure 7.47 PCA of soil moisture variables at T6_1b, with wet season minimum at 20 – 30 cm (L1) overlain as bubbles, where the smaller the bubble the lower the minimum. This variable accounted for the separation between soils in the three hydroperiod classes represented at this depth.

7.2.2.8 Ecoseep T6_4

The soils at T6_4 are mostly shallow, especially along Transects 1 and 2. Most access tubes on these transects are 30 cm and less, while a few points on Transect 3 reach below 40 cm. Each transect has some moisture monitoring points that remained at or close to saturation through the monitoring period, and these are generally located towards the middle and western portions of the seep (Figure 7.48). The seep dried out from its eastern edge during the dry season leaving a wetter portion along the western edge. The monitoring points across the ecoseep were either seasonally or perennially saturated with only one point intermittently saturated.

Both piezometers at this site recorded perennial saturation close to the ground surface, with little fluctuation in water levels (Section 3.1). This site is likely to be fed by the Peninsula Aquifer, and subsurface water emerges in two distinct places – in the upper portion of the site above Transect 1, and in the lower portion of the site above Transect 3 (see Volume 1: Monitoring Framework and Protocol for a full description of the site). The soil moisture probes close to the piezometers gave evidence of this – on Transect 1, SM3 was constantly wet throughout the monitoring period, at all depths (Figure 7.49), and on Transect 3, SM4 was also constantly wet below 10 cm, while moisture in the top 10 cm was more variable (Figure 7.50). Soil moisture at the latter monitoring point was variable in the top 10 cm in 2011/12, drying out from September 2011 during a period of low rainfall, but was constantly wet in 2012/13 (Figure 7.50).

The ecoseep was wetter overall in 2011/12 *versus* 2012/13, in both the wet and dry seasons (Figure 7.51). The increase was consistent at all depths, but the 40 – 50-cm depth category was the wettest layer, especially during the dry season. A clay layer was encountered at approximately 50 cm below ground level when auguring the soil moisture monitoring points and this may lead to the retention of water just above it. In the dry season, there was little difference between the other soil depth categories, and in the wet season the two shallower depth categories were distinct from the two deeper categories (Figure 7.51). This suggests that the seep dries out fairly uniformly, but in the wet season, the moisture lies predominantly in the deeper soils. Once again, this is an indication of a deep source of water that keeps the seep wet at depth, while the moisture in the surface layers fluctuate with rainfall.

Statistical analysis of the soil moisture data at this site was limited to the surface (L0) and shallow (20 – 30 cm) depth layers, due to numerous gaps in the data measured below 30 cm. A PCA of a subset of five soil moisture variables showed that the first three axes explained 79% of the variation between points (Table 7.8 and Figure 7.52). PC1 was driven by the wet and dry season variation in the top 10 cm (L0_Dsd, L0_Wsd), PC2 by the duration of saturation at 20 – 30 cm ($L1\_Sat_{dur}$), and PC3 by the wet season minimum in the top 10 cm (L0_Wmin).

Table 7.8 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for T6_4. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (48%)	PC2 (31%)	PC3 (16%)
L0_Dsd	**0.499**	0.401	-0.302
L0_Wsd	**0.496**	0.473	0.004
L0_Wmin	-0.449	0.064	**-0.786**
L1_Satdur	-0.338	**0.659**	-0.083
L1_Dsd	0.435	-0.421	-0.534

There were significant differences ($p \leq 0.05$) between monitoring points assigned to different hydroperiod classes in the top 10 cm and at 20 – 30 cm. The difference between the points at 20 – 30-cm depth was greater, with points separating along a gradient of dry season variation at this depth as illustrated in Figure 7.53 and Figure 7.54.

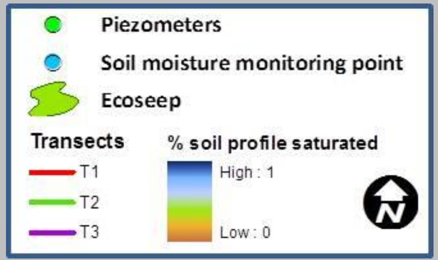
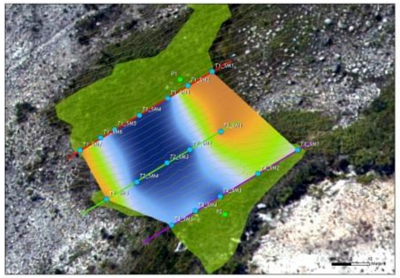
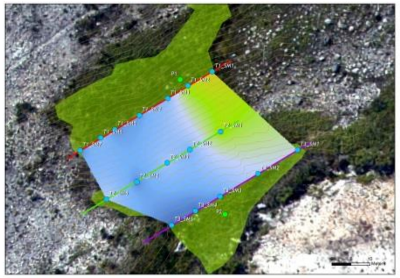
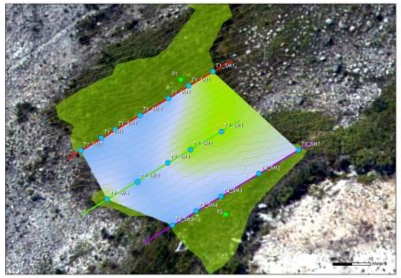
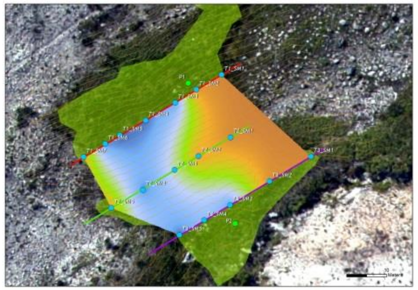
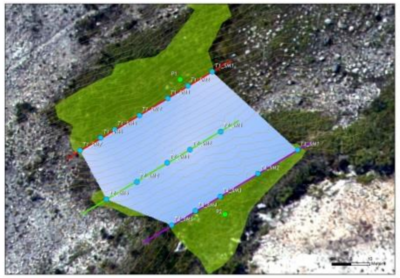
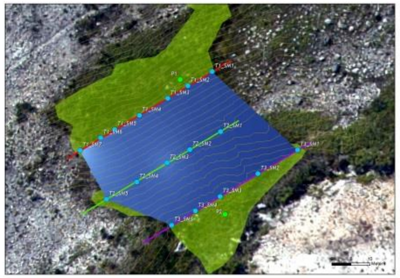
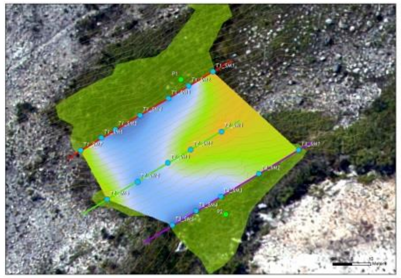
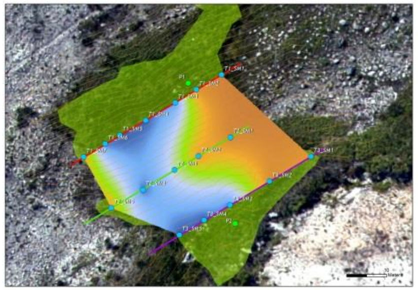
	March	June	September	December
2011				
2012				
2013				

Figure 7.48 Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at T6_4. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).

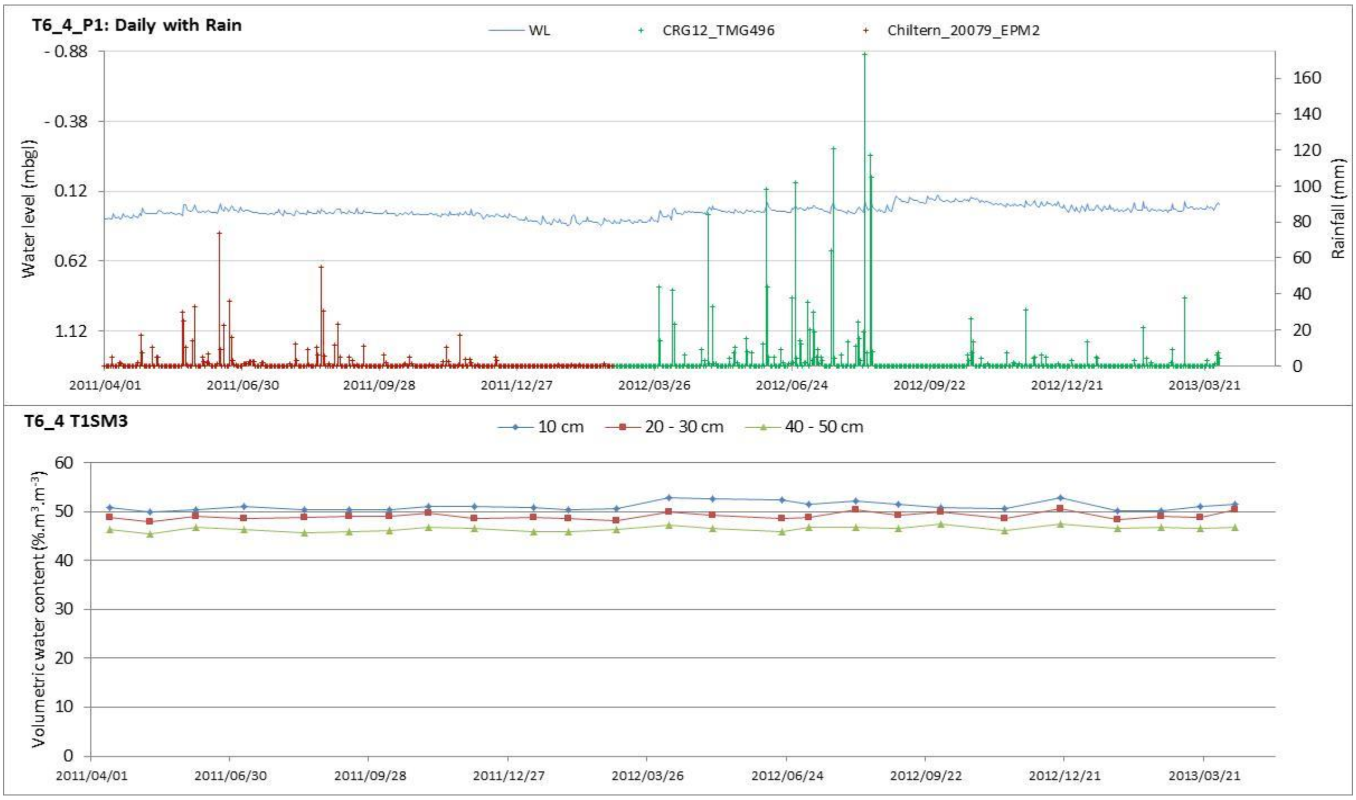


Figure 7.49 Comparison between the rainfall and groundwater level logged in P1 at T6_4 (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 1.

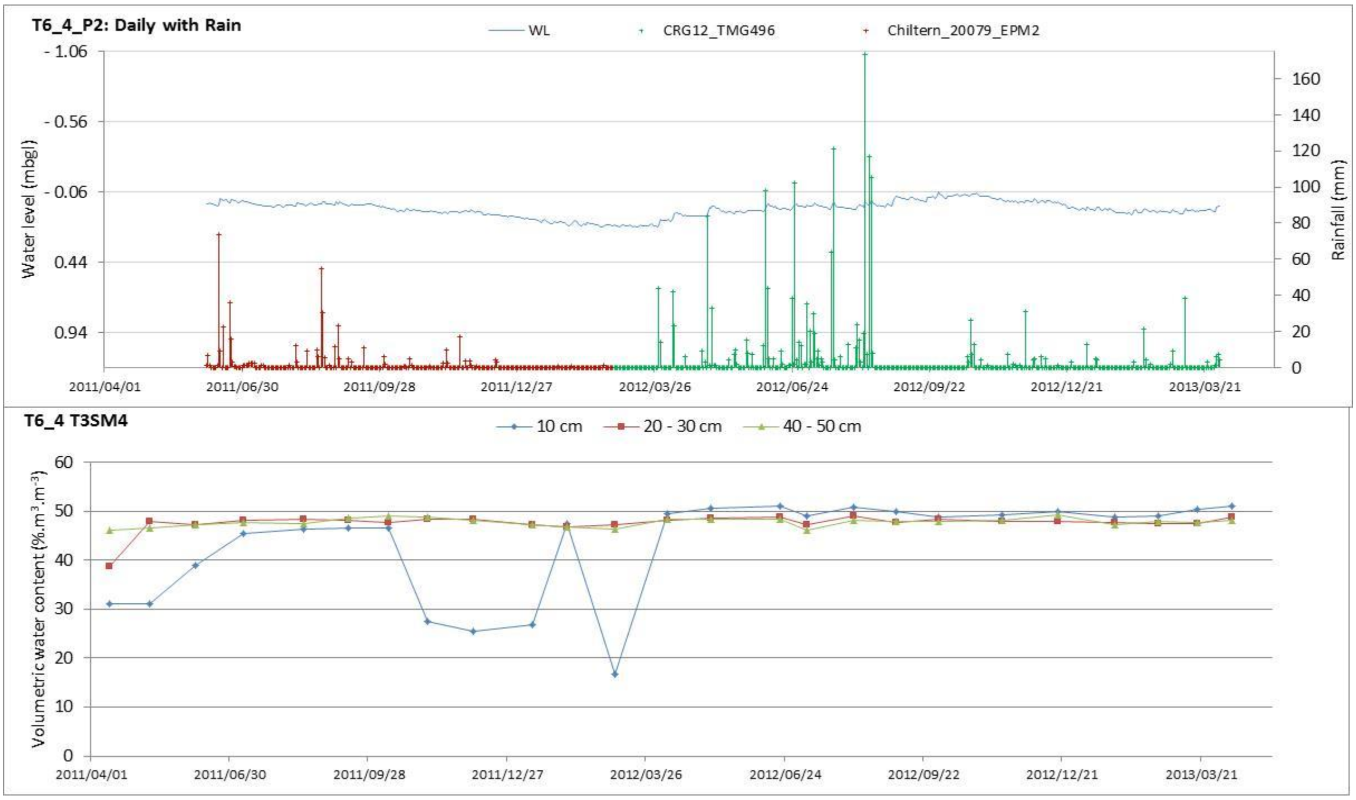


Figure 7.50 Comparison between the rainfall and groundwater level logged in P2 at T6_4 (top) and the volumetric soil water content (bottom) monitored at SM4 on Transect 3.

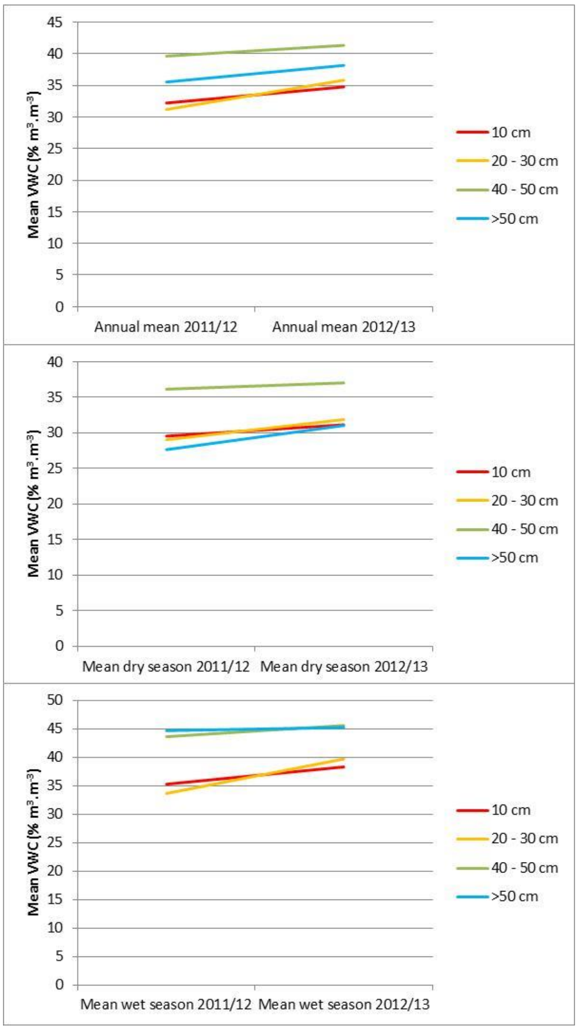


Figure 7.51 Mean volumetric water content (VWC) averaged across T6_4 and all soil depths, and expressed as annual means, and dry season and wet season means, for 2011/12 and 2012/13.

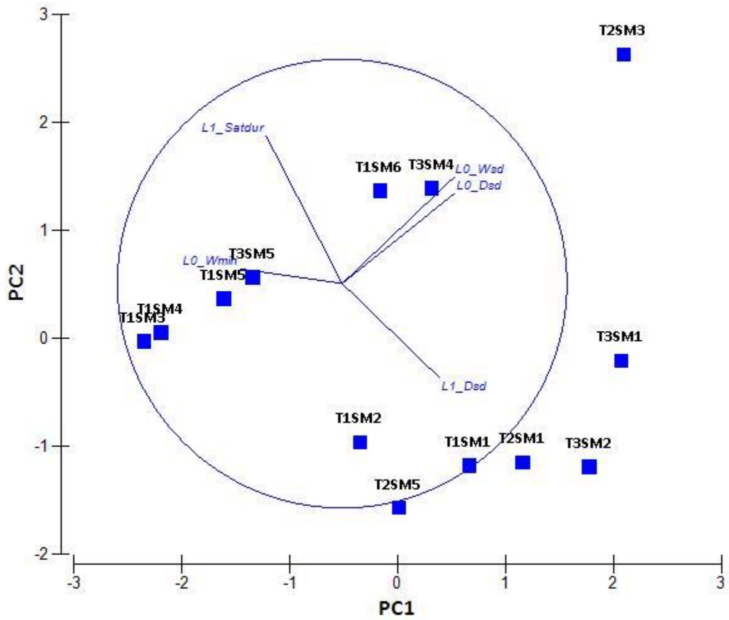


Figure 7.52 Principle Components Analysis of a subset of five soil moisture variables for T6_4. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 79% of the variation).

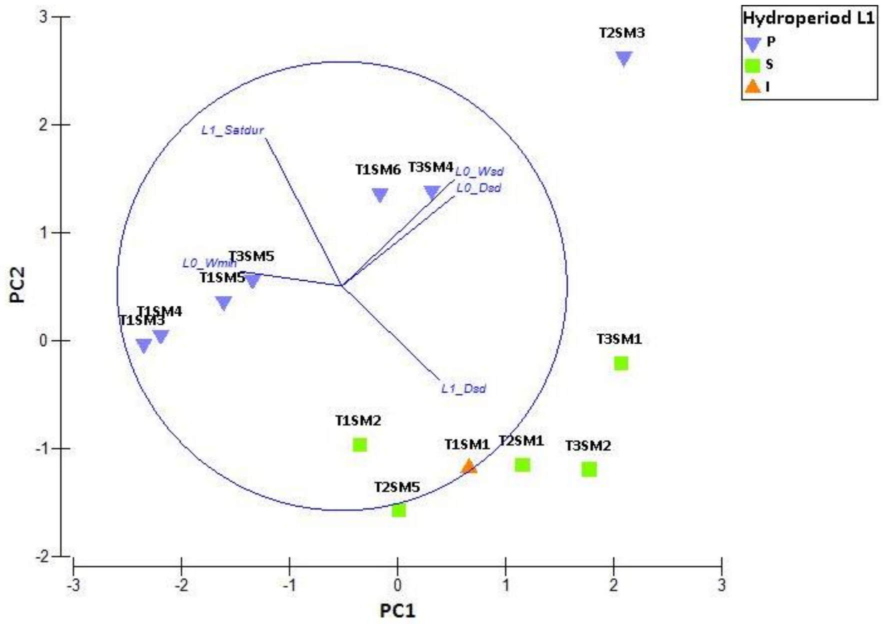


Figure 7.53 PCA of soil moisture variables at T6_4, with the hydroperiod classes in soils 20 – 30 cm below ground (L1) shown as symbols.

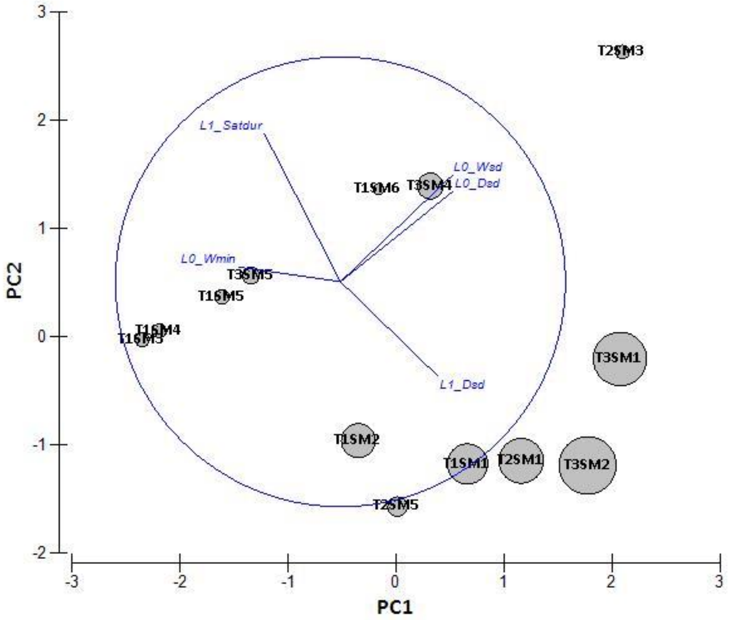


Figure 7.54 PCA of soil moisture variables at T6_4, with the dry season variation at 20 – 30 cm (L1) shown as bubbles, where the larger the bubble the greater the variation.

7.2.2.9 Ecoseep T8_2b

With the exception of Transect 2, all of the soil moisture access tubes reach between 20 and 50 cm depth. The terrain here is fairly fractured. With the exception of SM4 on Transect 3, none of the soil moisture monitoring points remained saturated throughout the year, but dried out towards March of each year (Figure 7.55). Transect 1 was drier than the other two transects – and indeed this is shown in the piezometer data, where water levels at P1 remained low (always below 0.9 mbgl) throughout most of the monitoring period (Figure 7.56). The closest soil moisture monitoring point, SM2 on Transect 1, showed that the soils remained fairly dry throughout EPM2, with the topsoil being slightly wetter than the 20 – 30-cm depth category.

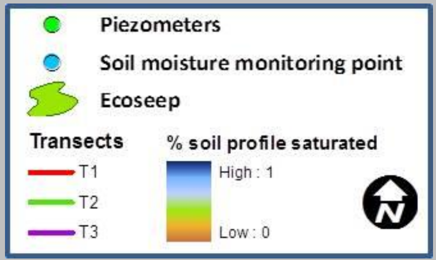
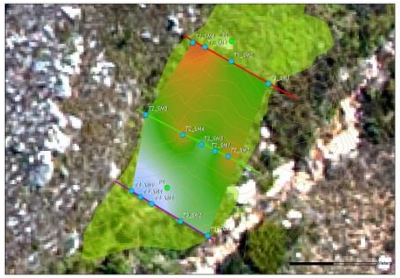
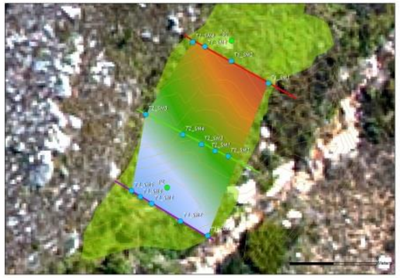
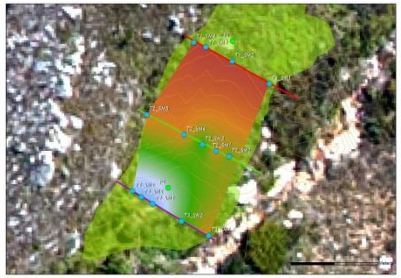
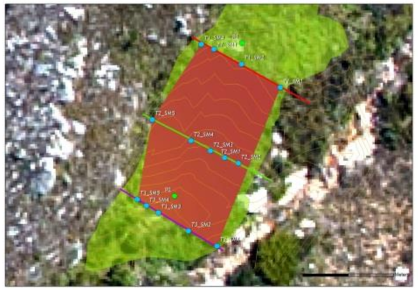
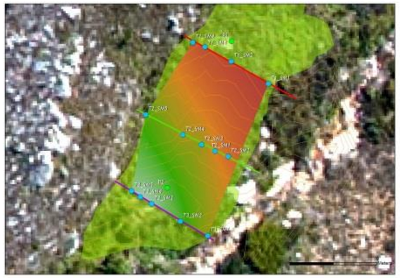
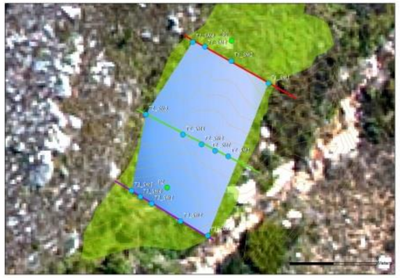
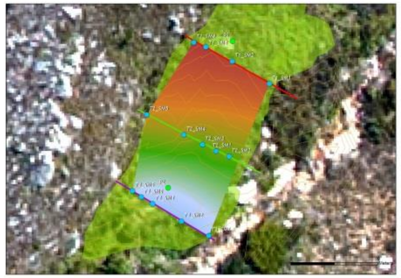
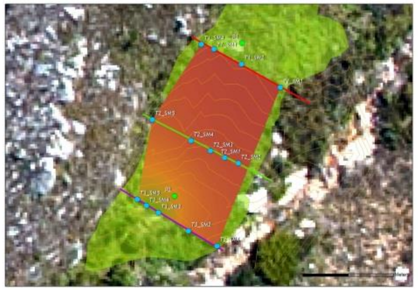
	March	June	September	December
2011				
2012				
2013				

Figure 7.55 Seasonal and annual shifts in the % of the soil profile that was saturated (degree of saturation > 0.90) in four months of the year from the start of monitoring at T8_2b. Soil saturation data were interpolated between the soil moisture monitoring points using Kriging. % saturation ranges from 0 to 1 (100%).

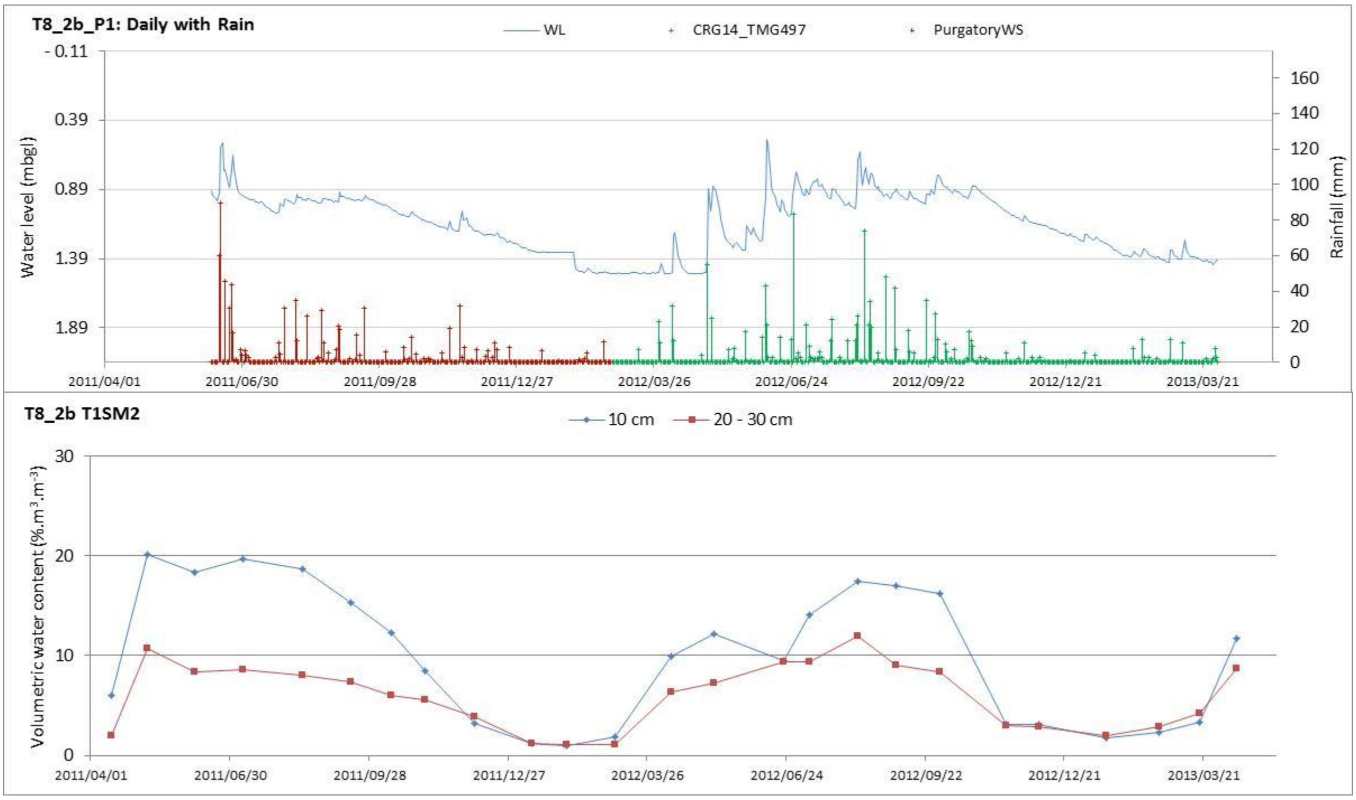


Figure 7.56 Comparison between the rainfall and groundwater level logged in P1 at T8_2b (top) and the volumetric soil water content (bottom) monitored at SM2 on Transect 1.

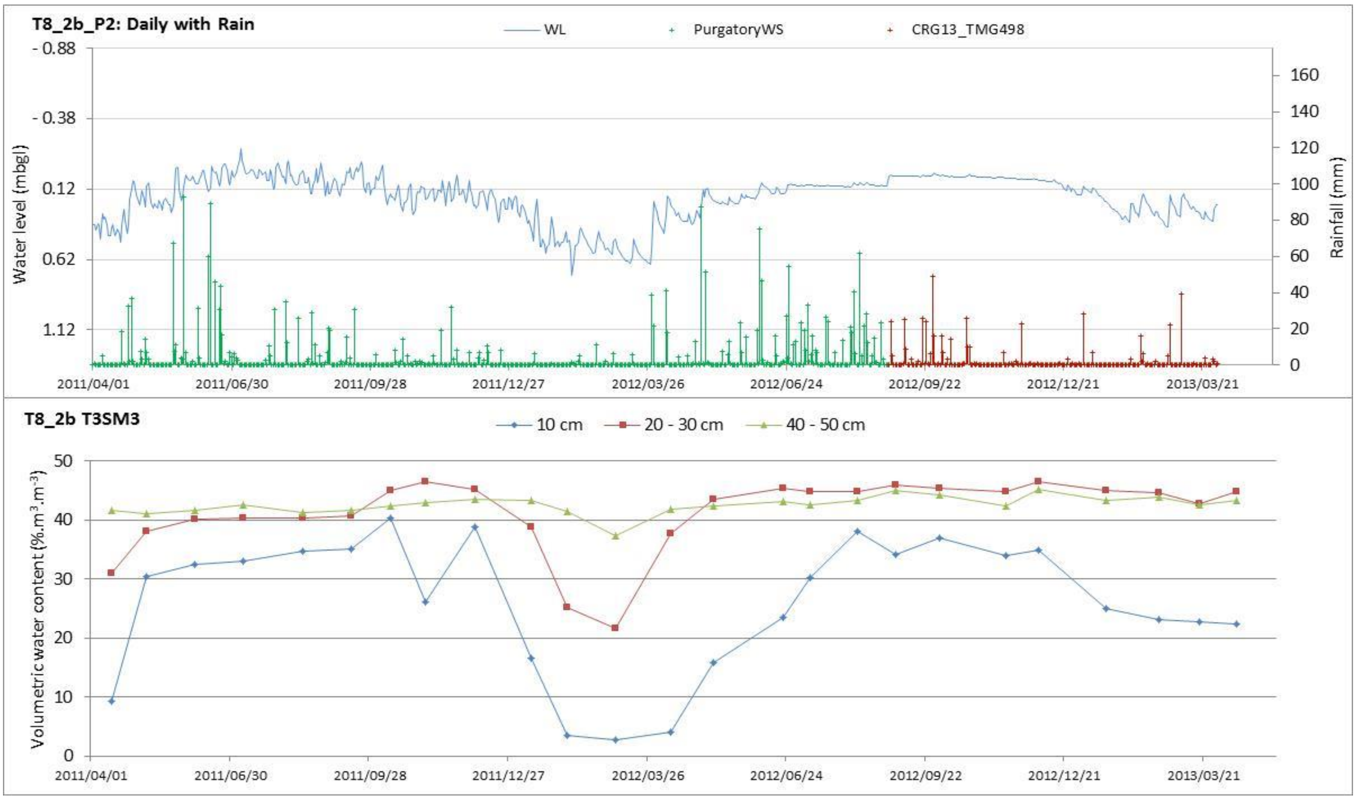


Figure 7.57 Comparison between the rainfall and groundwater level logged in P2 at T8_2b (top) and the volumetric soil water content (bottom) monitored at SM3 on Transect 3.

Water levels at the lower P2 remained close to the surface for most of the period, and soil moisture at the nearby SM3 on Transect 3 was also wetter than the top portion of the seep, more constantly so at depths greater than 30 cm (Figure 7.57).

The groundwater feeding this ecoseep is likely to be Peninsula Aquifer from the Peninsula-Pakhuis Formation contact, or from the surrounding deeper faults merges in the lower, southern portion of the site (see a full description of the setting in Volume 1: Monitoring Framework and Protocol). Thus, this groundwater emerges from the contact on Transect 3, while the remainder of the site is relatively dry. In this lower portion of the seep, the duration of saturation in the deeper soils was longer than in the shallower soils, also showing evidence of a perennial subsurface source of water.

Overall, the seep was slightly wetter in 2012/13 than in 2011/12. As at T6_4, soil moisture in the shallow soils (above 30 cm) was substantially lower than in the deeper soils (Figure 7.58). Soils below 50 cm showed the lowest increase between years, indicating a fairly constant water source at depth.

The PCA of a subset of six soil moisture variables showed that the first three axes explained 97% of the variation between monitoring points (Table 7.9 and Figure 7.59). The variation along PC1 was driven by

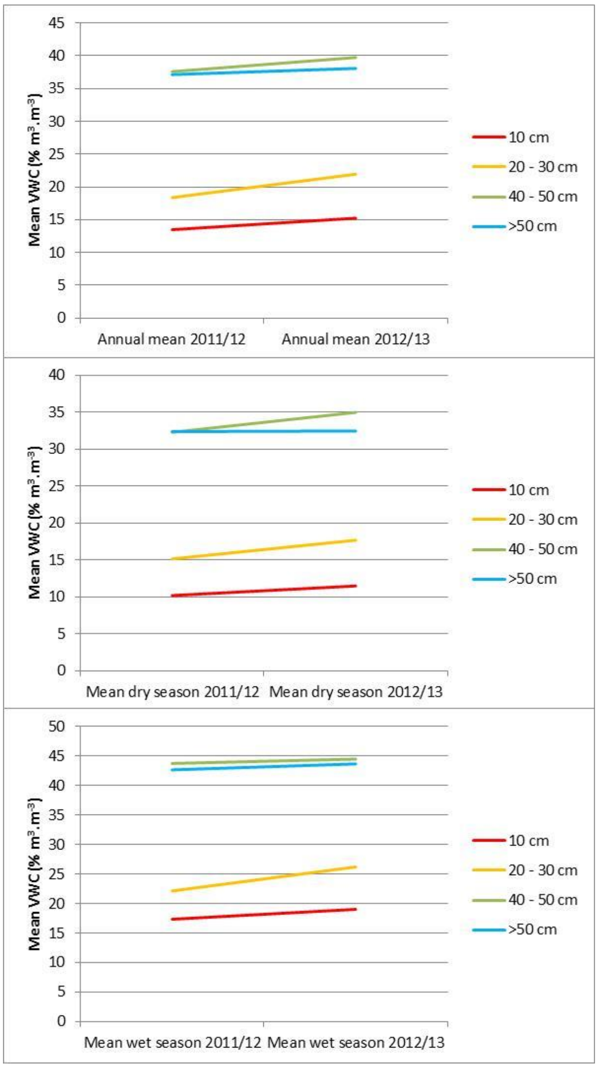


Figure 7.58 Mean volumetric water content (VWC) averaged across T8_2b and all soil depths, and expressed as annual means, and dry season and wet season means, for 2011/12 and 2012/13.

the wet season minimum in the surface soil (L0_Wmin), followed by the dry season maximum at 20 – 30 cm (L1) and the wet season maximum at the same depth (L1_Wmax). PC2 was driven by the wet season variation at both the surface and at 20 – 30-cm depth (L0_Wsd and L1_Wsd), while PC3 was clearly driven by the dry season variation at 20 30-cm depth (L1_Dsd).

Overall there were significant differences ($p \leq 0.05$) between the monitoring points in the surface (L0) and shallow (L1) soils, based on their hydroperiod classes, however, pairwise tests showed that there were no significant differences between each pair of classes. It is likely that this is due to the predominance of seasonally saturated points, and very few perennial or intermittent points. An ordination of the hydroperiod classes at L0 is shown in Figure 7.60. These points separate along a gradient of wet season minimum at this depth, the latter being the variable with the highest Eigenvalue along PC1 (Figure 7.61).

Table 7.9 The Eigenvalues calculated for the subset of soil moisture variables used in the Principle Components Analysis for T8_2b. Eigenvalues in bold are the dominant driving variables responsible for the spread of monitoring points along each axis.

Variable	PC1 (47%)	PC2 (36%)	PC3 (14%)
L0_Wsd	-0.124	**-0.633**	0.267
L0_Wmin	**0.576**	0.063	-0.194
L0_Dmax	**0.561**	-0.183	-0.021
L0_Wmax	**0.514**	-0.338	-0.033
L1_Dsd	-0.204	-0.241	**-0.938**
L1_Wsd	-0.180	**-0.624**	0.097

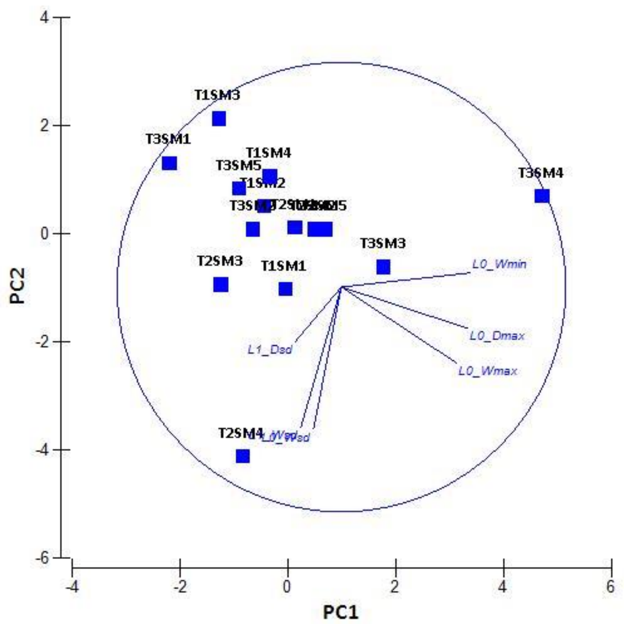


Figure 7.59 Principle Components Analysis of a subset of six soil moisture variables for T8_2b. The vectors represent the Eigenvalues describing the spread of soil moisture sampling points along two axes (PC1 and PC2 collectively explain 83% of the variation).

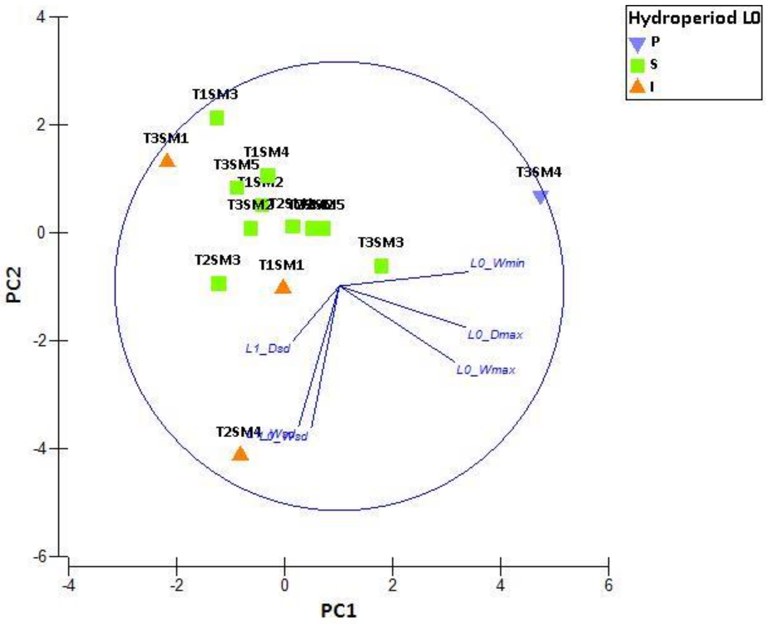


Figure 7.60 PCA of soil moisture variables at T8_2b, with the hydroperiod classes in the topsoil (top 10 cm) shown as symbols.

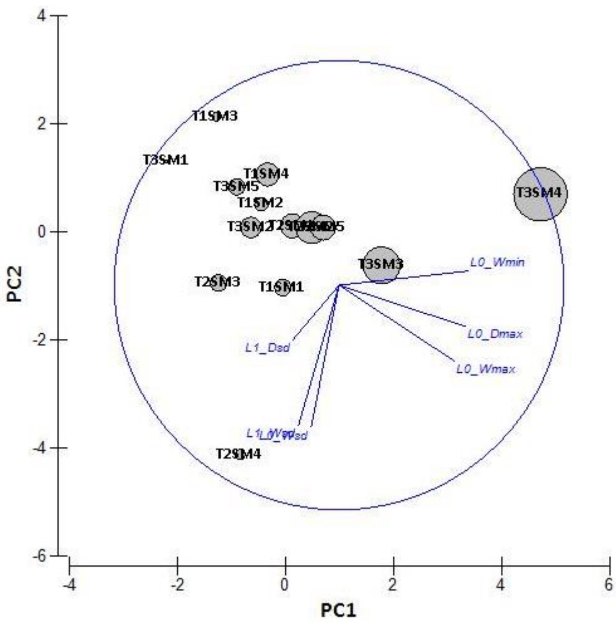


Figure 7.61 PCA of soil moisture variables at T8_2b, with wet season in the top 10 cm (L0) overlain as bubbles, where the smaller the bubble the lower the minimum. This variable best accounted for the separation between soils in the three hydroperiod classes represented at this depth.

7.3 Summary statements

- The wet soil season extended from June until November, and the dry season from December until May.
- The analysis of soil saturation at the nine ecoseeps showed that most of the seeps have a perennially wet core, surrounded by seasonally to intermittently saturated soils. Generally, the seeps were wetter at depth than in the topsoil.
- All seeps were wetter in 2012/13 than in 2011/12, and this showed in both the dry and wet season means for each seep. The increase in soil moisture from one year to the next was often more

pronounced in the shallow soils, especially the top 10 cm. This is likely to be linked with the increase in rainfall in 2012/13 compared with 2011/12. The deeper soils were thus wetter and less variable than the shallow soils.

- The soil moisture data corroborated the water level data logged in the piezometers, providing a finer level of detail regarding the wetting and drying cycles within each ecoseep. The data confirm the location of the wettest portions of each seep, and whether these core areas dry out or remain perennially saturated.
- Spatial variations in soil moisture throughout each ecoseep were explained by different soil moisture variables. Generally, the soil moisture monitoring points separated out along gradients of wet and dry season extremes (minima and maxima), but also along gradients of soil moisture variability in both the dry and wet seasons. Variation in soil moisture within each season was high when the extremes (minima and maxima) were at their highest or lowest. Thus, perennially and intermittently wet points always showed the least variation.
- PCAs of subsets of soil moisture variables filtered out the soil moisture variables that were driving the spatial separation between monitoring points within each ecoseep. It may be assumed that these variables will be the most sensitive to changes in soil moisture regime, and will be the most important variables to monitor at each site.
- It is recommended, however, that the full set of soil moisture variables be calculated for each year of monitoring, and for each depth category. The sensitivity of the soil moisture regimes at each site may only be gauged over time, and it is difficult to make assumptions with only 25 months of data.
- Draw-down of the Peninsula Aquifer could impact on the dry season or wet season soil moisture regimes, and may impact on the seasonal extremes as well as the variability. Thus, the setting of thresholds of potential concern for soil moisture should take all aspects of the soil moisture regime into account.

Table 7.10 Summary of annual, wet season and dry season means for each ecoseep as a whole, and the soil moisture variables driving the spatial separation of monitoring points, as determined through Principle Components Analysis in PRIMERv6.

Site	Annual mean		Wet season mean		Dry season mean		Variables driving spatial separation of SM monitoring points								
	2011/ 12	2012/ 13	2011/ 12	2012/ 13	2011/ 12	2012/ 13									
B1_1	17.85	21.20	23.02	26.15	13.41	16.26	L0_Dsd	L0_Wsd	L1_Dsd	L1_Wsd	L1_Dmax	L2_Dsd	L2_Wsd	L3_Dsd	L3_Wmin
H8_3b	35.67	40.99	40.71	43.65	31.35	38.33	L0_Dsd	L2_Dmax	L3_Satdur	L3_Wsd	L3_Wmin	L3_Wmax			
K_2b	32.17	33.83	38.81	41.61	26.48	26.05	L0_Dmin	L1_Dsd	L1_Wsd	L2_Dsd	L2_Dmax	L3_Wsd			
K_5b		24.71		26.78		22.98	L0_Wsd	L0_Dmin	L0_Wmin	L0_Dmax	L1_Dsd	L1_Wsd			
K_6		23.21		27.81		18.65	L0_Wsd	L0_Dmin	L1_Wsd	L1_Wmin	L1_Dmax	L1_Wmax			
T3_Pal4	21.25	25.20	22.85	28.09	19.89	22.32	L0_Wsd	L0_Dmax	L0_Wmax	L1_Dsd	L1_Wsd				
T6_1b	25.97	28.32	28.25	30.92	24.01	25.72	L0_Wsd	L1_Satdur	L1_Dsd	L1_Wsd	L1_Wmin				
T6_4	34.64	37.52	39.34	42.25	30.61	32.78	L0_Dsd	L0_Wsd	L0_Wmin	L1_Satdur	L1_Dsd				
T8_2b	26.64	28.74	31.44	33.31	22.52	24.17	L0_Wsd	L0_Wmin	L0_Dmax	L0_Wmax	L1_Dsd	L1_Wsd			

8 SEDIMENT COMPOSITION

8.1 *Introduction*

Sediment sampling was undertaken in March 2012 and 2013 to evaluate annual change in sediment composition in the ecochannels at the end of the dry season, and to describe changes in the proportions of flow-depth classes as a simple measure of habitat availability at the eight ecochannels at which biological sampling is taking place. The dataset comprises:

- Sediment composition of the channel and banks at each ecochannel, measured at 20 cm intervals across the three established vegetation monitoring transects, categorised into size classes:
  - Sand, mud, clay: (S)
  - Gravel: (G)
  - Cobble, (C)
  - Boulder: (Bl)
  - Bedrock (Br)
- Flow velocity and depth measurements, summarised according to four flow-depth classes:
  - Slow (<0.3 m/s) - Shallow (<0.25 m) (SS) trickles and backwaters
  - Slow (<0.3 m/s) - Deep (>0.25 m) (SD) runs, pools and backwaters
  - Fast (>0.3 m/s) -Shallow (<0.25 m) (FS) shallow riffles runs
  - Fast (>0.3 m/s) -Deep (>0.25 m) (FD) deep runs rapids and riffles

8.2 *Results*

Ecochannel H8_3a

- The proportion of sand increased both in the channel and on the banks and floodplain (Figure 8.1a), whilst the availability of cobble, already limited in this bedrock-boulder channel, was less than 1 %.
- Flows were slower in 2013 than in 2012, with a greater proportion of slow shallow flows. Slow-deep conditions were still present in the bedrock pool at Transect1. This probably reflects slightly drier conditions in March 2013, something observed at all the ecochannels, and a natural variation in summer low flow conditions.

Ecochannel K_2a

- The extent of sand at K_2a was far more extensive on the banks and floodplain in 2013 than 2012, and may have smothered boulders there, or the boulders may have shifter during flood flows. Both suggest sediment transport on the floodplain during winter floods (Figure 8.1b). In the main channel, cobble habitat was increased, similarly suggesting the movement of the sand fraction within the macro-channel.
- All fast shallow flows at K_2a were reduced to less than 0.3 m s^{-1}, again reflecting drier conditions in March 2013 than March 2012.

Ecochannel K_5a

- After the fires of 2010 and 2011, K_5a substrata were dominated by sand, as recorded in the 2012 sampling. The second year of data suggest considerable mobilisation of the sand fraction from the channel mainly but also from the floodplain (Figure 8.2a), with an increase particularly in the cobble sediments.
- Flows were somewhat slower, with all four flow classes present in 2012 being reduced to three, the loss of the Fast-deep component particularly noticeable, and a concomitant increase in shall slow flows. This was most marked at Transect 1, where velocities were reduced.

Ecochannel T4_Pal1

- Very little change was recorded in substratum conditions on the channel banks and floodplain in 2013 (Figure 8.2b), whilst the proportions of cobble in the channel expanded at the expense of boulders.
- Unlike at the other ecochannels, the proportion of slow-deep flow was increased in 2013 over that measured in 2012. In 2013 the portion of the channel carrying flow at Transect 1 was narrower, with greater depths, whilst at Transect 2 there was a slight shift in the thalweg closer to the left hand margin of the channel. Both depths and velocities were very similar at Transect 3 in 2012 and 2013. These changes suggest some sediment sorting during the previous winter floods.

Ecochannel T4_Pal3

- This site reflected nearly identical substratum and flow conditions in 2013 as in 2012 (Figure 8.3a)

Ecochannel T6_1a

- There was a shift from boulder to cobble in the main channel at T6_1a, with evidence of some sand loss (Figure 8.3b) whilst on the banks and floodplain substantial removal of the sand fraction was recorded from 2012 to 2013.
- As with K_5a - the only other stream in the monitoring programme with fast-deep flow in 2012 - drier conditions resulted in the loss of the fast-deep flow class here, with an expansion of slow deep conditions where velocities declined.

Ecochannel T6_2a

- This channel site recorded a loss of gravel, with increased proportion of cobbles in the substratum on the banks and floodplain (Figure 8.4a). On the other hand, cobbles declined to less than 1 % in the channel, but the proportions of boulder, sand and gravel remained roughly proportional to each other.
- The fast-shallow flow class was no longer recorded in 2013, reflecting the drier conditions, with only two, slow deep and slow shallow, flow conditions present.

Ecochannel T8_2a

- The stream at T8_2a reflects the physically disturbed conditions that resulted from the hot fires in 2004 and 2008, and the resulting catastrophic flooding and erosion that followed. In 2013 sand and gravel, which previously composed half the substratum in the channel, had been scoured to increase the availability of mainly cobble (Figure 8.4b). Similarly, the banks were slightly altered by sand removal, with a small showing of gravel and cobble close to the channel edge.
- Flow categories were very similar, notwithstanding these changes, although the proportion of deeper flow increased.

8.3 Summary and conclusion

Small shifts in the proportions of sediments on the banks and channels of the eight stream monitored in this programme most probably reflect the effects of winter floods. In some ecochannels, e.g. K_5a and T8_2a, these changes may be part of a progressive post-fire shift.

The reduction in flow velocities was observed at all sites and is explained through natural variation in summer baseflows. However, it is suggested that future analyses record the proportion of channel points that have any flow: simply representing all flow as “slow-shallow” does provide a measure of change, but may not indicate when there has been a significant reduction in wetted perimeter.

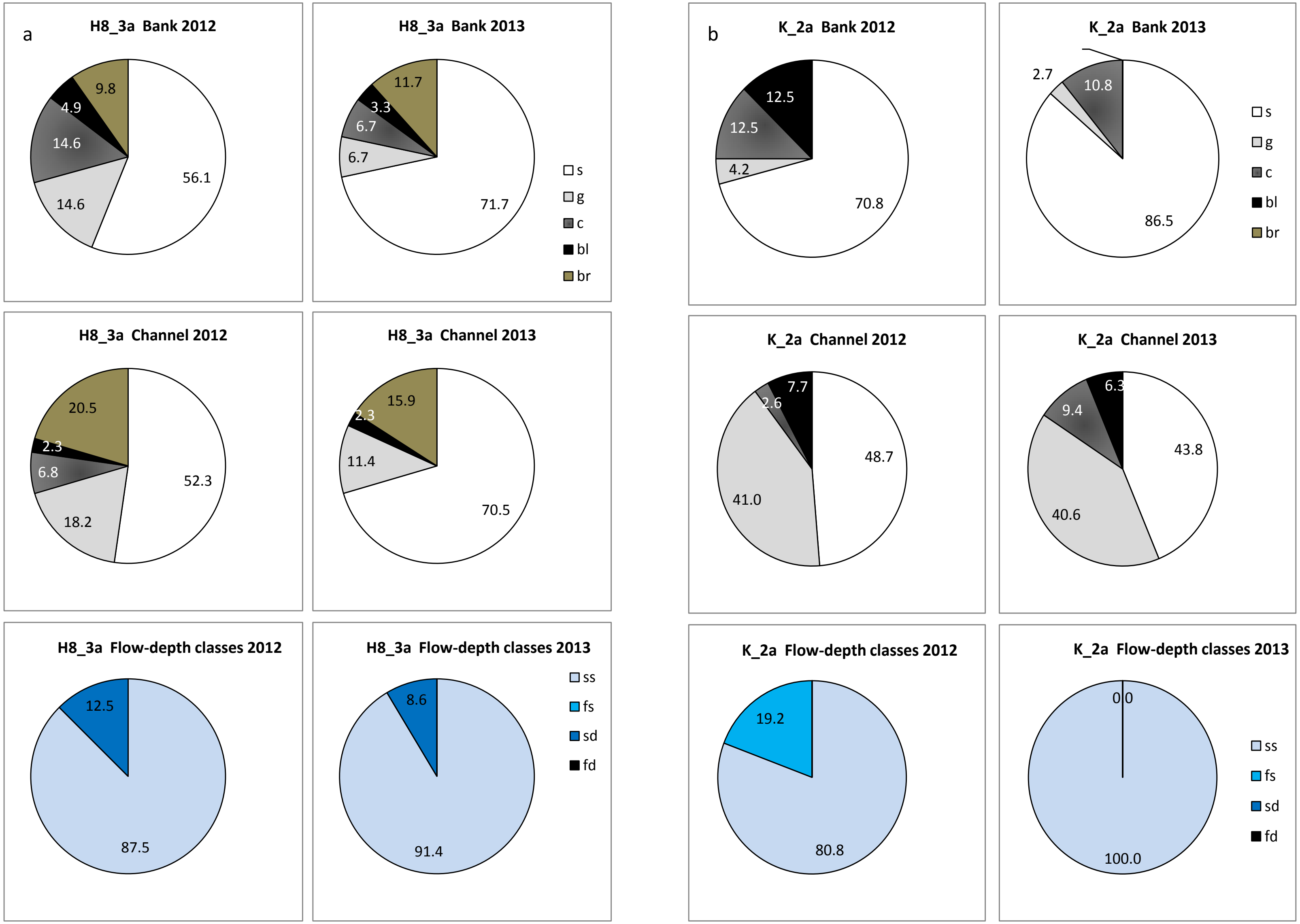


Figure 8.1 **Proportions of sediment by size class in the main channel and the channel margins, and of flow-depth classes at a) H8_3a and b) K_2a in March 2012 and March 2013.**

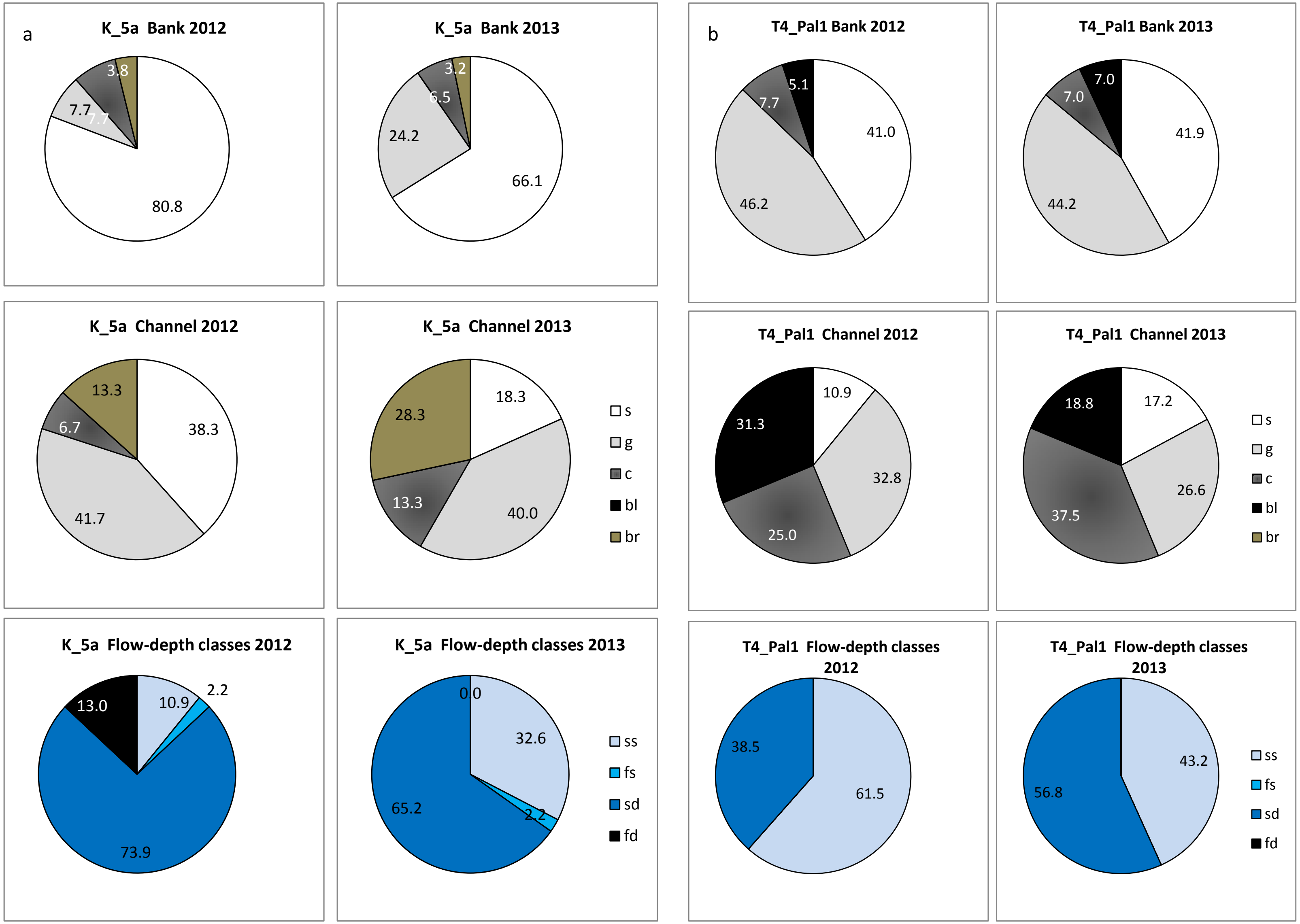


Figure 8.2 Proportions of sediment by size class in the main channel and the channel margins, and of flow-depth classes at a) K_5a and b) T4_Pal1 in March 2012 and March 2013.

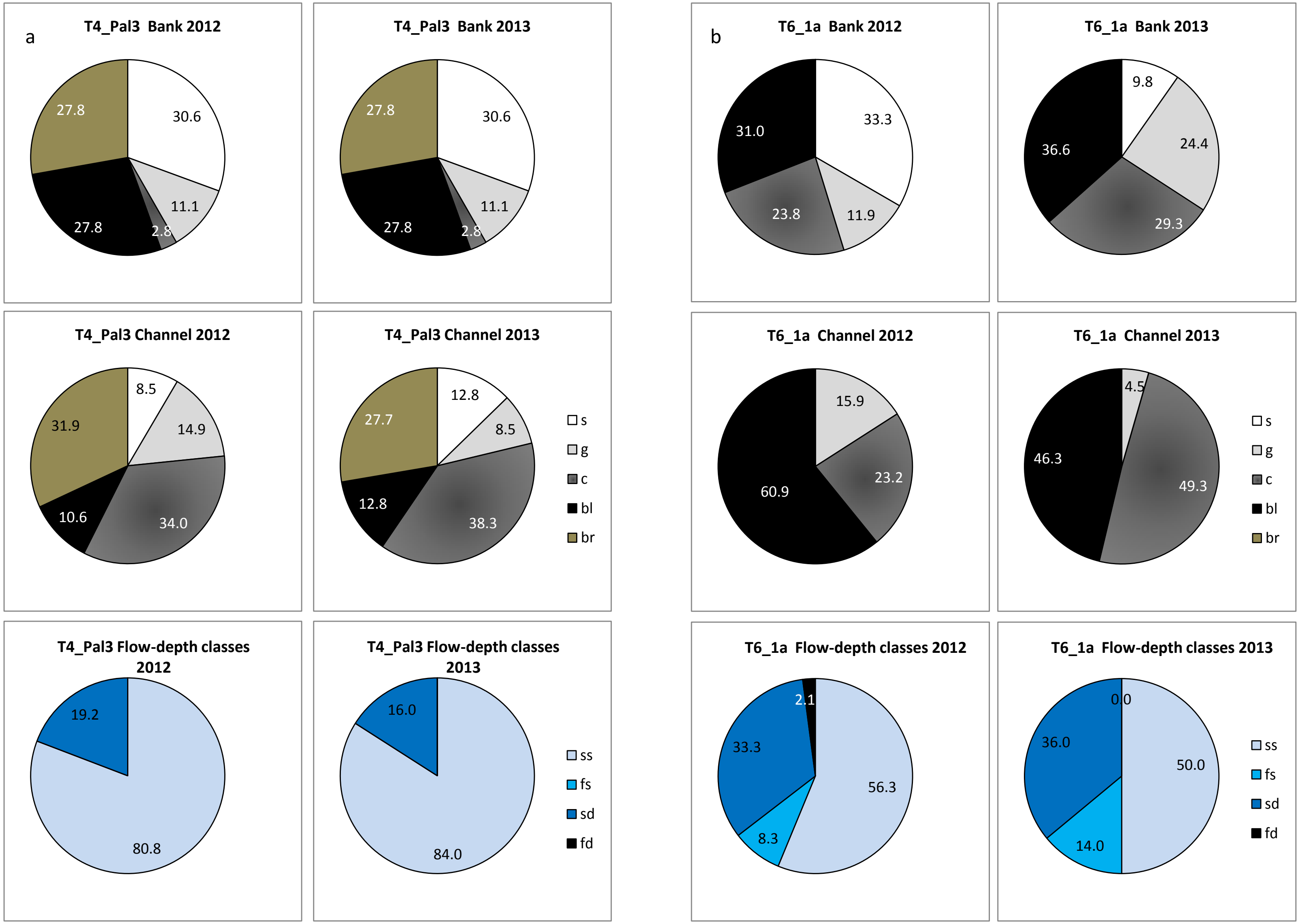


Figure 8.3 **Proportions of sediment by size class in the main channel and the channel margins, and of flow-depth classes at a) T4_Pal3 and b) T6_1a in March 2012 and March 2013.**

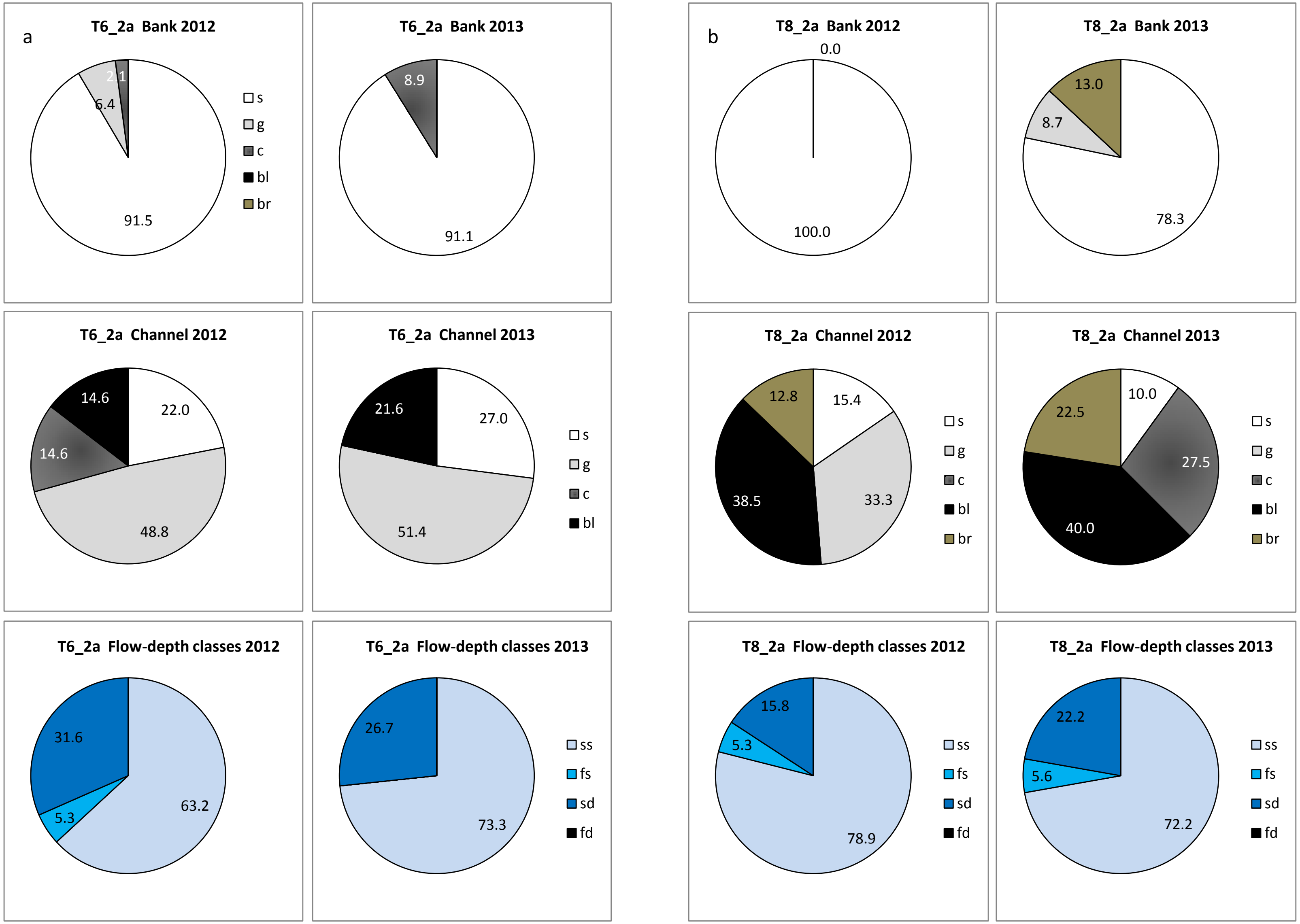


Figure 8.4 **Proportions of sediment by size class in the main channel and the channel margins, and of flow-depth classes at a) T6_2a and b) T8_2a in March 2012 and March 2013.**

9 VEGETATION

9.1 *Introduction*

The objective of the collection of vegetation data was to document the spatial and temporal variability of the plant communities at the ecosites. These data provide a baseline against which future data can be evaluated and contextualised, and to interpret monitoring data in other disciplines.

This section presents the results of the vegetation sampling baseline surveys collected at all 17 sites in October 2011 and October 2012.

The baseline dataset included in these analyses are as follows:

- Percentage cover of plant species in contiguous plots along three transects at each sampling site averaged between 2011 and 2012.
- A suite of environmental parameters representing soil moisture at different depths, substratum composition, debris cover, canopy cover and the proportion of bare rock or soil present within each plot. These parameters represent the environmental factors that were used to quantify the variability in vegetation composition at each site.
- Similarities of individual plots between 2011 and 2012 for each site. These data were used to establish the degree of temporal change in vegetation community composition. By comparing the vegetation composition between years, temporal variability, independent of abstraction impacts, can be determined and used as a baseline in the monitoring programme.
- The representation and average height of the three tallest individuals in each plot compared between 2011 and 2012 for each sampling site.

Detailed methods for the collection and analyses of these datasets are provided in Volume 2: Method Statements and the results of the Cluster, MDS and SIMPER analyses are provided in Appendix 1.

In summary, the data were firstly used to establish plant communities and describe the key characteristics of communities represented at each site. Secondly, plant community structure was quantitatively linked to the key environmental factors. Apart from the determination of vegetation communities as a preliminary baseline condition for benchmarking potential future changes following abstraction from the aquifer, monitoring year-on-year changes in the vegetation of *individual* plots was used to provide a basis for monitoring change in vegetation over time. Considering that only two years' worth of data are available to date, only a single comparison (i.e. 2011 vs 2012) could be presented in this report for each monitoring site.

Finally, almost all monitoring sites burnt in recent years and thus it is likely that temporal changes in the complexity or structure of these community may have taken place that are independent of changes in soil moisture. Therefore the height of the tallest three individuals in each plot measured in 2011 and 2012 was used to establish whether there was a shift or change in the community structure over time. Both a change in the average height of the dominant species and the extent or representation of species as the tallest from 2011 to 2012 provided an indication of these temporal changes in the plant communities at each site.

9.2 Results and discussion

9.2.1 Ecoseep B1_1

9.2.1.1 Plant communities

Five distinct plant communities were identified through PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes. An additional three plant communities were identified from the extrapolation of the cluster analysis to the full data set.

A diagrammatic representation of all plots along the three sampling transects, colour coded according to the plant community Group that each represents, is presented in Figure 9.1. The spatial position of the plots of each of the Groups is consistent with knowledge of the site: the plant communities of Group d and e, for example, occur on both left and right margins of the seep, and represent the species typical of drier ground, whilst Group a plots track the wet, lower-lying channel that curves through the seep from near P1 to P2 (Figure 9.1). Elsewhere, plots of different Groups intergrade as part of a continuum of change in soil moisture, for example Group us 3 plots along Transect 1 intergrading with and ultimately being replaced by Group e plots from the seep margin heading inward. A comparison between the spatial arrangement of these plant communities along each transect (Figure 9.1) and temporal changes in soil moisture over the site given in Section 7, suggest a strong link between soil moisture and vegetation communities at B1_1, for example in the agreement between the spatial extent of Group a plots and the pattern of seasonal drying of the seep during late summer. These links are addressed in more detail in the next section.

Key indicator species representing each of these groups were derived from the SIMPER analysis of the species that best describe the similarity within each group and the dissimilarity between groups. These details are given in Appendix 1. Based on Corry (2011), some indicator taxa could be assigned to specific categories of wetland indicator species as defined in Table 9.1.

Table 9.1 Definition of different categories of indicator taxa according to their occurrence in wetlands, based on Corry (2011).

Category	Definition
Obligate wetland species	Almost always grow in wetlands (>99% of occurrences).
Facultative wetland species	Usually grow in wetlands (67-99% of occurrences) but are occasionally found in non-wetland areas.
Facultative species	Are equally likely to grow in wetland and non-wetland areas (34-66% of occurrences).
Facultative dryland species	Usually grow in non-wetland areas but sometimes grow in wetlands (in wetlands in 1-34% of occurrences).
Dryland species	Almost always grow in drylands (>99% of occurrences).

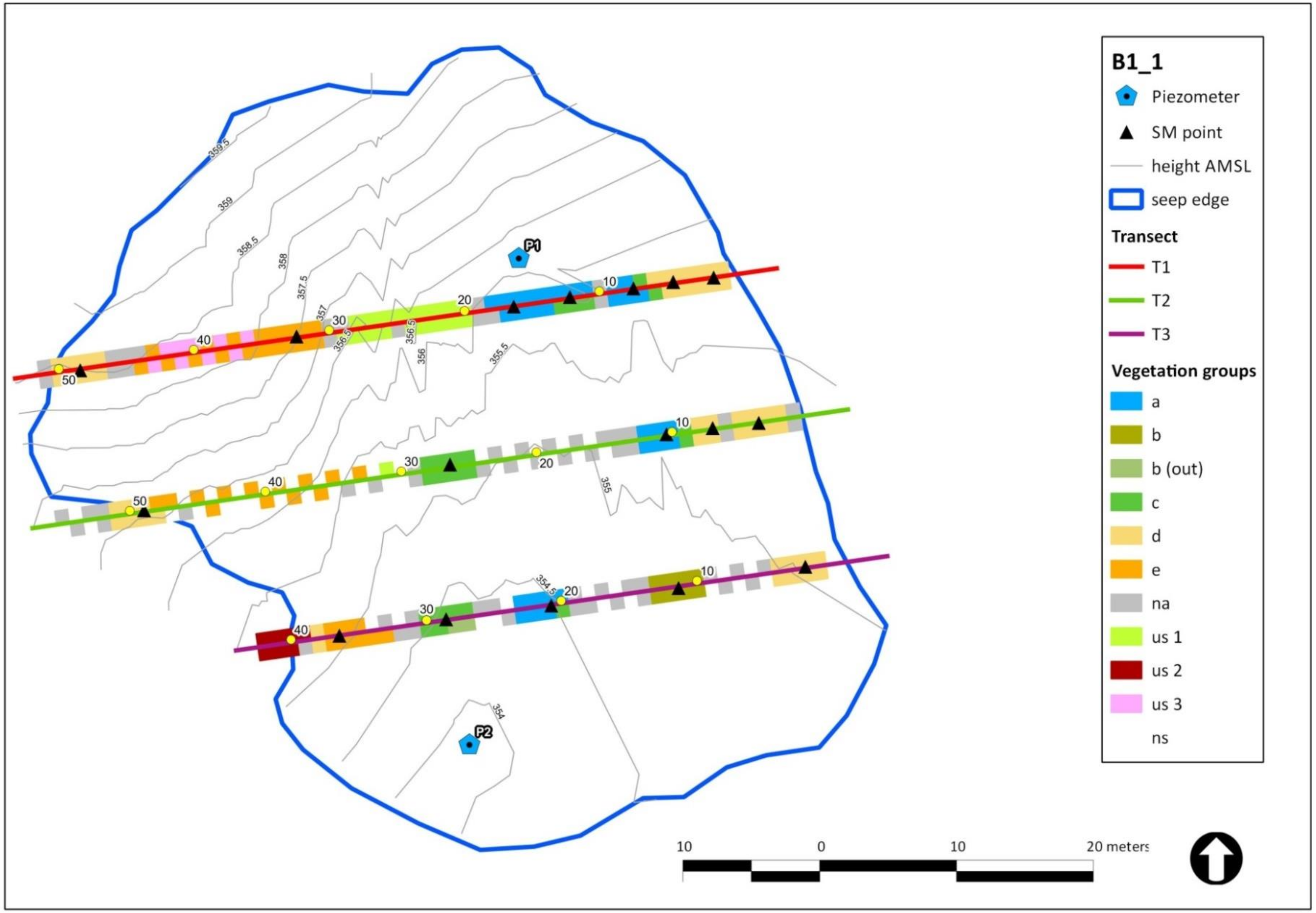


Figure 9.1 **Diagrammatic representation showing the position of all plots at B1_1, colour coded according to the plant community that each represents. Group b (out) represents an outlier of group b. The grey plots (na) represent those that could not be assigned to a plant group through extrapolation. Gaps in plots along the transect (ns) are plots that were not sampled as part of the monitoring programme.**

Whilst a suite of species might collectively account for differences between community groups (reported in Appendix 1) these have been reduced to one key indicator species that most consistently differentiates a group from all others, as follows:

Group a - *Isolepis prolifer* – obligate wetland species

Group b – *Cyperus thunbergii*

Group c - dominated by *Pteridium aquilinum* and dead *Pteridium aquilinum,* no clear indicator

Group d – *Restio gaudichaudianus*

Group e – *Ficinia trichodes*

Group us 1 – *Todea barbara* - obligate wetland species

Group us 2 – *Helichrysum indicum*

Group us 3 – *Searsia angustifolia*- facultative wetland species

The average abundance (% cover) of each of these key indicator species at B1_1 is shown in Figure 9.2. Here for example, although Groups us3, us2 and d are all plant communities dominated by *Pteridium aquilinum*, or dead *Pteridium,* they have key differences in cover values for *Searsia angustifolia, Helichrysum indicum* and *Restio gaudichaudianus*, which represent different conditions within the dry margins of the seep.

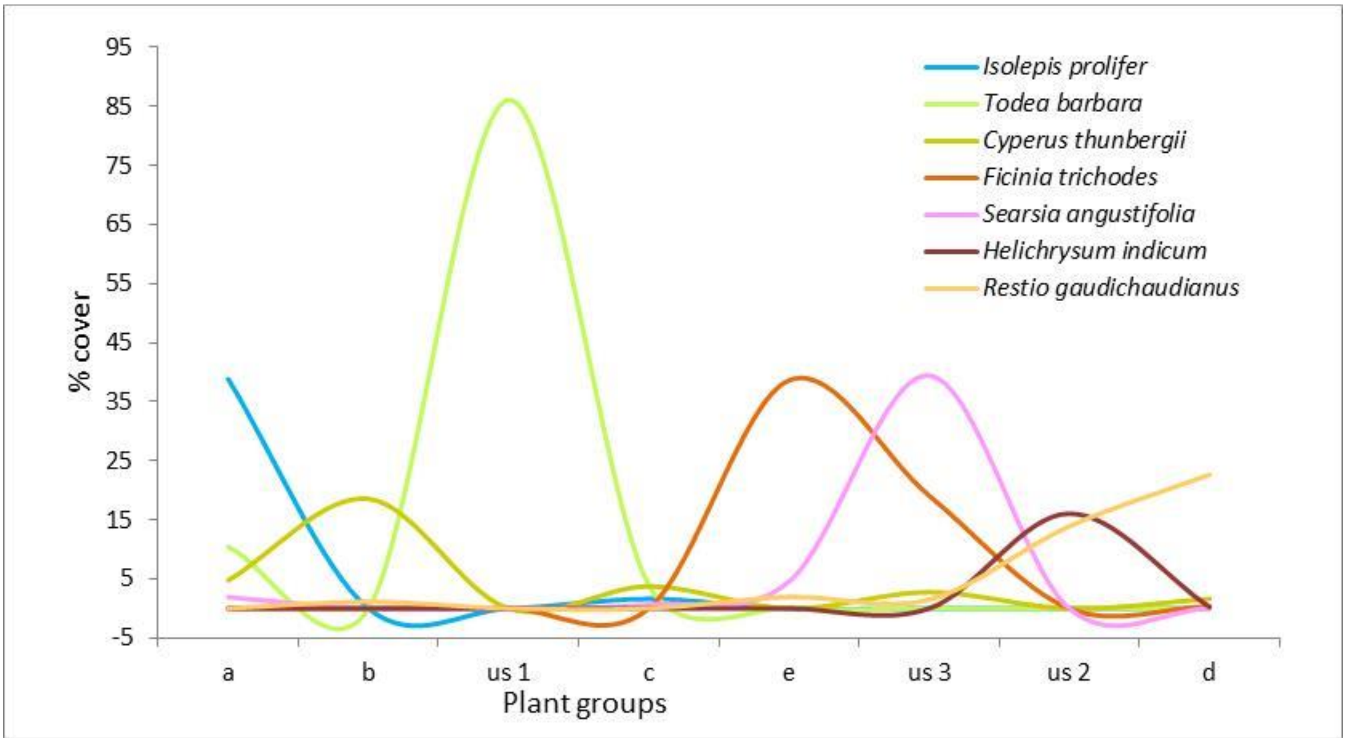


Figure 9.2 Average abundance (% cover) of indicator species for plant groups identified at Site B1_1. The order of the groups on the x-axis follows the groups typical of the wetter central portions (left) to the drier outer margins (right).

Dispersion among plots within each group varied considerably. The similarity percentages given in Table 9.2 are a quantitative measure of the cohesion within plant communities, with the greatest within-group similarity in Group us 1 (i.e. 72% similarity between the plots within this group), the plots here all being dominated by *Todea barbara.* By contrast, the "wet" group with *Isolepis prolifer* as the key indicator (Group a) had the lowest within-group similarity (47% similarity). Group a was also very dissimilar from Groups us 2, us 3 and d (4, 6 and 7 % similarity in pairwise comparisons, respectively, representing the outer margins of the seep.

Table 9.2 Average similarity within and between plant groups at B1_1.

	a	b	c	d	e	us 1	us 2	us 3
a	47							
b	17	51						
c	26	35	54					
d	7	34	38	54				
e	9	29	39	42	59			
us 1	16	20	25	18	18	72		
us 2	4	22	25	38	28	14	48	
us 3	6	27	25	30	42	16	18	54

9.2.1.2 Key environmental drivers of plant community structure

DistLM analysis was used to determine which variables best described variability in plant community structure. From this analysis it is evident that:

- Average soil moisture at the surface over the wet season (L0_Wave), was the single best predictor of plant community composition at this site, describing 34% of the variability in community structure (Table 9.3: marginal tests).
- Three other soil moisture parameters, namely the wet season three month minimum at 40-50 cm depth (L2_Wrunmin), the dry season three month minimum at the surface (L0_Drunmin) and the duration of saturation (L2_Satdur) individually described around 30% of the overall variability in community structure (Table 9.3: marginal tests).
- Although significant, the standard deviation in soil moisture in both the dry season (Dsd) and wet season (Wsd) did not contribute substantially to describing variability in plant communities at this site.
- Substratum composition was the only non-soil moisture related parameter that contributed significantly to describing a portion of the variability in community structure. However, substratum composition described only 17% of the variability (Table 9.3: marginal tests).
- In addition to L0_Wave, an additional 14 soil moisture parameters described 68% of the overall variability in plant community structure across the site, although only a small proportion of the variation could be attributed to any one of these parameters (Table 9.3: sequential tests).

The substantial links between soil moisture and plant community structure at this site are not surprising, considering the comparison of temporal changes in soil moisture at B1_1, (Section 7, Figure 7.2) and the spatial arrangement of plant communities given in Figure 9.1.

An ordination of the fitted model given by the dbRDA plot in Figure 9.3 shows that:

- Group a, which characterised the wettest portion of the wetland (Figure 9.1), was separated from groups characteristic of the outer margins, (particularly Groups d and e) largely along dbRDA1. The overlay of L0_Wave in Figure 9.3b, as the parameter that described most of the variability in plant communities, shows a clear change in average soil moisture with the highest supporting Group a and the lowest soil moisture levels characteristic of Group d. The soil moisture content of Groups b and c were intermediate between these the wettest and driest groups.

- Vegetation plots characterising Group d were somewhat separated along dbRDA 2, reflecting a difference in soil moisture between the left hand side (looking downstream) and the right hand side

Table 9.3 Results of the DistLM analysis: relationship between plant species composition and environmental variables at B1_1 based on a Euclidean Distance matrix. '% variation explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different (p ≤ 0.05) relationships are shown

Environmental variable	Parameter	*p*	% variation explained	
MARGINAL TESTS[1]				
Soil moisture	$L0\_Sat_{dur}$	0.0001	26.1	
	$L0\_W_{ave}$	**0.0001**	**34.1**	
	$L0\_D_{sd}$	0.0001	14.4	
	$L0\_W_{sd}$	0.0009	4.3	
	$L0\_D_{runmin}$	**0.0001**	**30.6**	
	$L1\_D_{sd}$	0.0004	4.9	
	$L1\_W_{sd}$	0.0001	5.6	
	$L1\_D_{runmin}$	0.0001	20.6	
	$L1\_D_{runmax}$	0.0001	29.1	
	$L1\_W_{runmax}$	0.0001	25.3	
	$L2\_Sat_{dur}$	**0.0001**	**30.0**	
	$L2\_D_{sd}$	0.0001	6.5	
	$L2\_W_{sd}$	0.0001	7.9	
	$L2\_W_{runmin}$	**0.0001**	**31.0**	
	$L2\_D_{runmax}$	0.0001	26.6	
	$L2\_W_{runmax}$	0.0001	20.0	
Substratum	% cover	0.0001	17.0	
SEQUENTIAL TESTS[2]	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Soil moisture	$+L0\_W_{ave}$	0.0001	34.1	32.9
	$+L2\_W_{runmax}$	0.0001	6.0	38.6
	$+L0\_Sat_{dur}$	0.0001	4.0	42.7
	$+L2\_D_{runmax}$	0.0002	1.8	44.7
	$+L2\_Sat_{dur}$	0.0001	2.5	46.5
	$+L1\_D_{sd}$	0.0001	2.2	48.6
	$+L0\_D_{sd}$	0.0002	1.8	50.7
	$+L1\_D_{runmin}$	0.0001	2.1	52.4
	$+L0\_W_{sd}$	0.0001	1.8	54.8
	$+L1\_W_{runmax}$	0.0001	2.0	56.2
	$+L0\_D_{runmax}$	0.0002	1.7	57.8
	$+L2\_D_{sd}$	0.0002	1.3	59.7
	$+L2\_W_{sd}$	0.0001	1.7	61.2
	$+L2\_W_{runmin}$	0.0002	1.4	62.7
	$+L1\_W_{sd}$	0.0001	4.7	66.2
	$+L1\_D_{runmax}$	0.0001	1.9	68.3

[1] *Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.*

[2] *Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.*

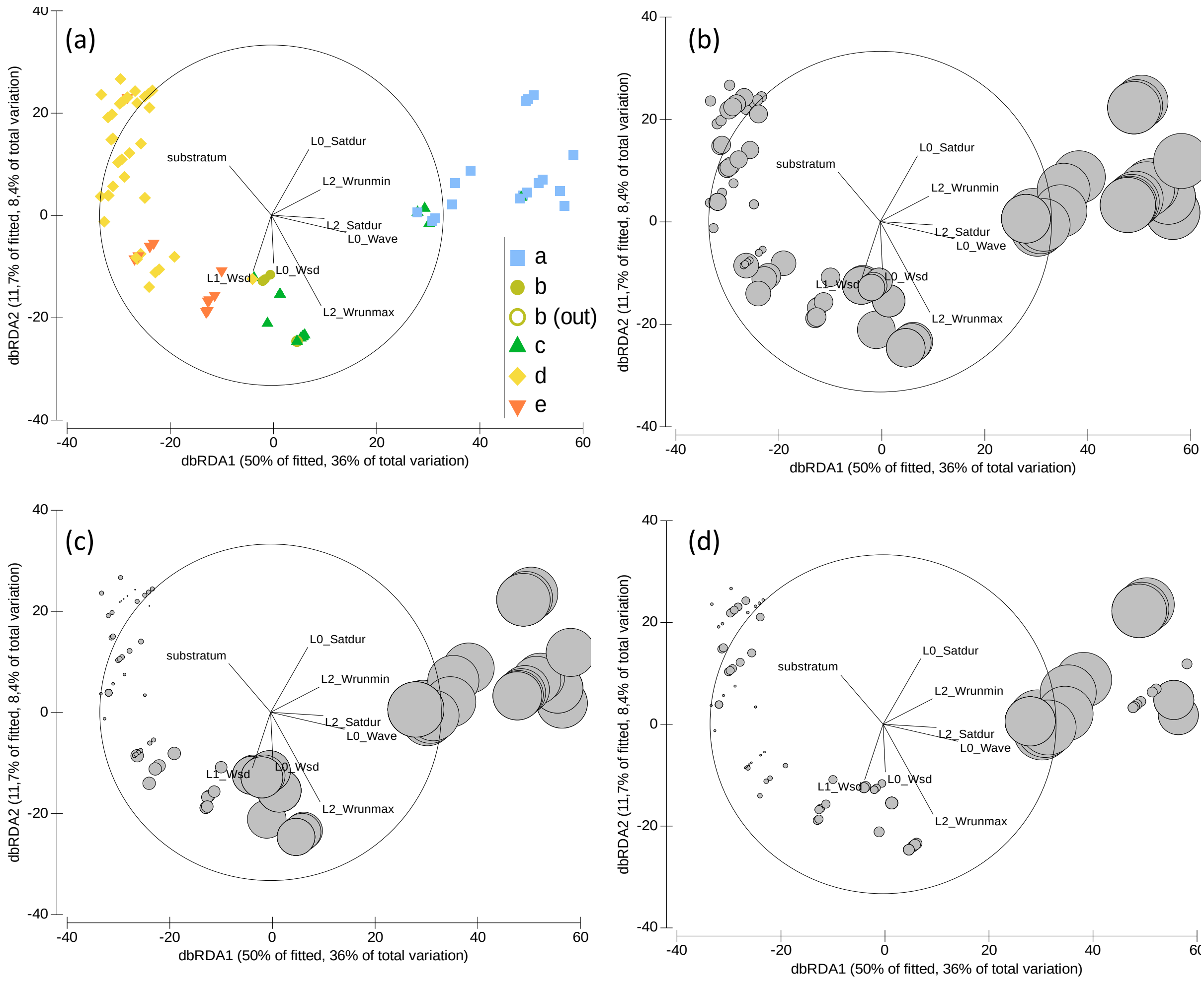


Figure 9.3 **dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at B1_1. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) is colour coded according to the plant communities defined by the cluster analysis. Bubble plots of the dbRDA ordination show the distribution of plots relative to b) L0_Wave; c) L2_Wrunmin; d) Lo_Drunmin - the larger the bubble, the greater the soil moisture content.**

of the ecoseep. In particular, plots characterised as Group d on the right hand side sit at the far top left of the ordination plot and separate from those along T1 and T2 on the left hand side of the wetland at the bottom of the ordination. An overlay of the wet season three-month minimum at 40-50 cm (L2_Wrunmin), which described 31% of the variation in vegetation, showed that the separation of Group d along dbRDA 2, can be attributed to far drier conditions at depth of plots along the right hand margin of the ecoseep (Figure 9.3c). This distinction is best depicted by the animation of temporal changes in soil moisture of the site given in Section 7.

- The affiliation of Groups b and c to the drier Groups d and e is best depicted by the dry season three-month minimum at the surface which also described 31% of the variation in plant communities at this site. Figure 9.3d shows that the dry season soil moisture minimum typical of Group a was substantially higher than that of all other Groups.

Considering the substantial links between soil moisture and plant community structure identified, it is anticipated that changes in soil moisture both near the surface (0-10 cm) and at depth (40-50cm) would result in a change in these communities.

9.2.1.3 Year-on-year comparison of monitoring plots

The year-on-year % similarity of individual plots, comparing 2011 with 2012, is presented Figure 9.4, summarised for each plant Group identified through cluster analysis. The similarity values ranged widely, from below 40% in plots that showed considerable shift in species complement, to 96% in highly stable plots. Plots with the lowest similarity values (often * outliers in Figure 9.4) tended to be those where the 2012 year was associated with greater cover values, suggesting that vegetation in many plots is still in a growth phase after the burn in 2010. An example is Plot T2_9a (Group e community) with only 38% similarity: here cover values for *Wachendorfia, Cyperus* and *Pteridium* increased, whilst *Kniphofia* declined. Similarly, an increase from 0 to 70% cover in *Isolepis* was a contributor to the 38% similarity at Plot T1_17b (Group a). The low similarity in plots belonging to Group us2 was based on only two plots.

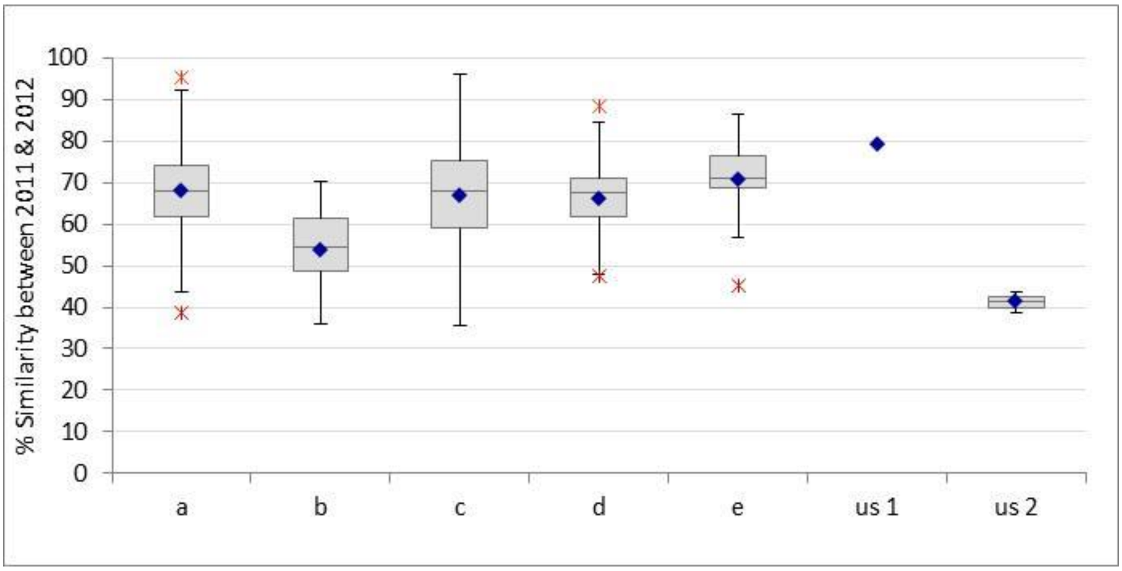


Figure 9.4 Percentage similarity in species composition between individual plots monitored in 2011 and 2012 at B1_1. The data are summarised by the plant community (Group) affiliation of each plot.

9.2.1.4 Inter-annual change in the height of dominant species

The heights of the tallest species recorded at B1_1 increased from 2011 to 2012, suggesting succession-related growth in wetland vegetation (Table 9.4). A decline in the number of plots (n) in which any given species was one of the three tallest suggests a shift in the canopy community over time, regardless of the growth of individuals. For example, *Restio gaudichaudianus* was the tallest species in 68 plots (31% of plots) in 2011 with an average height of 0.72 m (Table 9.4). By 2012, this species was the tallest in only 17% of plots with an average height of 0.83 m. This suggests that other species had overtaken *R. gaudichaudianus* in about of the plots were it was the tallest species the year before. By contrast, there was a slight increase in the number of plots where *Pteridium aquilinum* was the tallest species from 2011 to 2012. *Pteridium aquilinum*, which was dominant among vegetation communities on the drier margins of the wetland, is usually an indication of disturbance. Alien clearing and fires through the area in 2008 probably accounted for the disturbance along the dry margins, which has resulted in the proliferation of *Pteridium aquilinum,* as a pioneer in disturbed areas at this site. Also considerable die off of *Pteridium aquilinum* was also evident from 2011 to 2012 as reflected by the substantial increase in the number of plots where dead *Pteridium aquilinum* was recorded as the tallest species. This is further evidence that the communities along the drier margins of B1_1 are still undergoing successional change following disturbance by fire and alien removal.

Table 9.4 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at B1_1. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	222	Total N:	619	#Plots:	218	Total N:	608
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Acacia mearnsii					1	0.46	1.80	
Aira cupaniana (European grass)	1	0.45	0.10					
Anthospermum aethiopicum	6	2.70	0.67	0.48	2	0.92	0.75	0.64
Anthospermum galioides	2	0.90	0.50	0.14				
Aristea capitata	2	0.90	1.20	0.00	2	0.92	1.00	0.00
Aristida junciformis	1	0.45	0.20					
Asparagus lignosus	1	0.45	1.20					
Asparagus rubicundus	1	0.45	0.80		1	0.46	0.60	
Cannomois virgata	2	0.90	1.20	0.00	4	1.83	1.23	0.15
Carpha glomerata	1	0.45	1.20		3	1.38	1.17	0.06
Cassytha ciliolata	2	0.90	2.25	0.35	6	2.75	2.22	0.32
Chrysanthemoides monilifera	1	0.45	1.00		1	0.46	1.40	
Conyza ulmifolia	1	0.45	0.80		3	1.38	0.70	0.53
Cyperus thunbergii	26	11.71	0.88	0.33	19	8.72	1.00	0.22
Diospyros glabra	5	2.25	1.00	0.38				
Disparago ericoides					1	0.46	2.00	
Elegia capensis	1	0.45	1.60		1	0.46	1.80	
Erica muscosa	3	1.35	0.57	0.06	2	0.92	0.55	0.07
Eucalyptus sp.					4	1.83	1.70	0.81
Ficinia bulbosa					1	0.46	0.10	
Ficinia indica	7	3.15	0.37	0.24				
Ficinia nigrescens	6	2.70	0.45	0.10	3	1.38	0.43	0.06
Ficinia oligantha	2	0.90	0.20	0.00	1	0.46	0.20	
Ficinia trichodes	37	16.67	0.28	0.09	25	11.47	0.22	0.05
Helichrysum foetidum					1	0.46	0.90	
Helichrysum helianthemifolium	2	0.90	0.08	0.04				
Helichrysum indicum	1	0.45	0.10		3	1.38	0.10	0.00
Isolepis prolifer	21	9.46	0.88	0.26	19	8.72	0.97	0.22
Kniphofia uvaria	17	7.66	0.94	0.19	7	3.21	1.06	0.24
Leucadendron salignum	7	3.15	0.81	0.13	3	1.38	0.87	0.12
Morella serrata	1	0.45	0.20					
Moss					2	0.92	0.06	0.06
Muraltia pauciflora	3	1.35	0.47	0.15				
Myrsine africana	6	2.70	0.60	0.19	2	0.92	0.40	0.00
Oxalis obtusa	10	4.50	0.08	0.04	2	0.92	0.10	0.00
Passerina corymbosa	2	0.90	0.25	0.07	1	0.46	1.00	
Pentameris airoides					1	0.46	0.20	
Pseudognaphalium undulatum	1	0.45	0.05					
Pseudognaphalium undulatum - dead					2	0.92	0.90	0.00
Psoralea aphylla	62	27.93	2.34	0.75	53	24.31	3.23	2.31
Psoralea pinnata	4	1.80	1.85	0.45	2	0.92	3.30	0.99
Pteridium aquilinum	152	68.47	0.93	0.43	168	77.06	1.24	0.38
Pteridium aquilinum - dead	6	2.70	0.55	0.16	125	57.34	1.04	0.77
Restio gaudichaudianus	68	30.63	0.72	0.34	36	16.51	0.82	0.24
Restio paniculatus	40	18.02	1.80	0.68	31	14.22	2.24	0.52
scroph 1	1	0.45	0.10					
Searsia angustifolia	16	7.21	1.94	0.46	7	3.21	2.21	0.46
Senecio hastatus	1	0.45	0.40					
Senecio rigidus	12	5.41	1.14	0.43	13	5.96	1.40	0.41
Seriphium cinereum	13	5.86	0.55	0.16	6	2.75	0.67	0.08
Seriphium plumosum	4	1.80	0.38	0.17	1	0.46	0.30	
Skiatophytum tripolium	3	1.35	0.20	0.00	1	0.46	0.10	
Thamnochortus gracilis	1	0.45	0.40					
Thelypteris confluens	6	2.70	0.53	0.18	3	1.38	0.47	0.12
Thesium strictum	4	1.80	1.68	0.15	3	1.38	1.93	0.12
Todea barbara	24	10.81	1.69	0.43	18	8.26	1.77	0.35
Todea barbara - dead					6	2.75	1.13	0.34

Cont.

Species	2011				2012			
	#Plots:	222	Total N:	619	#Plots:	218	Total N:	608
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Tribolium brachystachyum	1	0.45	0.10					

Tribolium uniolae	1	0.45	0.40					
Wachendorfia thyrsifera	12	5.41	1.16	0.31	9	4.13	1.22	0.35
Watsonia angusta	8	3.60	0.84	0.32	2	0.92	2.65	1.91
Watsonia angusta - dead					1	0.46	0.30	
Zantedeschia aethiopica	1	0.45	0.40					

9.2.2 Ecoseep H8_3b

9.2.2.1 Plant communities

Four distinct plant communities were identified through PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes, and were extrapolated to all plots in the dataset.

A diagrammatic representation of all plots along the three sampling transects, colour coded according to the plant community (Group) that each represents, is given in Figure 9.5. This shows the dominance of Group b, which was prevalent across the entire length of Transect 1 and most of Transect 2 (Figure 9.5). Groups b and c characterised the wetter areas of the seep at H8_3b, while Groups a and d were typical of the drier margins.

Between group similarities reflect the differences between the drier and the wetter groups with the least similarity shared between Group d and Group b (Table 9.5). Group b had the highest within-group similarity compared with the other three plant communities identified (Table 9.5), despite the fact that by far the majority of plots clustered into this group.

Table 9.5 Average similarity within and between plant groups at H8_3b.

	a	b	c	d
a	50			
b	34	52		
c	24	21	46	
d	26	12	23	34

The key indicator species of each of these groups are described in Appendix 1 and summarised as follows:

Group a – *Chrysitrix capensis* – terrestrial (SANBI)

Group b – *Erica campanularis* – obligate wetland species

Group c – *Elegia mucronata* – facultative wetland species

Group d- *Ficinia minutiflora* – seeps on moist slopes (SANBI)

The average abundance (% cover) of each of these key indicator species at H8_3b is given in Figure 9.6. The spatial arrangement of these plant communities (Figure 9.5) was fairly consistent with soil moisture characteristics over the site given in Section 7, Figure 7.16, which showed that Transect 3 remains saturated throughout the year (all Group b plots), whilst the seep margins, in the vicinity of Group a and d plots, has more seasonal hydrology. The links between soil moisture and plant communities at H8_2b are addressed in more detail in the next section.

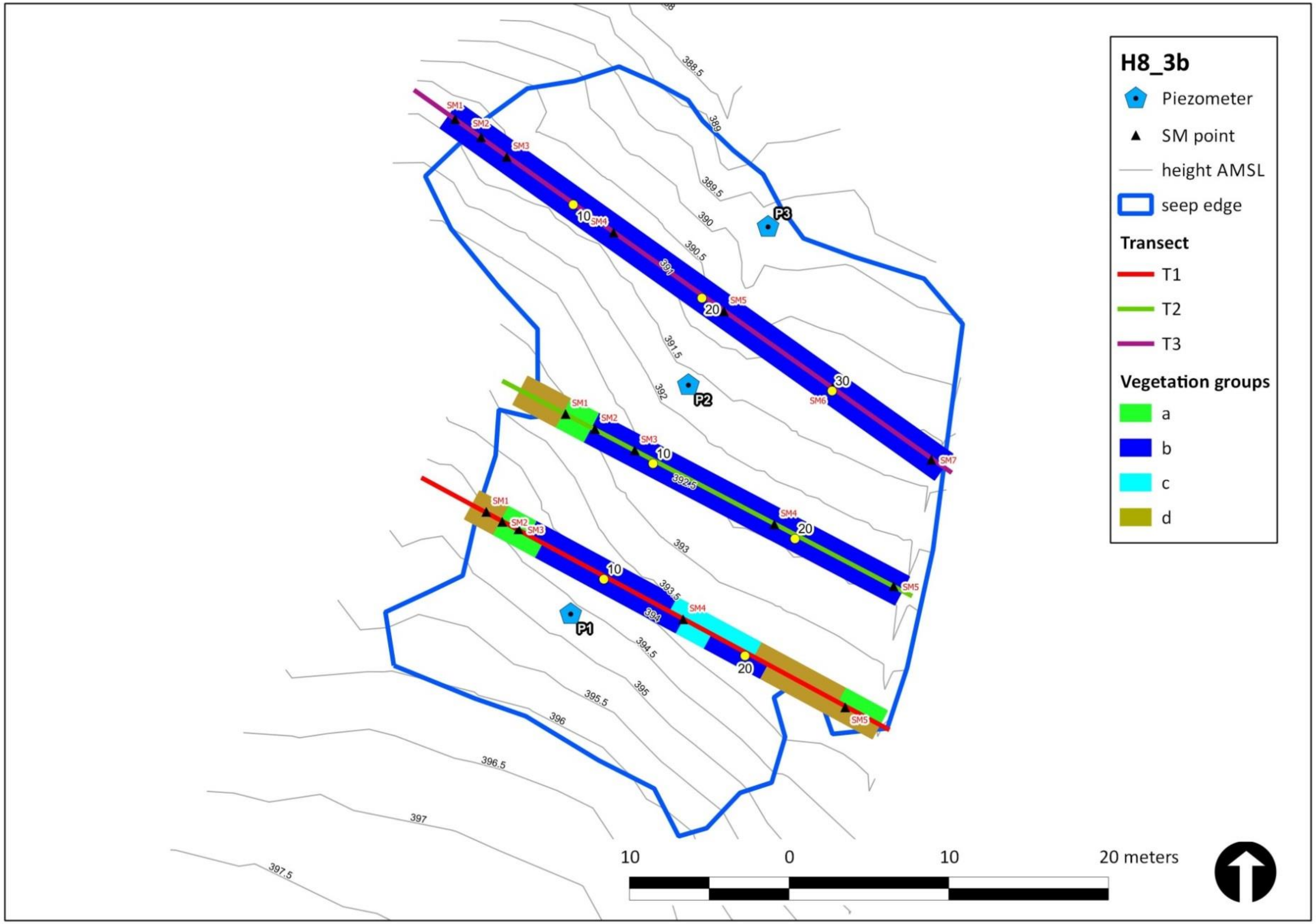


Figure 9.5 **Diagrammatic representation showing the position of all plots at H8_3b, colour coded according to the plant community that each represents. All plots along the three transects were sampled. No outliers were identified and all plots could be assigned to a plant group.**

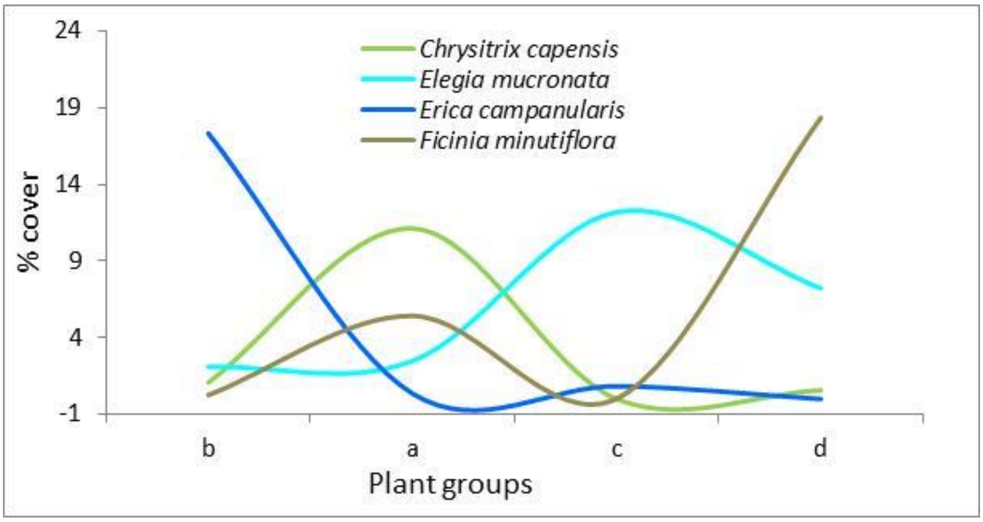


Figure 9.6 Average abundance (%cover) of indicator species for plant groups identified at H8_3b.

9.2.2.2 Key environmental drivers of plant community structure

DistLM analysis to determine the variables that best describe variability in plant community structure show the following:

- Average soil moisture over the wet season between 10-30 cm (L1_Wave) was the single best predictor of plant community composition at this site, describing 25% of the variability in community structure (Table 9.6: marginal tests).
- A number of other soil moisture parameters between 10-30 cm (i.e. L1) and between 30-50 cm (i.e. L2) individually described about 20% of the variability in plant community structure at this site, suggesting that soil moisture characteristics between 10 and 50 cm may be important determinants of vegetation characteristics at H8_3b.
- Nevertheless, the sequential tests in Table 9.6 indicate that soil moisture deeper than 50 cm, particularly the average soil moisture minimum over the driest three (consecutive) wet season months (L3_Wrunmin) as well as soil moisture at the surface (i.e. L0_Wrunmax) describe some of the residual variability in plant communities across the seep.

The relative contribution of these variables to describing differences in plant communities at H8_3b can be seen in the ordination of the fitted model by in by the dbRDA plot in Figure 9.7. Essentially, the ordination plots show that:

- Group b was separated from all other plant communities by L1_Wave (Figure 9.7a), largely along dbRDA1, indicating that plots within Group b have the highest average wet season soil moisture at a depth between 10-30 cm (Figure 9.7b).
- The average dry season minimum at depths of 50 cm or greater (L3_Drunmin) was highest for plots belonging to Group c, and lowest for plots in Groups a and d (Figure 9.7c), suggesting that this parameter separated vegetation communities along the drier margins from those within the central core of the seep.
- Interestingly, the variability in soil moisture at L2 during the dry season separated plots within Group b along transects. Figure 9.7d shows that soil moisture for plots within Group b along transect 1 varied far less than those along transects 2 and 3 over the season. This suggests that the plant community characterised by Group b is not particularly sensitive to differences in the variability in soil moisture over this period.

These results reflect a relatively strong link between soil moisture and plant community at this site. It is therefore likely that changes in soil moisture, particularly within the 10-50 cm depth profile, will lead to a shift in the plant communities in the seep.

Table 9.6 Results of the DistLM analysis: rrelationship between plant species composition and environmental variables at H8_3b based on a Euclidean Distance matrix. '% variation explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different ($p \leq 0.05$) relationships are shown.

Environmental variable	Parameter	*p*	% var	Cum % var
MARGINAL TESTS[1]				
Substratum	% cover	0.0001	8.1	-
Bare soil or rock	% cover	0.0001	6.2	-
Soil moisture	L0_W_{runmax}	0.0001	11.5	-
	L1_D_{ave}	0.0001	18.2	-
	L1_W_{ave}	0.0001	25.0	-
	L1_W_{sd}	0.0001	17.5	-
	L1_W_{runmin}	0.0001	23.9	-
	L1_W_{runmax}	0.0001	23.2	-
	L2_$_{Satdur}$	0.0001	22.4	-
	L2_D_{ave}	0.0001	21.2	-
	L2_W_{ave}	0.0001	19.6	-
	L2_D_{sd}	0.0001	8.3	-
	L2_W_{sd}	0.0001	16.8	-
	L2_W_{runmin}	0.0001	21.5	-
	L2_D_{runmax}	0.0001	23.4	-
	L3_D_{runmin}	0.0001	18.2	-
	L3_W_{runmin}	0.0002	6.5	-
SEQUENTIAL TESTS[2]				
Soil moisture	L1_W_{ave}	0.0001	25.0	25.0
	L3_W_{runmin}	0.0001	6.7	31.7
	L2_D_{sd}	0.0001	5.1	36.8
	L3_D_{runmin}	0.0001	4.8	41.5
	L0_W_{runmax}	0.0001	4.8	46.4
	L1_W_{sd}	0.0001	3.8	50.2
	L2_$_{Satdur}$	0.0001	3.5	53.7
	L2_W_{ave}	0.0001	3.1	56.7
	L1_W_{runmax}	0.0001	2.3	59.1
Bare soil or rock	% cover	0.0001	2.2	61.2
Soil moisture	L1_W_{runmin}	0.0001	1.8	63.0
	L1_D_{ave}	0.0001	1.4	64.4
	L2_D_{runmin}	0.0002	1.5	66.0
	L2_D_{ave}	0.0001	1.6	67.6
Substratum	% cover	0.0003	1.3	68.9
	L2_W_{sd}	0.0016	1.1	70.0
	L2_W_{runmin}	0.0023	1.0	71.0

[1] *Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.*

[2] *Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.*

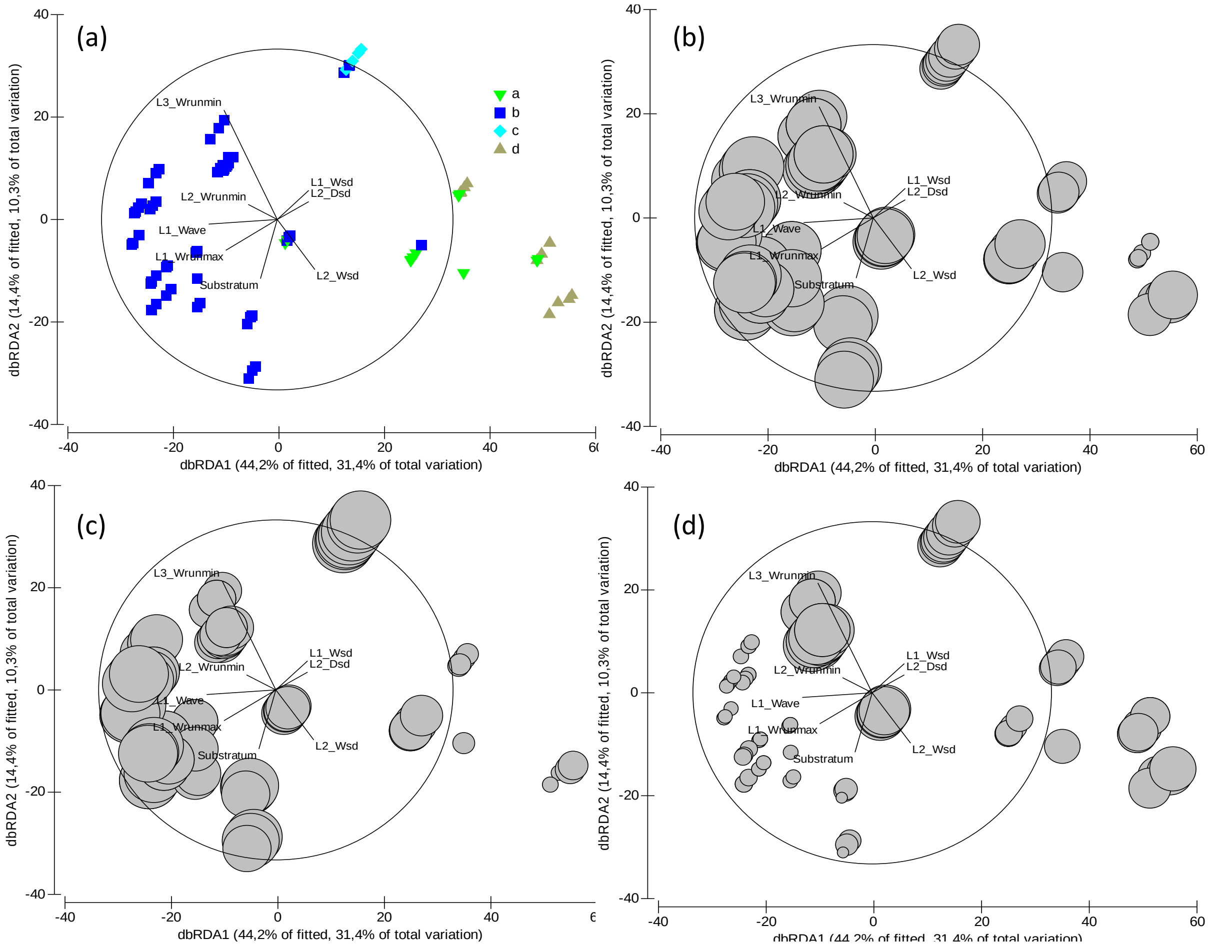


Figure 9.7 dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at H8_3b. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) is colour coded according to the plant communities defined by the cluster analysis. Bubble plots of the dbRDA ordination show the distribution of plots relative to b) L1_Wave; c) L3_Drunmin; d) L2_Dsd - the larger the bubble, the greater the soil moisture content

9.2.2.3 Year-on-year comparison of monitoring plots

Few plots at H8_3b recorded year-on-year similarities below 40% (Figure 9.8), and average similarity for plots from all plant communities (Groups) was between 50 and 70%, suggesting generally little species turnover for the year. Where low similarities were recorded, these were usually associated with an increase in cover values, or the appearance of new seedlings, at fairly low densities. For example, Plot T3_3a (Group b, year-on-year similarity of 34%) had an increase in cover of Berzelia, *E. campanularis, Grubbia, Neesenbeckia, Soroveta* and a decline in *Epischoenus*. At Plot T1_22a (Group d, year-on-year similarity of 35%) species such as *Carpacoce*, L. *salicifolium*, *Ficinia bergiana*, and also *Seriphium* were recorded newly in 2012 but at densities of 5% or less. These sorts of changes suggest plant communities still undergoing successional change.

9.2.2.4 Inter-annual change in the height of dominant species

A comparison between 2011 and 2012 of the average height of species comprising the tallest individuals in each plot shows that most of these species increased in height over the year (Table 9.7). In particular,

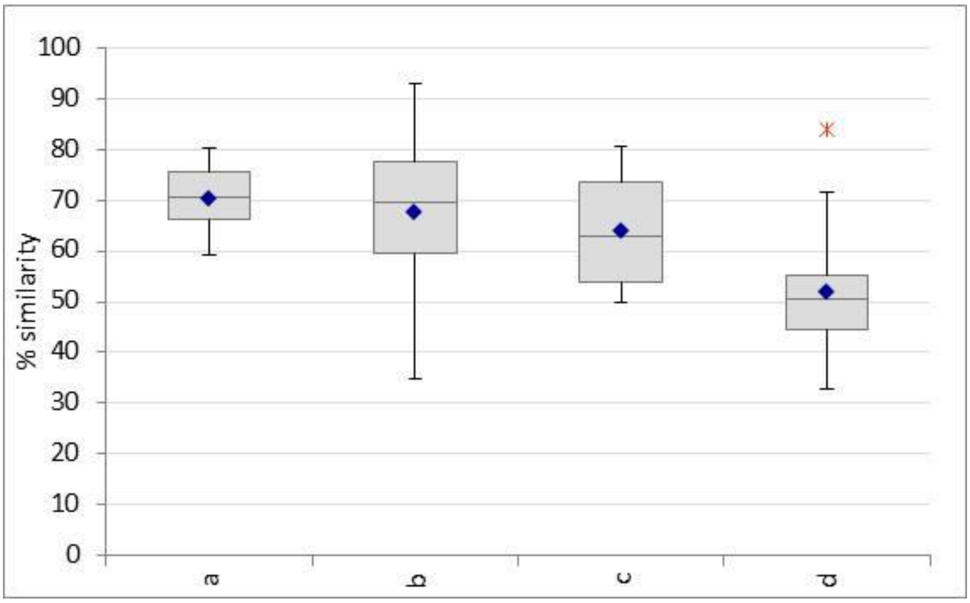


Figure 9.8 Percentage similarity in species composition between individual plots monitored in 2011 and 2012 at H8_3b. The data are summarised by the plant community (Group) affiliation of each plot.

Berzelia alopecuriodes increased in height by 0.13 m on average and increased its representation as one of the tallest three species from about 6% to 12% over a year. Similarly, *Grubbia rosmarinifolia* grew by 0.05 m over the year and increased its extent as the tallest species from 2% to 24% over an annual cycle. Although not recorded as the tallest species in any plots in 2011, *Erica campanularis* was one of the tallest species recorded in 34% of plots in 2012. The representation of a number of species as the tallest in 2011 decreased considerably in 2012. Most notable of these were *Bobartia gladiata, Cyathocoma hexandra, Ehrharta ramosa* and *Neesenbeckia punctoria*. These results suggest a change in the community structure at H8_3b over the annual period, consistent with low year-on-year similarity values recorded for some of the plots. Considering that this site was burnt in 2008, these temporal changes may reflect post-fire succession in the community that is still on-going.

Table 9.7 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at H8_3b. The number of plots and the percentage of the total number of plots represented by each species is also given.

	2011				**2012**			
	#Plots:	**189**	**Total N:**	**566**	**#Plots:**	**168**	**Total N:**	**478**
	N	**%**	**AveHeight**	**StdDev**	**N**	**%**	**AveHeight**	**StdDev**
Berzelia alopecuroides	11	5.82	0.31	0.13	20	11.90	0.44	0.16
Berzelia lanuginosa	3	1.59	0.30	0.09	2	1.19	0.35	0.07
Bobartia gladiata	33	17.46	0.65	0.19	4	2.38	0.40	0.08
Carpha glomerata	1	0.53	0.80					
Cassytha ciliolata	5	2.65	0.39	0.13	8	4.76	0.36	0.07
Chrysitrix capensis	24	12.70	0.50	0.13	6	3.57	0.53	0.08
Cyathocoma hexandra	77	40.74	0.89	0.31	32	19.05	0.83	0.25
Ehrharta ramosa	67	35.45	0.47	0.11	12	7.14	0.46	0.17
Elegia mucronata	44	23.28	0.40	0.09	30	17.86	0.75	0.34
Elegia mucronata - dead					2	1.19	0.65	0.07
Epischoenus lucidus	11	5.82	0.38	0.12	16	9.52	0.31	0.08
Epischoenus villosus	1	0.53	0.20					
Erica campanularis					57	33.93	0.29	0.08

Cont.

	2011	**2012**

	#Plots:	189	Total N:	566	#Plots:	168	Total N:	478
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Erica intervallaris					4	2.38	0.25	0.06
Ficinia bergiana	1	0.53	0.20		1	0.60	0.20	
Ficinia minutiflora	4	2.12	0.21	0.07	1	0.60	0.10	
Ficinia minutiflora - dead					3	1.79	0.13	0.06
Grubbia rosmarinifolia	4	2.12	0.43	0.10	41	24.40	0.48	0.14
Helichrysum litorale					1	0.60	0.01	
Leucadendron salicifolium	1	0.53	0.32		2	1.19	1.10	0.14
Neesenbeckia punctoria	20	10.58	1.10	0.23	10	5.95	1.27	0.16
Nevillea obtussissima	6	3.17	0.65	0.17	1	0.60	0.60	
Pentameris colorata	1	0.53	0.45		1	0.60	0.40	
Platycaulos compressus	67	35.45	0.75	0.26	53	31.55	0.85	0.22
Psoralea pinnata	1	0.53	0.45		1	0.60	1.00	
Restio bifidus	42	22.22	0.46	0.06	42	25.00	0.44	0.07
Restio dispar	4	2.12	1.15	0.17	3	1.79	1.07	0.23
Restio fusiformis					6	3.57	0.40	0.00
Restio leptostachyus	3	1.59	0.32	0.15	20	11.90	0.29	0.09
Restio pedicellatus	1	0.53	0.40					
Restio versatilis					1	0.60	0.10	
Seriphium cinereum	2	1.06	0.15	0.07	3	1.79	0.40	0.00
Soroveta ambigua	2	1.06	0.45	0.00	7	4.17	0.37	0.29
Syncarpha speciocissima	2	1.06	0.45	0.07	3	1.79	0.53	0.15
Tetraria capillacea	58	30.69	1.03	0.13	32	19.05	0.93	0.18
Tetraria fasciata	3	1.59	0.50	0.09	4	2.38	0.55	0.06
Tetraria flexuosa	57	30.16	0.91	0.19	40	23.81	0.95	0.16
Tetraria thermalis					1	0.60	0.50	
Tribolium uniolae	1	0.53	0.10					
Ursinia paleacea	9	4.76	0.29	0.16				
Ursinia paleacea - dead					4	2.38	0.35	0.10
Villarsia manningiana					4	2.38	0.10	0.00

9.2.3 Ecoseep K_2b

9.2.3.1 Plant communities

Three plant communities were identified through PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes, and were extrapolated to all but five plots in the dataset.

The diagrammatic representation of all plots along the three sampling transects, colour coded according to the plant community Group that each represents (Figure 9.9) shows that Group c was the dominant community along all three transects (Figure 9.9) indicating very little variation in vegetation communities within this seep. K_2b was burnt only a year prior to data collection in 2011 and is therefore in early succession post fire. It may be that the early successional stage of this wetland obscures what might in future be greater differentiation of the communities within the seep, or that the seep naturally has a fairly undifferentiated flora. Despite this overall uniformity, plots in Group a formed a small community along the eastern margin of the wetland, with a few more located towards the western edge of Transect 1. Plots within Group b were arranged in a small cluster along the western margin of the wetland at Transect 1. A comparison between the spatial arrangement of these plant communities and the animation of temporal changes in soil moisture over the site given in Section7, Figure 7.16 suggest a poor link between soil moisture patterns and plant communities at K_2b: the seasonally driest portion of the seep appears to be the centre of Transect 1, which along with most of the rest of the site, comprised Group c plots.

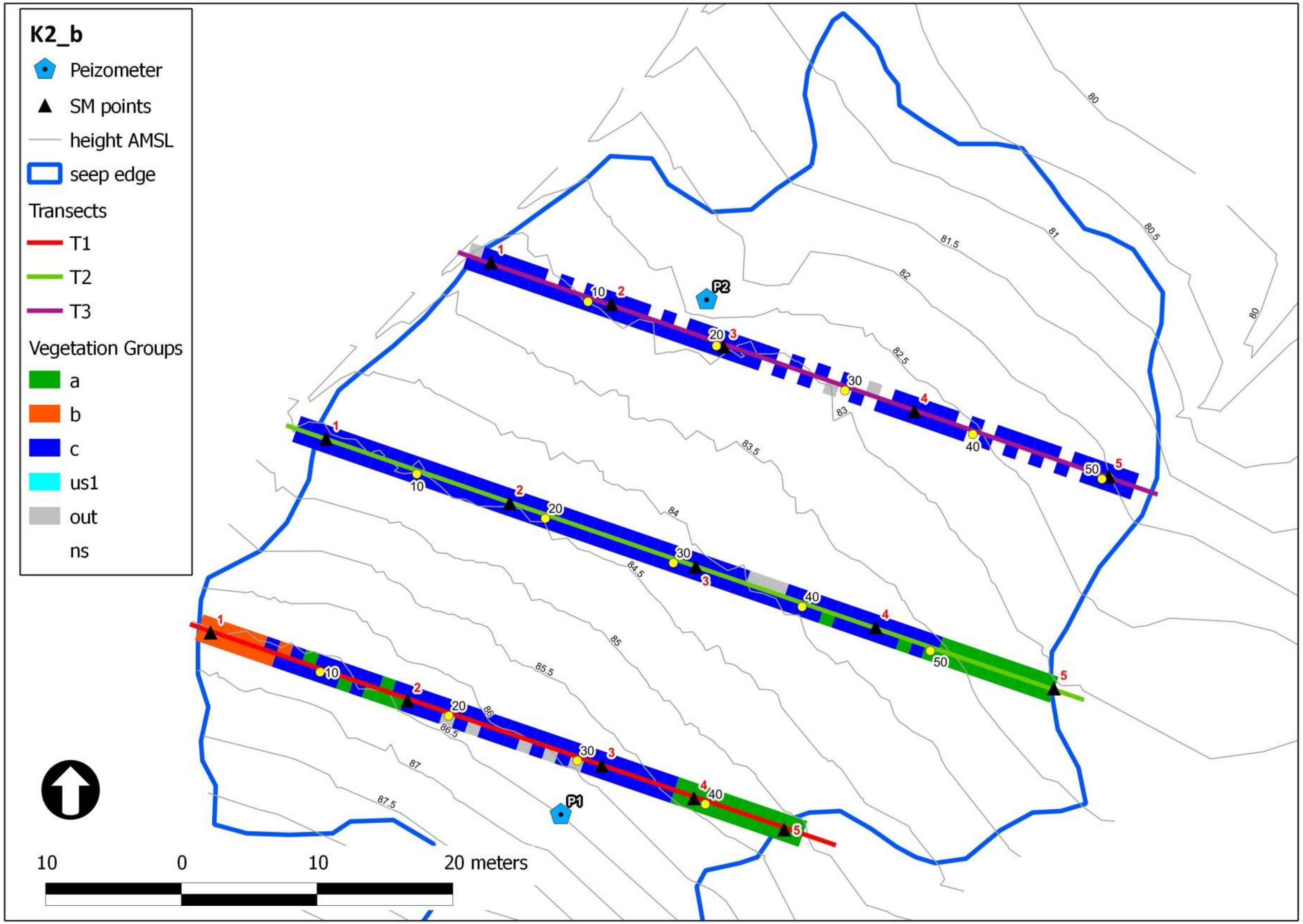


Figure 9.9 Diagrammatic representation of all plots at K_2b, colour coded according to the plant community that each represents. The light grey plots represent outliers and the plots that were not sampled (ns) are left blank.

The links to soil moisture variables are addressed in more detail the following section.

The key indicator species of each of the groups are described in Appendix 1 and summarised as follows:

Group a: *Othonna quinquedentata*

Group b: *Ficinia distans* – seeps on lower slopes, threatened status VU (SANBI)

Group c: *Berzelia lanuginosa*

The average abundance (% cover) of each of these key indicator species at K_2b is shown in Figure 9.10.

The similarity percentages given in Table 9.8 emphasise the lack of distinction between plant communities identified at K_2b, and may explain why there is a poor overlap between these communities and the soil moisture conditions described above. Although within-group similarity for Group b was relatively high at 60% indicating relatively good cohesion among plots within this group, Group b shared 44% similarity with Group c. *Ficinia distans*, the key indicator species for Group b (Figure 9.10), is a Vulnerable species described as characteristic of moist seeps on lower slopes (SANBI Red Data list website), occurs in both Groups b and c, but mainly along the western edge of the seep where is abuts the stream, and particularly at T1. Its near-absence in Group a plots is largely responsible for the low similarity between these groups (29% Table 9.8), suggesting a gradient along Transect 1, but not one that appears to be related to the soil moisture measurements.

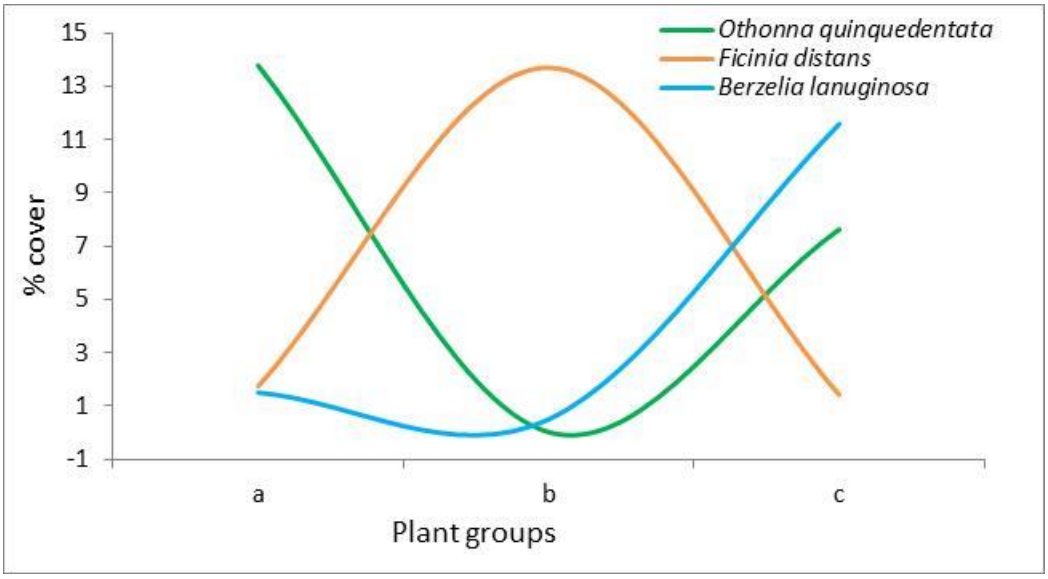


Figure 9.10 Average abundance (% cover) of indicator species for plant groups identified at K_2b.

Table 9.8 Average similarity within and between plant groups at K_2b.

	a	b	c
a	51		
b	29	60	
c	40	44	51

9.2.3.2 Key environmental drivers of community structure

DistLM analysis was used to determine with variables best described variability in plant community structure. From the analysis it is evident that:

- Less than 15% of the variability in the vegetation was explained by any single environmental variable measured during the assessment (Table 9.9). This suggests that factors other than soil moisture, substratum type and the various other factors measured are the key drivers of variability in the vegetation at this site.

Table 9.9 Results of the DistLM analysis: relationship between plant species composition and environmental variables at K_2b based on a Euclidean Distance matrix. '% variation explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different (p ≤ 0.05) relationships are shown.

Environmental variable	Parameter	*p*	% variation explained	
MARGINAL TESTS [1]				
Soil moisture	$L1\_D_{sd}$	0.0001	10.432	
	$L1\_D_{runmax}$	0.0001	9.7567	
	$L1\_W_{runmax}$	0.0001	13.826	
	$L2\_W_{runmax}$	0.0001	10.462	
	$L3\_W_{runmin}$	0.0001	9.2213	
	$L3\_D_{runmax}$	0.0001	9.2945	
SEQUENTIAL TESTS [2]	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Soil moisture	$L1\_W_{runmax}$	0.0001	13.8	13.8
	$+L1\_D_{sd}$	0.0001	8.1	21.9
	$+L3\_W_{runmin}$	0.0001	5.4	27.3
	$+L2\_D_{sd}$	0.0001	5.5	32.8
	$+L2\_W_{runmax}$	0.0001	3.5	36.3
	$+L0\_D_{sd}$	0.0001	3.3	39.6
	$+L3\_D_{sd}$	0.0001	5.0	44.7
	$+L0\_W_{runmin}$	0.0001	5.2	49.9
	$+L3\_Sat_{dur}$	0.0001	2.3	52.2
	$+L3\_D_{runmin}$	0.0001	3.1	55.3
	$+L2\_W_{sd}$	0.0001	3.7	58.9
	$+L1\_W_{runmax}$	0.0001	1.9	60.8
	$+L0\_D_{runmin}$	0.0006	1.9	60.8
	$+L2\_W_{runmin}$	0.0009	1.1	63.2

[1] *Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.*
[2] *Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.*

- Nevertheless, 14 soil moisture parameters representing the full wetland soil profile (to 50 cm), together described 63% of the variability in the vegetation at this site (sequential tests, Table 9.9).

An ordination of the fitted model given in the dbRDA plot in Figure 9.11a shows very little distinction between the three plant communities based on the measured soil moisture parameters at this site. Nevertheless, the bubble plot of L1_Wrunmax indicates that there is some difference between Group a and the other two groups along dbRDA 1 with a lower average of the three wettest consecutive wet season months for plots within Group a (Figure 9.11).

Considering the recent burning of K_2b, the plant community patterns observed during this assessment may describe different recovery / recruitment adaptations of various species, which may account more for spatial variation than soil moisture which shows no strong spatial differentiation over the site.

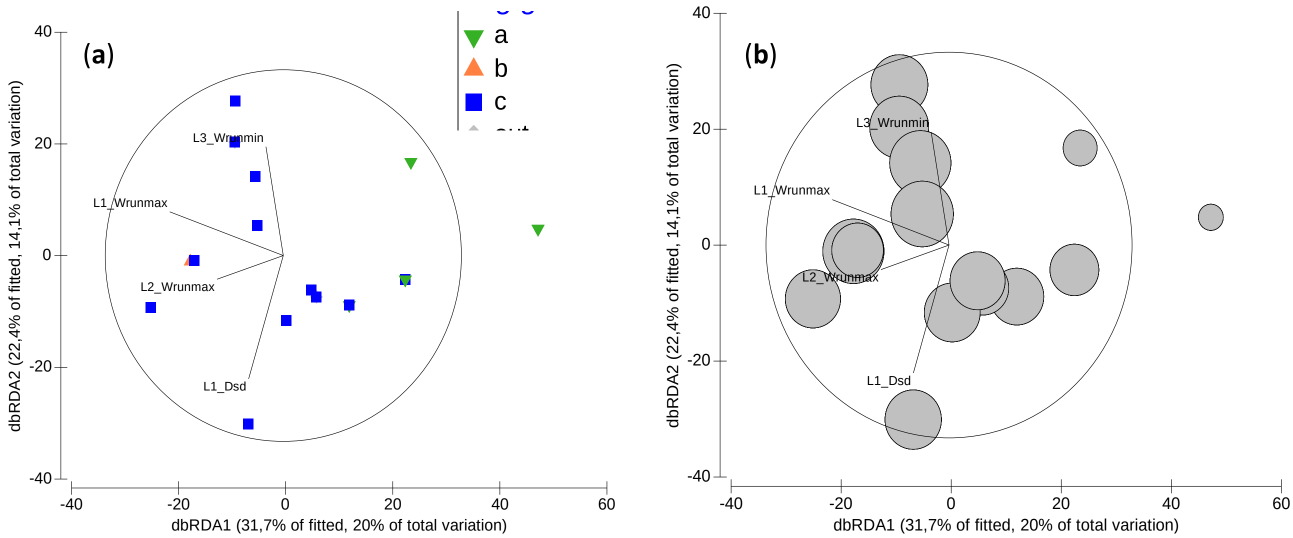


Figure 9.11 dbRDA ordination of plant species represented by the subset of data at K_2b. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) gives the distribution of data represented by the plant communities identified in the hierarchical cluster analysis. The bubble overlay of b) L1_Wrunmax shows a weak relationship between plant community composition and soil moisture - the larger the bubble, the greater the soil moisture content.

9.2.3.3 Year-on-year comparison of monitoring plots

On average, the year-on-year similarities of plots were greater than 60% (Figure 9.12) suggesting that the species composition of individual plots did not change considerably between 2011 and 2012. This is surprising, considering that the site was burnt in 2010 and that the community is in a state of recovery following fire damage when temporal changes are expected. However, temporal changes in vegetation composition may only become apparent over a longer time frame and thus baseline monitoring in sub sequent years is essential to describe longer term average characteristics of plant communities at the site.

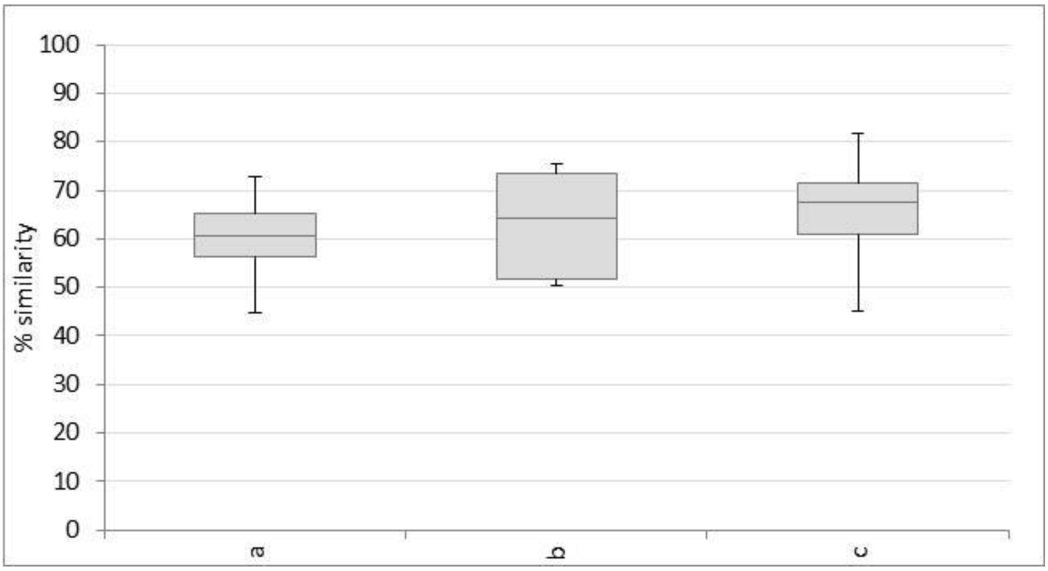


Figure 9.12 Percentage similarity in species composition between individual plots monitored in 2011 and 2012 at K_2b. The data are summarised by the plant community affiliation of each plot.

9.2.3.4 Inter-annual change in the height of dominant species

Despite little year-on-year difference in species composition between plots at K_2b, a comparison between 2011 and 2012 of the average height per species of the tallest individuals in each plot shows both a shift in the species that are the tallest, and growth (i.e. an increase in height) from 2011 to 2012 of these species. In particular, *Berzelia lanuginosa,* which was the key indicator species for Group c*,* increased its representation as one of the tallest species from 17% in 2011 to 26% in 2012 and the average height of this species more than doubled within a year (Table 9.10). Similarly, *Cliffortia odorata* almost doubled in height on average and increased from 13% to 26% in its representation as one of the tallest species from 2011 to 2012. By contrast, the number of plots where *Elegia thyrsifera* was one of the tallest decreased considerably from 2011 to 2012, even though the average height of this species increased over the year. Also, the representation of *Othonna quinquedentata*, as the tallest in 2011 decreased considerably in 2012, despite a substantial increase in growth (almost 1 m). The representation of *Pteridium aquilinum* as one of the tallest species also declined between 2011 and 2012. These data suggest that the community may still be in an early successional stage following the fire damage in 2011.

9.2.4 Ecoseep K_5b

9.2.4.1 Plant communities

Four distinct plant communities were identified through PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes, and were extrapolated to all plots in the dataset.

The diagrammatic representation of the plots (Figure 9.13) shows the distribution of per community. A comparison with this distribution and the temporal changes in soil moisture of the site in Section 7 (see Figure 7.23) suggests that plots in Group a and b are defined by generally greater moisture levels, whilst plots in the north-eastern corner of Transect 1 reflect seasonally drier conditions – this portion of the seep being characterised by Group d plots. Group a plots track the wettest portion of the seep based

Table 9.10 Average height (m) of the tallest three individual plants in each plot measured in 2011 and in 2012 at K_2b. The number of plots and the percentage of the total number of plots represented by each species is also given.

Species	2011				2012			
	#Plots: 289		Total N: 832		#Plots: 227		Total N: 651	
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Aulax umbellata	1	0.35	0.60					
Berzelia lanuginosa	49	16.96	0.31	0.18	59	25.99	0.75	0.23
Bobartia gladiata	1	0.35	1.15		2	0.88	0.85	0.21
Carpacoce spermacocea	9	3.11	0.35	0.23	51	22.47	0.70	0.22
Cassytha ciliolata	21	7.27	0.73	0.30	15	6.61	1.17	0.41
Chrysitrix capensis					2	0.88	1.00	0.00
Cliffortia heterophylla	1	0.35	0.55		2	0.88	1.15	0.21
Cliffortia odorata	37	12.80	0.49	0.14	59	25.99	0.95	0.21
Ehrharta setacea subsp. *uniflora*	1	0.35	0.40					
Elegia thyrsifera	134	46.37	1.38	0.23	68	29.96	1.51	0.17
Epischoenus gracilis	4	1.38	0.70	0.14	2	0.88	0.80	0.00
Epischoenus villosus/quadrangularis complex	35	12.11	0.70	0.20	35	15.42	1.02	0.62
Erica hispidula	3	1.04	0.10	0.00	2	0.88	0.30	0.14
Erica muscosa					4	1.76	0.65	0.24
Erica perspicua	8	2.77	0.29	0.09	35	15.42	0.85	0.25
Ficinia acuminata	1	0.35	0.46					
Ficinia capillifolia					3	1.32	0.53	0.15
Ficinia distans	8	2.77	0.53	0.13	3	1.32	0.63	0.06
Ficinia zeyheri	6	2.08	0.48	0.54	5	2.20	0.22	0.11
Gnidia humilis	1	0.35	0.60					
Gnidia oppositifolia	2	0.69	1.30	0.28	4	1.76	1.88	0.15
Gnidia oppositifolia cut back					1	0.44	2.00	
Indigofera ionii	5	1.73	0.61	0.21				
Leucadendron salicifolium	1	0.35	0.50		4	1.76	0.98	0.13
Neesenbeckia punctoria	68	23.53	1.27	0.30	66	29.07	1.45	0.27
Osmitopsis asteriscoides	49	16.96	0.66	0.32	51	22.47	1.04	0.31
Othonna quinquedentata	87	30.10	0.69	0.27	38	16.74	1.59	0.38
Penaea mucronata					3	1.32	0.67	0.25
Platycaulos compressus	78	26.99	1.06	0.21	55	24.23	1.24	0.20
Psoralea pinnata	33	11.42	1.20	0.34	13	5.73	1.95	0.55
Pteridium aquilinum	92	31.83	0.60	0.20	29	12.78	0.91	0.19
Pteridium aquilinum - dead					13	5.73	0.58	0.15
Retsia capensis	2	0.69	0.88	0.32	1	0.44	1.20	
Senecio rigidus	47	16.26	1.26	0.25				
Struthiola myrsinites	1	0.35	0.60					
Ursinia caledonica	1	0.35	0.50					
Watsonia angusta	43	14.88	0.78	0.28	24	10.57	1.07	0.19
Watsonia borbonica	3	1.04	1.03	0.06				
Widdringtonia nodiflora					1	0.44	1.40	
Widdringtonia nodiflora - dead					1	0.44	3.40	

on average soil moisture (section 7, Figure 7.23Figure 7.23), along with Group b, whilst Group c plots occur mostly in the lower (Transect 3) portions of the site. All parts of the seep are characterised as seasonally saturated, however (see section XXX). The links with soil moisture are addressed in more detail in the next section.

Key indicator species for each of these groups are described in Appendix 1 and summarised as follows:

Group a - *Psoralea aphylla* – obligate wetland species

Group b - *Ficinia zeyheri*- facultative wetland species

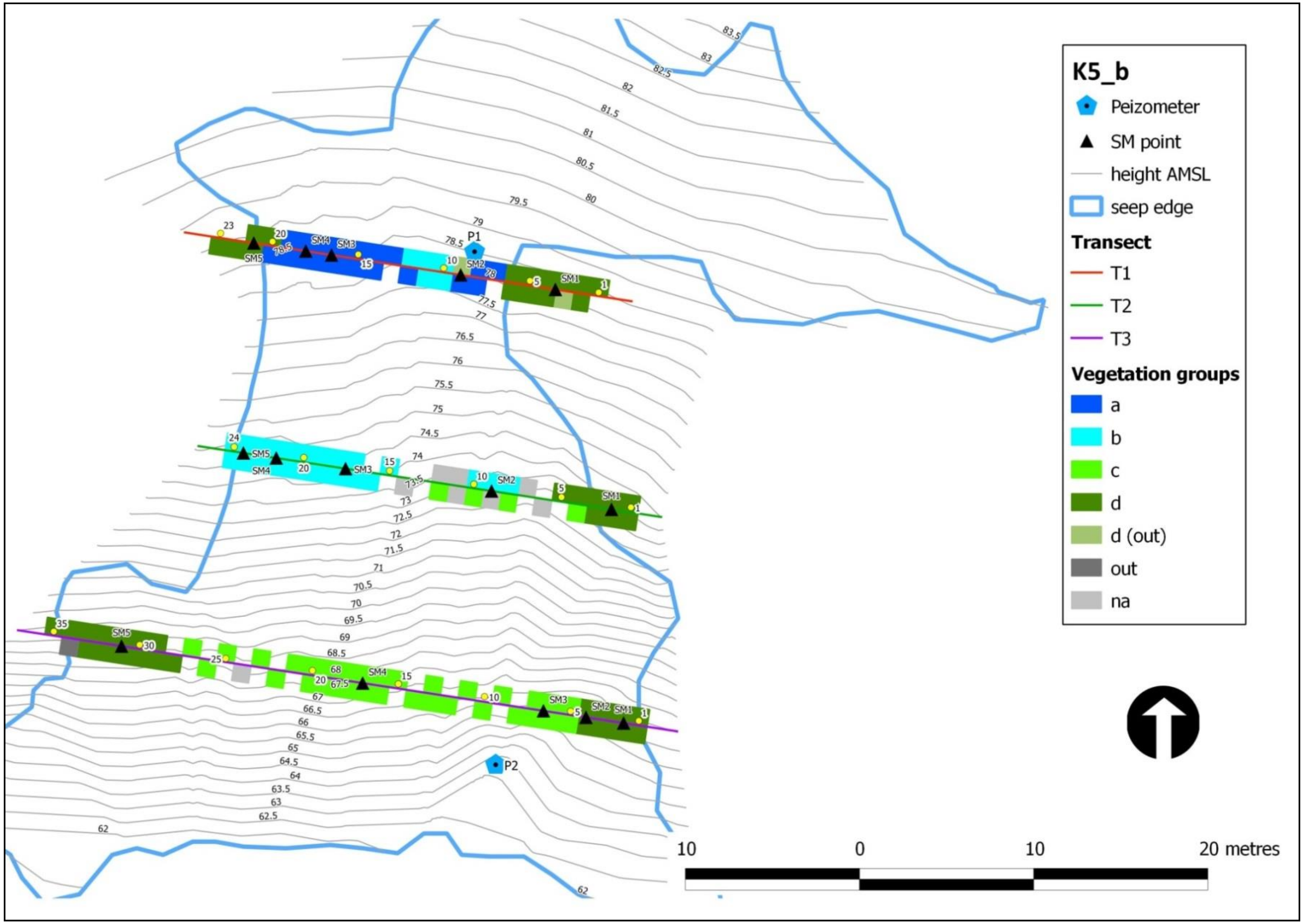


Figure 9.13 **Diagrammatic representation showing the position of all plots at K_5b, colour coded according to the plant community (Group) that each represents. Group d (out) represents outliers of group d, while the complete outlier is indicated by the dark grey plot. The light grey plots (na) represent those that could not be assigned to a vegetation group through extrapolation. Gaps in plots along the transect (ns) are plots that were not sampled as part of the monitoring programme.**

Group c - *Indigofera filifolia*- facultative wetland species

Group d - *Ehrharta setacea* subsp. *uniflora*- - – seeps on lower slopes, threatened status VU (SANBI)

The average abundance (% cover) of each of these key indicator species is shown in Figure 9.13Figure 9.14.

The most prevalent (key indicator) species in Group d plots was *Ehrharta setacea* subsp. *uniflora* which is described as a Vulnerable species characteristic of moist seeps on lower slopes (SANBI Red Data list website). However the community represented by Group d plots also contained *Pteridium aquilinum* as a sub-dominant species, this often associated with drier conditions at these monitoring sites (see Appendix 1). Group a plots were dominated by the obligate wetland species, *Psoralea aphylla* and *Todea barbara*, although these species were also sub-dominant key species in Group b and c plots respectively, and thus not good distinguishers between groups.

Group a, the "wettest" of the four groups had the greatest within group similarity while Group d, the "driest" group along the margins had the lowest degree of within group similarity. Also Groups a and d were the least similar to each other as reflected by the lowest between group similarity (Table 9.11). Nevertheless, the distinction between groups was not particularly high as indicated by the relatively high percentage similarity between these groups.

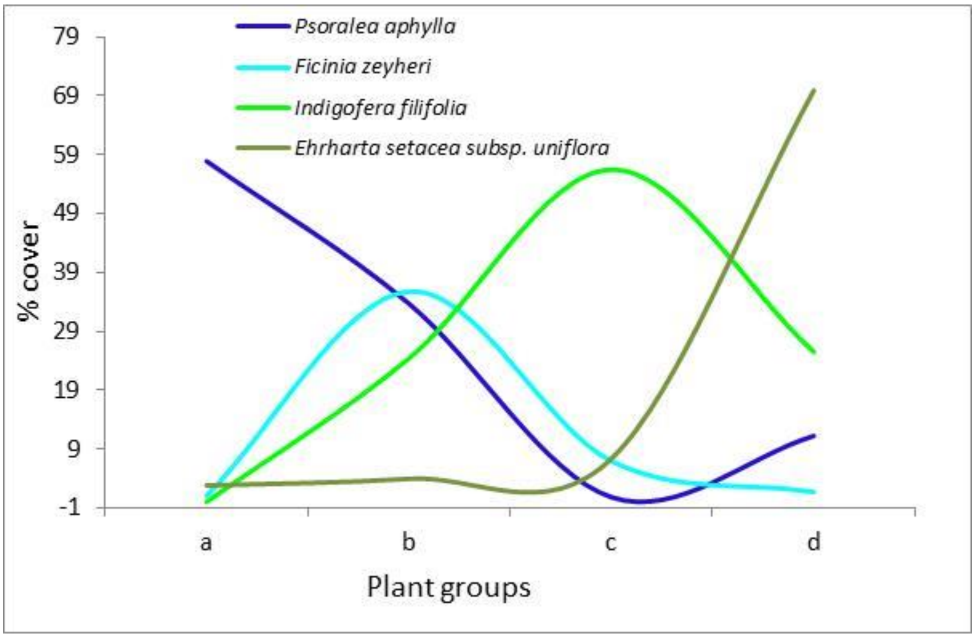


Figure 9.14 Average abundance (% cover) of indicator species for plant groups identified at K_5b.

Table 9.11 Average similarity within and between plant groups at K_5b.

	a	b	c	d
a	57			
b	43	55		
c	33	41	55	
d	30	33	33	52

9.2.4.2 Key environmental drivers of community structure

DistLM analysis of the vegetation composition in relation to various environmental variables was used to determine with variables best described variability in plant community structure. Soil moisture parameters from the deep profile (i.e. 30-50 cm) could not be included in the analysis because the soils were generally shallow at this site and only limited data were collected below 30 cm. From the analysis it was evident that:

- No single measured parameter described a substantial portion of the variability in plant communities at this site (Table 9.12).
- the average soil moisture minimum over both the driest three (consecutive) dry season (L1_Drunmin) and wet season (L1_Wrunmin) between 10-30 cm depth described around 12% of the variability, while all other parameters individually described less than 10% of the variability in plant community structure at this site (Table 9.12: marginal tests).
- A combination of eight variables, including seven soil moisture parameters as well as the % cover of bare rock or soil, together described a total of 50% of the variability in plant community structure (Table 9.12: sequential tests).

Table 9.12 Results of the DistLM analysis: relationship between plant species composition and environmental variables at H8_3b based on a Euclidean Distance matrix. '% variation explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different (p ≤ 0.05) relationships are shown.

Environmental variable	Parameter	*p*	% variation explained	
MARGINAL TESTS [1]				
Soil moisture	$L0\_D_{sd}$	0.031	3.1	
	$L0\_W_{sd}$	0.0184	3.5	
	$L0\_D_{runmin}$	*0.0002*	*6.9*	
	$L1\_Sat_{dur}$	0.0279	3.3	
	$L1\_D_{sd}$	*0.0048*	*4.2*	
	$L1\_W_{sd}$	*0.0208*	*3.4*	
	$L1\_D_{runmin}$	*0.0001*	*11.9*	
	$L1\_W_{runmin}$	*0.0001*	*11.3*	
	$L1\_W_{runmax}$	*0.0001*	*9.5*	
Substratum	*% cover*	*0.0015*	*5.1*	
Bare soil/rock	*% cover*	*0.0008*	*5.8*	
SEQUENTIAL TESTS [2]	**Parameter**	**p**	**% variation explained**	**Cumulative % variation explained**
Soil moisture	*$+L1\_D_{runmin}$*	*0.0001*	*11.891*	*11.9*
	$+L1\_Sat_{dur}$	*0.0001*	*5.8557*	*17.7*
	$+L0\_D_{sd}$	*0.0001*	*5.3621*	*23.1*
Bare soil/rock	*+% cover*	*0.0002*	*5.1072*	*28.2*
	$+L0\_W_{sd}$	*0.0002*	*4.7519*	*33.0*
	$+L1\_W_{sd}$	*0.0003*	*4.3952*	*37.4*
	$+L1\_W_{runmin}$	*0.0001*	*4.6782*	*42.0*
	$+L1\_W_{runmax}$	*0.0018*	*2.9069*	*44.9*

[1] Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.
[2] Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.

- both the marginal tests and the sequential tests, suggest that of the soil moisture parameters measured, those at a depth between 10 and 30 cm are the best (although relatively poor) predictors of vegetation communities at this site (Table 9.12).

Despite the tentative link between soil moisture and plant community structure at this site, an ordination of the fitted model given by the dbRDA plot in Figure 9.15 shows some separation of the plant communities based on soil moisture parameters. In particular, the ordination plots show that:

- Group d, the "driest" group was separated from all other plant communities largely along dbRDA1 (Figure 9.15a). This separation is based largely on the difference in L1_Drunmin between Group d and the other three "wetter" groups, indicating that plots within Group d were generally drier during the dry season between 10-30 cm, although the distinction is not particularly evident given the bubble plots in Figure 9.15b.

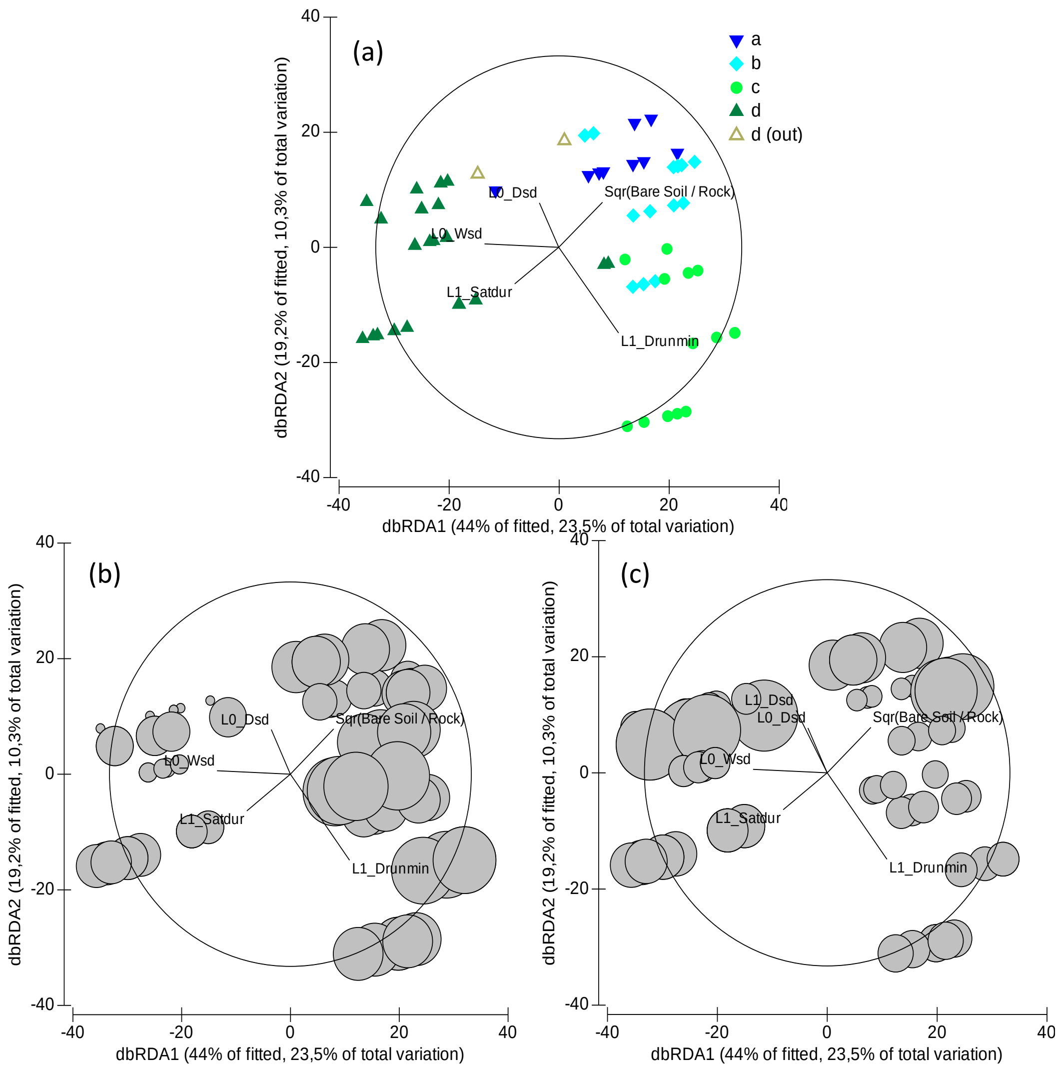


Figure 9.15 a) dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at K_5b. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) is colour coded according to the plant communities defined by the cluster analysis. The bubble plots show the distribution of plots relative to b) L1_Drunmin and c) L1_Dsd – the larger the bubble, the greater the soil moisture content.

- Groups a and b appear to be separated from Group c along dbRDA 2 (Figure 9.15a) and this separation appears to be driven by a difference in the variability in soil moisture over the dry season between 10-30 cm (L1_Dsd) (Figure 9.15c).
- The average dry season minimum at depths of 50 cm or greater (L3_Drunmin) was highest for plots belonging to Group c, and lowest for plots in Groups a and d (Figure 9.7c). Evidently, soil moisture at plots represented by Groups a and b, vary more than those in Group c during the dry season.

Although there is some evidence of a link between soil moisture and plant communities at K_5b, the evidence from this dataset is tentative, and may relate to the fact that soil moisture differences across the site are not large and plant communities are fairly similar. Considering that this site burnt in March 2011, it is possible that the community structure is still undergoing succession. It is possible that both community differentiation and links between soil moisture and plant communities at this site will strengthen as the plant communities recover from fire disturbance. It is therefore recommended that the baseline assessment for identifying plant communities for possible change in soil moisture content be established once the seep has reached its climax community.

9.2.5 Ecoseep K_6

9.2.5.1 Plant communities

Five distinct plant communities were identified through PRIMER cluster analysis of the 2012 species data from the monitoring plots that were linked to soil moisture probes, and were extrapolated to all but four plots in the dataset.

The diagrammatic representation of all plots along the three sampling transects, colour coded according to the plant community Group that each represents is shown in Figure 9.16. As expected plots associated with the upper western portion of the seep formed a distinct group (Group d) which was also associated with wetter soil moisture patterns over the year. A second distinct group, Group e, was associated with conditions that were visually assessed as being wetter than the adjacent area during site establishment, and linked to the placement of the lower Piezometer P2 (Figure 9.16). This moisture difference, however, was not demonstrated by the soil moisture patterns reflected in the animation of temporal changes in soil moisture of the site given in 7, Figure 7.28, which rather shows a gradient of increasing soil moisture from north-east to south-west, with the wettest conditions at the south-central portion of Transect 1(Group d plots) and southern end of Transect 3 (corresponding with Group b plots). A noteworthy feature of the soil moisture monitoring results is that they show the site to be seasonally saturated at almost all points, with little differentiation in terms of hydroperiod classification across the site (except for the afore-mention areas), and so the soil moisture patterns should be seen in the context of a site that is fairly uniform in moisture patterns, and more seasonal than many of the other ecoseeps.

The links between the various soil moisture variables and plant communities are addressed in more detail in the next section.

Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a: *Indigofera glomerata* - facultative wetland species

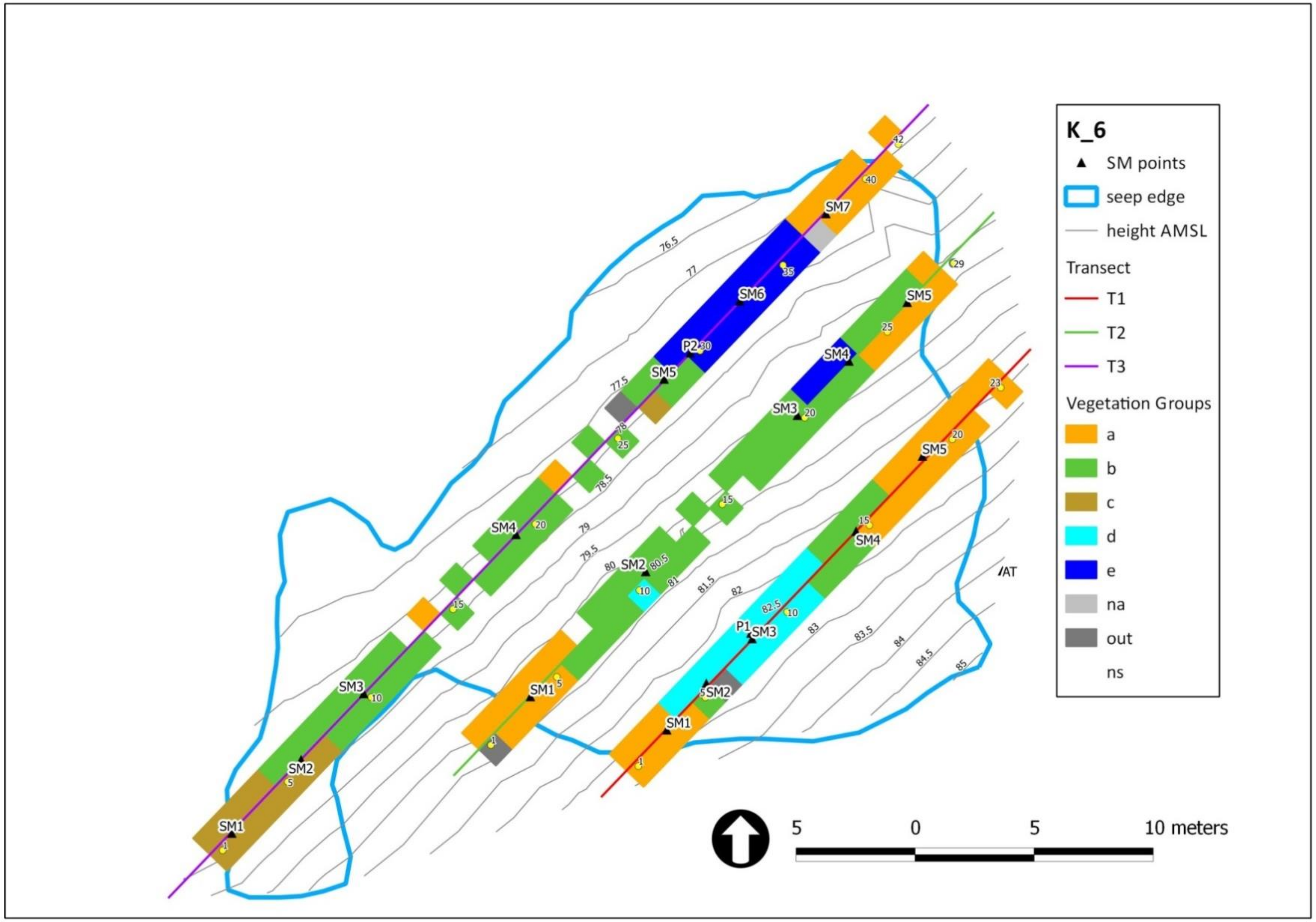


Figure 9.16 Diagrammatic representation of all plots at K_6, colour coded according to the plant community that each represents. The dark grey plots represent outliers, while those that could not be assigned to a plant community through extrapolation are represented as light grey plots (na). Gaps in plots along the transects (ns) are plots that were not sampled as part of the monitoring programme.

Group b: *Ficinia trichodes* - facultative dry land species

Group c: *Culumia setosa* var *setose* – usually found in dry sandstone slopes (Reinecke and Brown 2013)

Group d: *Ficinia distans* – seeps on lower slopes, threatened status VU (SANBI)

Group e: *Elegia thyrsifera* – obligate wetland species

The average abundance (% cover) of each of these key indicator species is shown in Figure 9.17.

Plots on both the left and right margins of the wetland were within the Group a community, with *Indigofera glomerata* distinguishing this community from the others at K_6. The other species prevalent in Group a plots were *Carpacoce spermacocea* and *Cassytha cilliolata* (see Appendix 1), but these were generally also prevalent in Group b, and c plots, making *I. glomerata* the key distinguisher between Group a and these plant groups. Similarly, *Culumia setosa* was the key distinguishing species for Group c, indicating its drier status. The greatest similarity among plots was evident for Group c, which represents the drier wetland margin at the end of Transect 3 (Figure 9.16). However, Group c was most similar to Group b, with an overlap in "key species" between these groups (Figure 9.17). That and the fact that Group b plots extend across areas of the seep with different soil moisture conditions suggests that the community is not well differentiated, probably the result of the early succession stage at this site.

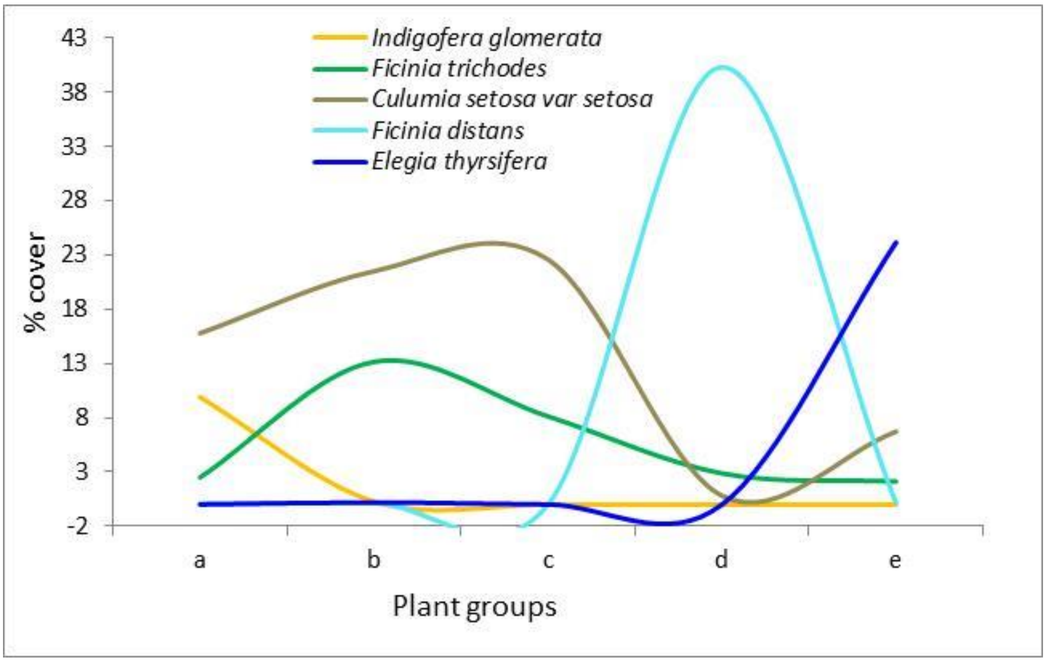


Figure 9.17 **Average abundance (% cover) of indicator species for plant groups identified at K_6.**

Table 9.13 **Average similarity within and between plant groups at K_6.**

	a	b	c	d	e
a	46				
b	36	49			
c	31	40	58		
d	22	33	20	55	
e	27	39	24	33	51

The two "wetter" groups (i.e. Groups d and e) had relatively high within-group similarity, suggesting cohesion between plots within these groups. Although both were characterised by relatively high cover values of *Psoralea pinnata* (see Appendix 1), Group d was differentiated by the high cover of *Ficinia distans* in these plots (Figure 9.17), the same species that characterised the wet-seep edge at K_2b (SANBI threatened status Vulnerable). *Elegia thyrsifera*, characteristic of damp slopes differentiated Group e plots. Although this species was not well represented across all plots in Group e, it is the one species that distinguishes this group from all others. *Psoralea aphylla* was well represented in Group e and distinguishes this group from most others, but was also a co-dominant in group d so it is not a good overall discriminator of Group e.

The poor overlap between the plant indicators of Group e and the soil moisture "picture" presented of the site is probably influenced by the fact that soil moisture tubes were restricted in depth of installation by the rocky ground. Section XX shows that whilst the upper layers of the soil, to 30 cm, do dry out, where there are deeper moisture tubes, these show far less seasonality at depth. It is likely that the vegetation is responding to conditions at depth, rather than at the surface.

9.2.5.2 Key environmental drivers of plant community structure

Soils were generally shallow at this site and therefore only soil moisture parameters measured to a depth of 30 cm could be used in the DistLM analysis for determining which variables best account for the variability in plant community structure. From the analysis it was evident that:

- Only a small proportion (10% or less) of the variability in plant community composition at K6 could be attributed to environmental factors measured at this site (Table 9.14: marginal tests).
- The % cover of bare rock or soil was the single best predictor of plant community composition at this site but this variable only accounted for 10.5% of the variability (Table 9.14: marginal tests).
- A combination of 15 parameters, including the % cover of bare rock or soil, as well as 13 soil moisture parameters and the vegetation canopy cover together described a total of 55% of the variability in plant community structure (Table 9.14: sequential tests).

Despite the tentative link between soil moisture and plant community structure at this site, an ordination of the fitted model given by the dbRDA plot in Figure 9.18 shows some separation of the plant communities based on the measured environmental factors. In particular, the ordination plots show that:

- Groups a and c typical of the marginal habitat separated from Groups d and e typical of the wetter areas of the wetland, largely along dbRDA1 (Figure 9.18a).
- However, the bubble plot in Figure 9.18b suggests that this distinction is based largely on the difference in the % of bare rock or soil (which is greater along the outer margins), rather than on any of the soil moisture parameters for this site.
- Some distinction between groups can however be attributed to the average dry season soil moisture between 10-30 cm (L1_Dave) (Figure 9.18c) and the average dry season minimum soil moisture concentration at the same depth (L1_Drunmin) (Figure 9.18d). In particular, these two soil moisture parameters show some separation between Group d (characteristic of the margins) and Group a (characteristic of the central channel).

Table 9.14 Results of the DistLM analysis: relationship between plant species composition and environmental variables at K_6 based on a Euclidean Distance matrix. '% variation explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different (p ≤ 0.05) relationships are shown.

Environmental variable	Parameter	*p*	% variation explained	
***MARGINAL TESTS*[1]**				
Soil moisture	$L0\_Sat_{dur}$	0.0001	5.8	
	$L0\_W_{ave}$	0.0001	**6.3**	
	$L0\_D_{sd}$	0.0001	8.9	
	$L0\_W_{sd}$	0.0001	6.8	
	$L0\_D_{runmax}$	0.0072	2.7	
	$L0\_W_{runmax}$	0.0001	**7.5**	
	$L1\_Sat_{dur}$	0.0001	**7.8**	
	$L1\_D_{ave}$	0.0001	**6.6**	
	$L1\_D_{sd}$	0.0001	8.6	
	$L1\_D_{runmin}$	0.0001	4.7	
	$L1\_D_{runmax}$	0.0001	7.3	
	$L1\_W_{runmax}$	0.0001	6.5	
		0.0001	6.7	
Debris cover on ground	% cover	0.0001	**4.7**	
Substratum	% cover	0.0002	4.5	
Vegetation canopy cover	% cover	0.0001	7.5	
Bare soil/rock	% cover	0.0001	**10.5**	
***SEQUENTIAL TESTS*[2]**	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Bare soil/rock	+%cover	0.0001	10.5	10.5
Soil moisture	$+L1\_D_{ave}$	0.0001	6.6	17.1
	$+L1\_D_{runmin}$	0.0001	9.8	26.9
	$+L0\_W_{ave}$	0.0002	2.9	29.8
	$+L0\_D_{ave}$	0.0001	3.5	33.2
	$+L0\_W_{sd}$	0.0001	3.2	36.4
Vegetation canopy cover	+%cover	0.0001	2.4	38.8
Soil moisture	$+L0\_Sat_{dur}$	0.0009	1.9	40.7
	$+L1\_W_{runmax}$	0.0003	2.2	42.9
	$+L0\_W_{runmax}$	0.0001	2.3	45.2
	$+L0\_D_{runmax}$	0.0001	2.1	47.3
	$+L1\_D_{sd}$	0.0015	1.6	49.0
	$+L1\_Sat_{dur}$	0.0001	2.1	51.1
	$+L0\_D_{sd}$	0.0001	2.5	53.6
	$+L1\_D_{runmax}$	0.0005	1.6	55.2

[1] *Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.*

[2] *Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.*

The tentative evidence of a link between soil moisture and vegetation communities at K_6 may relate to the shallow depth of the majority of soil moisture tubes, which placed limitations on the data set that could be used. Deeper soil moisture probes indicate that seasonal patterns of wetting and drying are different at depth from the surface, and this is probably more influential in the vegetation. A second caveat is that, as was the case for many other monitoring sites, K_6 was burnt in June 2010, and therefore it is possible that the community is in a state of early succession following fire damage. However, based on the spatial arrangement of plots into communities representative of the "drier" wetland margins and central "wetter" areas, as well as the patterns evident in the ordination plots, it is likely that the links between soil moisture and plant communities at this site will strengthen as the plant communities recover from fire disturbance. It is therefore recommended that the baseline assessment for identifying plant communities for possible change in soil moisture content be established once the seep has reached its climax community.

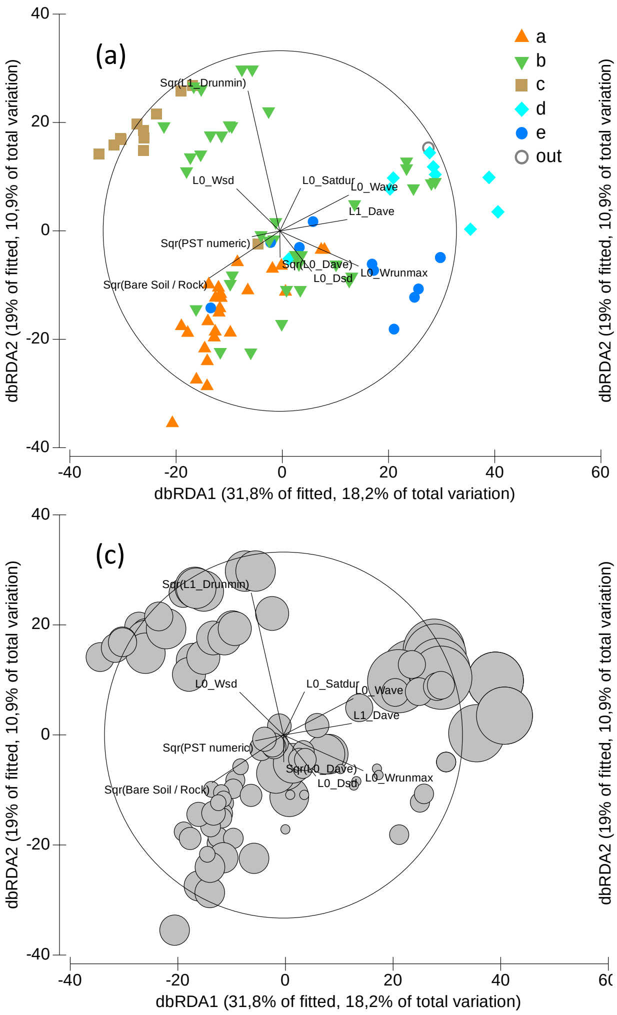


Figure 9.18 dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at K_6. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) is colour coded according to the plant communities defined by the cluster analysis. The bubble plots show the distribution of plots relative to b) % cover of bare soil or rock; c) L1_Dave and d) L1_Drunmin – the larger the bubble, the greater the soil moisture content.

9.2.6 Ecoseep T3_Pal 4

9.2.6.1 Plant communities

Four distinct plant communities were identified in the analysis of 107 plots linked to soil moisture probes. An additional group, with unknown links to soil moisture[7], was identified from the extrapolation of the cluster analysis to 129 plots.

Figure 9.19 is a diagrammatic representation of all plots along the three sampling transects, colour-coded according to the plant community Group that each represents. Group a, which was relatively distinct from the other groups in the cluster analysis (see Appendix 1) was associated with the perennial central spring in the north-western corner of the seep,and wet seep line crossing Transect 1 but extending to a few plots following the seep line along Transect 2. Group c plots formed a cluster overlapping Group a in the core / spring area of the seep, and along the northern border of the seep, Transect 3, where the main seepline meets the river channel downstream of P2 (Figure 9.19). A comparison of the spatial arrangement of the plant communities along the transects with the animation of temporal changes in soil moisture over the site given in Section 7, Figure 7.33 confirms these as the perennially wet portions of the seep.

The soil moisture animation show an abrupt shift is soil moisture content along Transect 1, consistent with the shift in plant communy from Group a to Group b as shown in Figure 9.19. Group b plots formed the bulk of the centre and south-western portion of the seep, which is the driest, the analysis of soil moisture in Section 7, Figure 7.33 showing this to be intermittently saturated, while Group d plots comprised the northern portion of Transect 2 and extended across most of the lower portion of the seep, on Transect 3, these plots characterised by a mixture of conditions from seasonal to intermittent, based on soil moisture patterns, characterising this group as transitional between the wet and intermittent portions of the seep.

Whilst *Seriphium cinereum* was a dominant species in all but Group a plots, key indicator species that best distinguished between groups are described in Appendix 1 and are summarised as follows:

Group a: *Soroveta ambigua*

Group b: *Pentameris colorata* – usually found in dry sandstone slopes (Reinecke and Brown 2013)

Group c: *Epischoenus quadrangularis/villosus* complex – facultative wetland species

Group d: *Ficinia zeyheri* – facultative wetland species

Group us 1: *Ehrharta ramosa* – facultative wetland species

The average abundance (% cover) of each of these key indicator species is shown in Figure 9.20.

Based on the similarity percentages given in Table 9.15, all groups at this site were reasonably coherent, with all within-group similarities greater than 50%. The greatest distinction between Groups was evident between Group a and Group us 1, as well as Group b, which represent the wettest (i.e. the seep line at transect 1) and the two driest (i.e. the central and southern margins of the site) habitats respectively. The transitional character of Group d is illustrated by its relatively

[7] *Since this group represents a distinct plant community, it would be important in the future to install soil moisture probes adjacent to the core plots of these groups, to relate change in this community to soil moisture.*

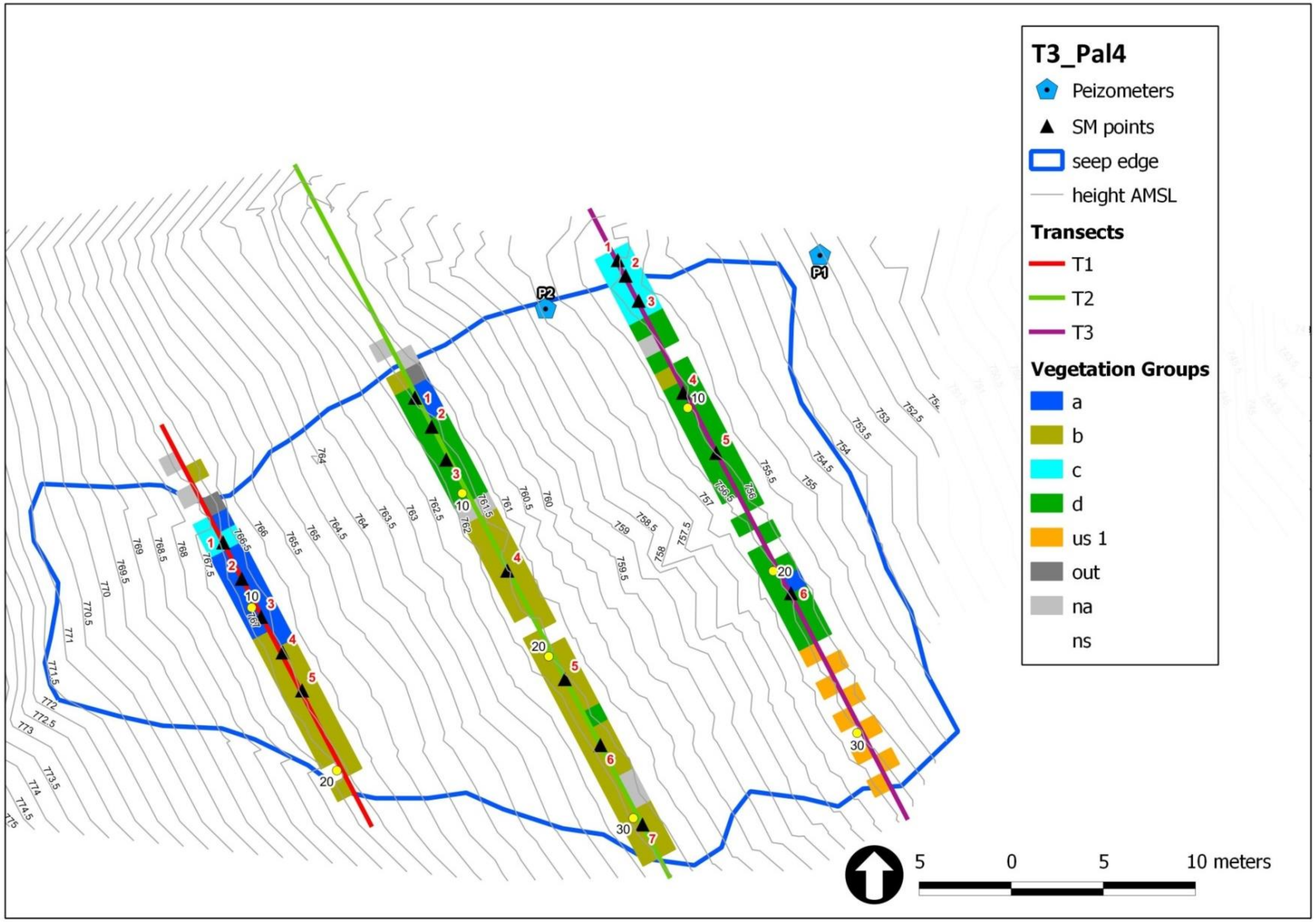


Figure 9.19 Diagrammatic representation of all plots at T3_Pal4, colour coded according to the plant community (Group) that each represents. The dark grey plots represent outliers, while those that could not be assigned to a plant group through extrapolation are represented as light grey plots (na). Gaps in plots along the transects (ns) are plots that were not sampled as part of the monitoring programme.

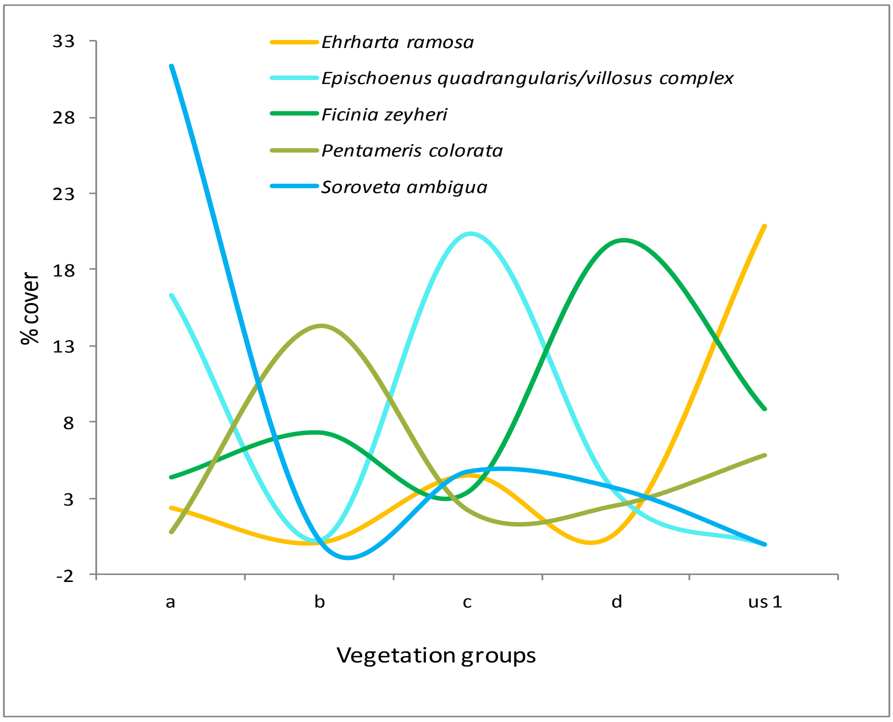


Figure 9.20 Average abundance (% cover) of indicator species for plant groups identified at T3_Pal4.

high between-group similarity to both the dry Group us1 and the seasonal Group c (41 % Table 9.15). The overlap in key distinguishing species (Figure 9.20) between Group c and d (*Soroveta ambigua, Epischoenus quadrangularis* and *Ficinia zeyheri*) further illustrate this.

Table 9.15 Average similarity within and between plant groups at T3_Pal4.

	a	b	c	d	us 1
a	59				
b	25	54			
c	39	34	50		
d	34	39	41	56	
us 1	20	37	31	41	56

9.2.6.2 Key environmental drivers of plant community structure

DistLM analysis was used to determine with variables best described variability in plant community structure. Soil moisture parameters from the deep profile (i.e. 30-50 cm) could not be included in the analysis because the soils were generally shallow at this site and only limited data were collected below 30 cm. From the analysis it was evident that:

- The average three month dry season running minimum between 10 – 30 cm depth (L1_Drunmin) was the single best predictor of variability in vegetation composition at this site (Table 9.16: marginal tests).
- In addition to L1_Drunmin, eight soil moisture parameters together accounted for 63% of the overall variation in plant community structure at this site (Table 9.16: sequential tests).

Table 9.16 Results of the DistLM analysis: relationship between plant species composition and environmental variables at T3_Pal4 based on a Euclidean Distance matrix. '% variation

explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different (p ≤ 0.05) relationships are shown.

Environmental variable	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
***MARGINAL TESTS*[1]**				
Soil moisture	$L0\_Sat_{dur}$	0.0001	11.1	
	$L0\_D_{sd}$	0.0001	10.6	
	$L0\_W_{sd}$	0.0001	6.8	
	$L0\_D_{runmin}$	0.0009	9.6	
	$L0\_W_{runmax}$	0.0001	5.6	
	$L1\_Sat_{dur}$	0.0004	17.7	
	$L1\_D_{sd}$	0.0001	6.8	
	$L1\_W_{sd}$	0.0001	15.2	
	$L1\_D_{runmin}$	0.0001	22.1	
	$L1\_W_{runmax}$	0.0001	18.4	
***SEQUENTIAL TESTS*[2]**	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Soil moisture	$+L1\_D_{runmin}$	0.0001	22.1	22.1
	$+L0\_W_{sd}$	0.0001	7.5	29.7
	$+L1\_W_{sd}$	0.0004	5.2	34.9
	$+L1\_D_{sd}$	0.0001	5.9	40.8
	$+L1\_Sat_{dur}$	0.0001	5.3	46.1
	$+L0\_W_{runmax}$	0.0001	6.2	52.3
	$+L0\_Sat_{dur}$	0.0001	4.8	57.1
	$+L1\_W_{runmax}$	0.0003	2.9	60.0
	$+L0\_D_{runmin}$	0.0007	2.6	62.6

[1] *Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.*

[2] *Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.*

An ordination of the fitted model given by the dbRDA plot in Figure 9.21 shows that:

- All four of the plant communities linked to soil moisture probes form relative discreet groups within the ordination (Figure 9.21a)
- Groups a and Group b, representing the seep line and transitional margin of the wetland respectively (Figure 9.19), were largely separated along dbRDA1, which describes most of the variability among plant communities.
- The links between these plant communities and L1_Drunmin and the variability on soil moisture (L1_Wsd) are clearly evident from the bubble overlays in (Figure 9.21b and c).

Considering the substantial links between soil moisture and plant community structure at T3_Pal4, it is anticipated that changes in soil moisture will result in a change in these communities.

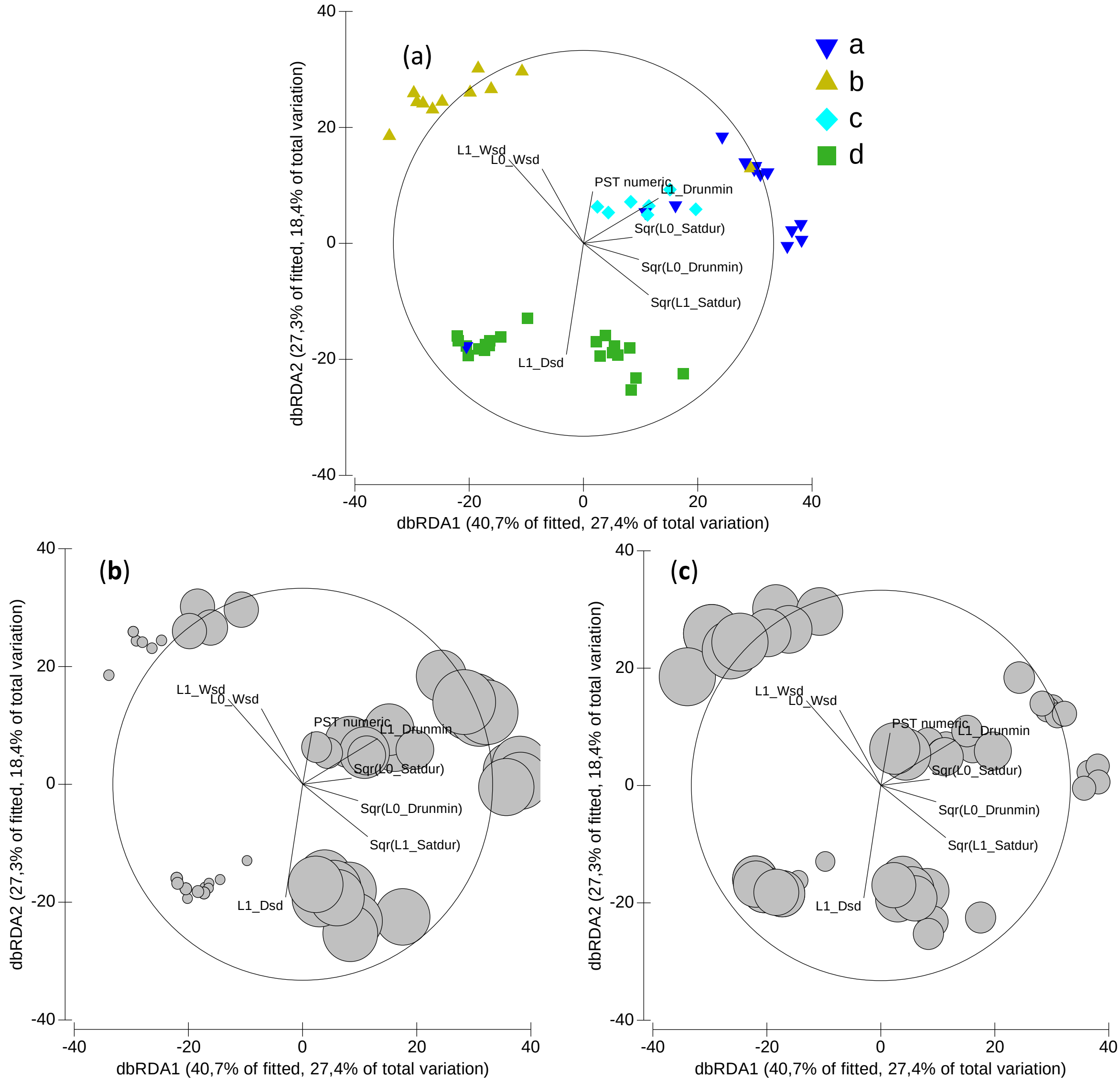


Figure 9.21 dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at T3_Pal4. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) gives the distribution of data represented by the plant communities identified in the hierarchical cluster analysis. Bubble overlays of b) L1_Drunmin, c) L1_Wsd show a relationship between plant composition and soil moisture - the larger the bubble, the greater the soil moisture content.

9.2.6.3 Year-on-year comparison of monitoring plots

The % similarity of individual plots is summarised for each of the plant communities identified at T3_Pal4 (Figure 9.22). On average, the year-on-year similarities of plots belonging to all five groups were greater than 60%. Plots within Group b showed the greatest variability in inter-annual similarities between plots with some plots only showing 39% similarity between 2011 and 2012. The substantial change in the plant community structure between these plots may be a consequence of recovery in 2012 following the post – fire erosion disturbance that was evident in 2011.

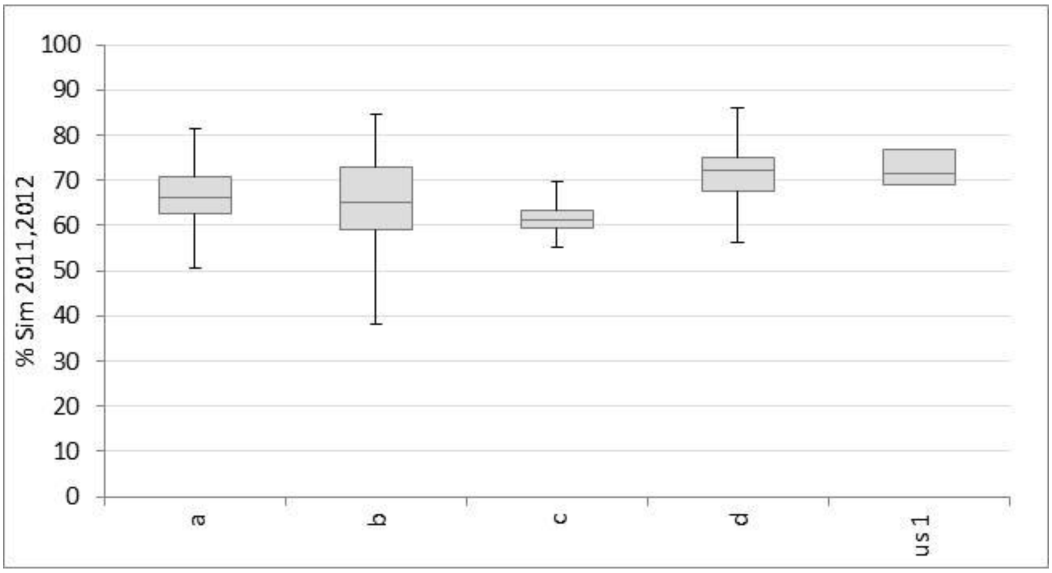


Figure 9.22 Percentage similarity in species composition between individual plots monitored in 2011 and 2012 summarised by the plant community (Group) affiliation of each plot at T3_Pal4.

9.2.6.4 Inter-annual change in the height of dominant species

A comparison of averaged height of the tallest species in each plot between 2011 and 2012 shows that almost all of the species represented in this dataset increased in height from 2011 to 2012, suggesting growth in the tallest individuals over an annual period (Table 9.17). *Restio dispar* was the tallest species in 37% of plots in 2011 but was not recorded at all in 2012 as one of the tallest species. By contrast, *Berzelia lanuginosa* increased in its representation as one of the tallest species from only 2% in 2011 to 15% in 2012 suggesting a change or shift in the canopy community over time.

9.2.7 Ecoseep T6_1b

9.2.7.1 Plant communities

Five plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes and extrapolated to all but five plots of the full data set.

The diagrammatic representation of all plots along the three sampling transects, colour coded according to the plant community Group that each represents (Figure 9.23), shows that Groups a and b were associated with the core central portion of the seep, while plots belonging to Groups d and e were evident on the outer margins of the seep. Group c was somewhat transitional between the wetter central areas and the drier margins of the wetland. The spatial arrangement of the plant communities at T6_1b is consistent with the animation of temporal changes in soil moisture at over the site given in Section 7, Figure 7.41. This suggests a strong link between soil moisture and plant communities at T6_1b. These links are addressed in more detail below.

Key indicator species representing each of these groups, described in Appendix 1, and summarised as:

Group a : *Anthochortus graminifolius* – obligate wetland species

Table 9.17 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T3_Pal4. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	144	Total N:	420	#Plots:	143	Total N:	402
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Anthochortus crinalis	10	6.94	0.22	0.04	9	6.29	0.33	0.07
Berzelia lanuginosa	3	2.08	0.27	0.12	22	15.38	0.48	0.20
Brunia fragarioides	1	0.69	0.60					
Cassytha ciliolata					4	2.80	0.93	0.38
Chrysitrix capensis/ dodii	4	2.78	0.60	0.14	7	4.90	0.63	0.15
Corymbium glabrum	1	0.69	0.60					
Diospyros glabra					1	0.70	1.00	
Ehrharta ramosa	17	11.81	0.70	0.19	7	4.90	0.73	0.08
Ehrharta rupestris subsp. tricostata	33	22.92	0.46	0.10	29	20.28	0.60	0.21
Elegia thyrsifera	2	1.39	0.75	0.21				
Epischoenus quadrangularis/villosus	18	12.50	0.79	0.14	17	11.89	0.92	0.17
Erica intervallaris					2	1.40	0.40	0.14
Erica sessiliflora					1	0.70	0.50	
Ficinia monticola	1	0.69	0.40					
Ficinia zeyheri	34	23.61	0.14	0.05	24	16.78	0.18	0.04
Gibbaria ilicifolia	2	1.39	0.43	0.04	1	0.70	0.40	
Gnidia oppositifolia	14	9.72	1.29	0.32	11	7.69	1.45	0.27
Hypodiscus aristatus	1	0.69	1.00		1	0.70	0.80	
Metalasia cephalotes	3	2.08	0.42	0.08	2	1.40	0.55	0.07
Osmitopsis afra	1	0.69	0.10					
Pentameris colorata	44	30.56	0.47	0.12	41	28.67	1.57	6.96
Restio bifarius					1	0.70	0.80	
Restio bifidus	14	9.72	0.46	0.07	11	7.69	0.63	0.25
Restio dispar	37	25.69	1.18	0.30				
Restio dispar/occultus					22	15.38	1.34	0.22
Restio occultus	6	4.17	1.15	0.29	5	3.50	1.20	0.37
Restio versatilis					9	6.29	0.14	0.05
Senecio pubigerus	1	0.69	0.60					
Seriphium cinereum	78	54.17	0.47	0.11	95	66.43	0.69	0.18
Soroveta ambigua	10	6.94	0.29	0.03	11	7.69	0.35	0.09
Syncarpha vestita					1	0.70	0.60	
Tetraria fasciata					3	2.10	0.52	0.14
Tetraria flexuosa	68	47.22	1.12	0.18	54	37.76	1.13	0.23
Tetraria microstachys					1	0.70	1.00	
Tetraria thermalis					2	1.40	0.90	0.00
Thamnochortus gracilis	2	1.39	0.70	0.00	2	1.40	0.95	0.21
Thesium bathyschistum					2	1.40	1.05	0.07
Ursinia chrysanthemoides	13	9.03	0.38	0.13	1	0.70	1.10	
Ursinia paleacea	2	1.39	1.15	0.07				
Villarsia manningiana					3	2.10	0.20	0.00

Group b: *Elegia thyrsifera* – obligate wetland species

Group c: *Ficinia distans* – obligate wetland species

Group d: *Ursinia paleacea*

Group e: *Ehrharta ramosa* – facultative wetland species

The average abundance (% cover) of each of these indicator species at T6_1b is shown in Figure 9.24.

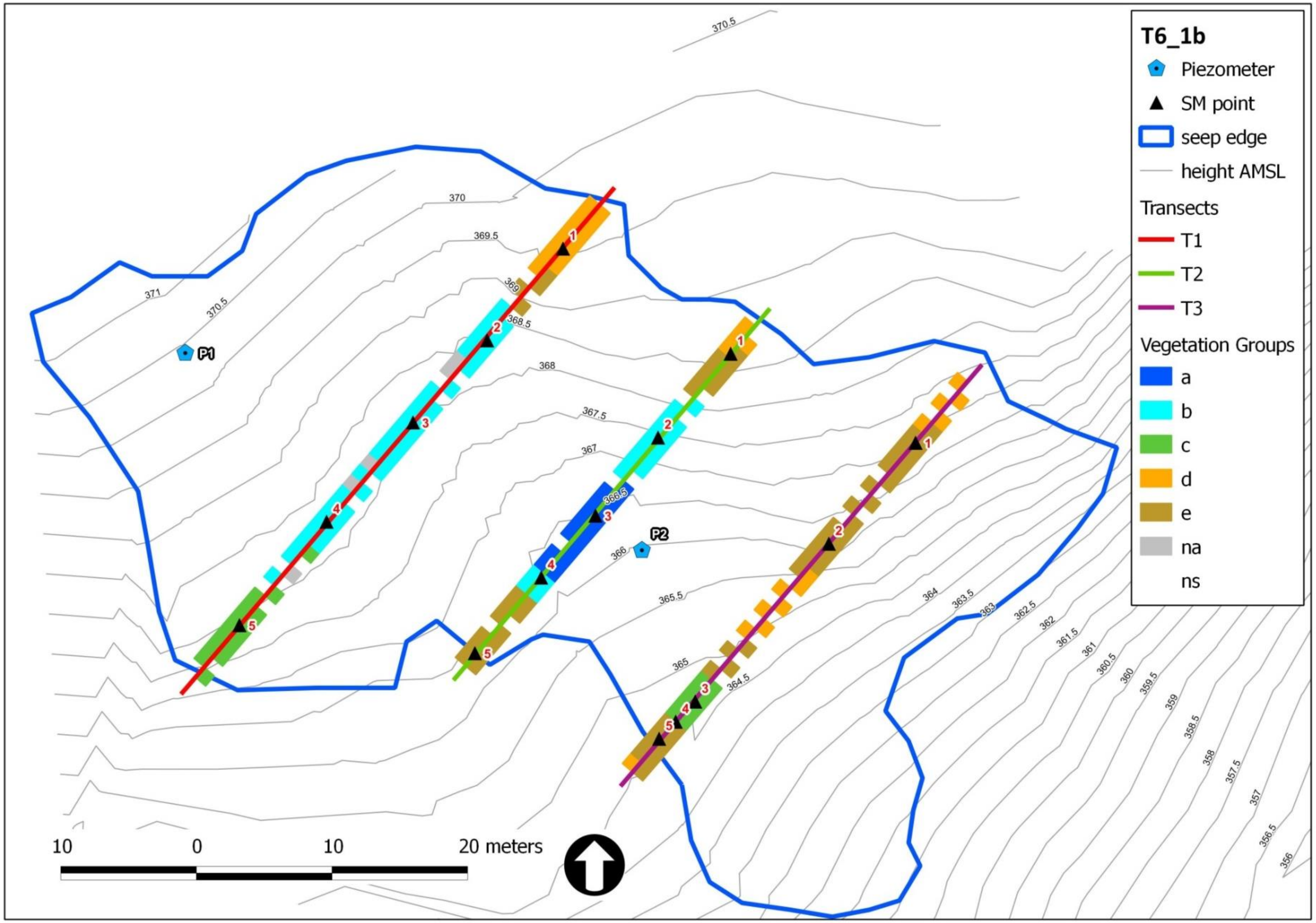


Figure 9.23 Diagrammatic representation showing the position of all plots at T6_1b, colour coded according to the plant community that each represents. The grey plots (na) represent those that could not be assigned to a plant community through extrapolation. Gaps in plots along the transect (ns) are plots that are not sampled as part of the monitoring programme.

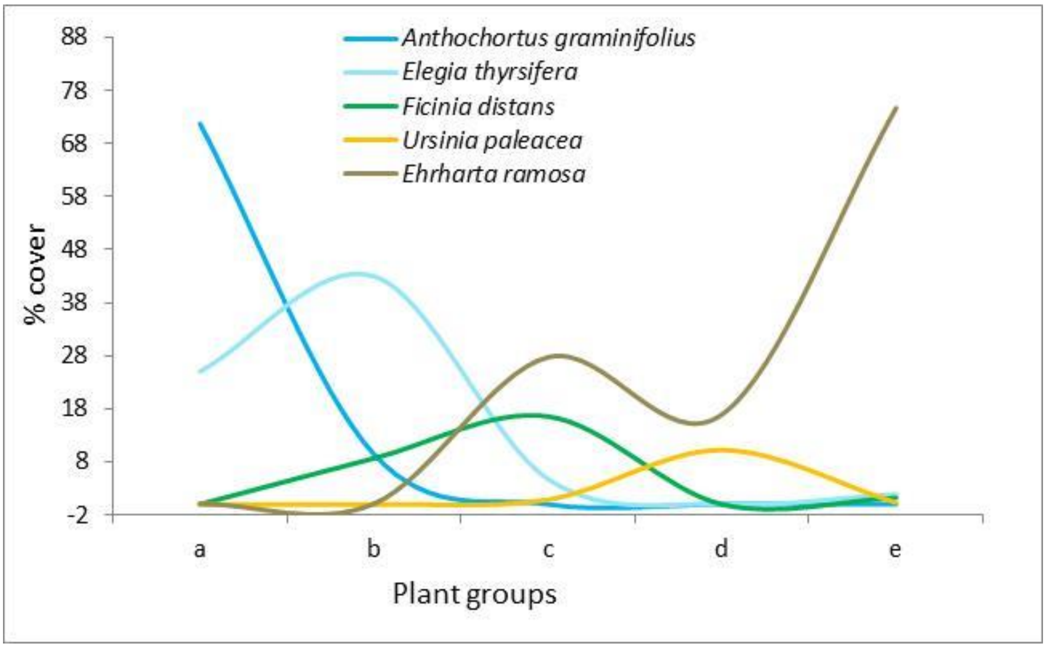


Figure 9.24 Average abundance (% cover) of indicator species for groups identified at T6_1b.

Table 9.18 Average similarity within and between plant groups at T6_1b.

	a	b	c	d	e
a	76				
b	39	60			
c	17	33	45		
d	5	5	20	43	
e	9	14	28	25	48

The key indicator species of Groups a, b and c are generally obligate wetland species, while those characteristic of Groups d and e are facultative wetland species (see Appendix 1 for details). The similarity within and between groups varied considerably at T6_1b (Table 9.18), reflecting a difference in the cohesion within the plant communities. Group a plots were most similar (i.e. 76% similarity within the group), followed by Group b (i.e. 60% similarity). Both groups are representative of the central seep area (Figure 7.23). Besides their stronger within-group similarity, these two groups were also particularly different from Groups d and e - there was only 5% similarity between Groups a and d as well as between Groups b and d (Table 9.18). These results reflect the differences between communities typical of the central wet areas of this site and the marginal communities transitional between wetland and terrestrial habitats.

9.2.7.2 Key environmental drivers of community structure

DistLM analysis was used to determine which variables best described variability in plant community structure. Soil moisture variables from the deep profile (i.e. > 30cm) could not be included in the analysis because the soils are generally shallow at this site and only limited data were collected below 30 cm. From the analysis it was evident that:

- The average three month dry season soil moisture minimum at 10-30 cm depth (L1_Drunmin) was the single best predictor of variability in vegetation composition at this site (Table 9.19), explaining 39 % of the variation in the vegetation assemblage when considered alone (Table 9.19: marginal tests).

- Several other soil moisture parameters also explained a considerable proportion of the variability in vegetation composition when considered alone (Table 9.19: marginal tests).
- Environmental factors other than soil moisture also explained a substantial amount of the variation in vegetation, particularly substratum type (Table 9.19: marginal tests).
- A combination of 10 soil moisture parameters, together with the % cover of debris, the proportion of bare soil or rock, and substratum type accounted for 79% of the total variation in the vegetation (Table 9.19: sequential tests).

Table 9.19 Results of the DistLM analysis: relationship between plant species composition and environmental variables at T6_1b based on a Euclidean Distance matrix. '% variation explained' indicates the percentage of variation in plant species explained by each variable alone. 'Cumulative. % variation.' is the cumulative percentage variation explained for each additional co-variate in the sequential tests. Only significantly different (p ≤ 0.05) relationships are shown.

Environmental variable	Parameter	*p*	% variation explained	
MARGINAL TESTS[1]				
Soil moisture	$L0\_Sat_{dur}$	0.0001	26.1	
	$L0\_D_{sd}$	0.0001	17.5	
	$L0\_W_{sd}$	0.0005	5.3	
	$L0\_D_{runmin}$	0.0001	33.3	
	$L0\_W_{runmax}$	0.0001	38.9	
	$L1\_Sat_{dur}$	0.0001	33.5	
	$L1\_D_{sd}$	0.0001	7.8	
	$L1\_W_{sd}$	0.0001	15.2	
	$L1\_D_{runmin}$	0.0001	39.1	
	$L1\_W_{runmax}$	0.0001	35.5	
Substratum	% cover	0.0001	36.5	
Veg canopy	% cover	0.0001	7.4	
Debris in veg	% cover	0.0164	3.1	
Debris on ground	% cover	0.0001	11.6	
Bare soil/rock	% cover	0.0001	12.8	
SEQUENTIAL TESTS[2]	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Soil moisture	$+L1\_D_{runmin}$	0.0001	39.1	39.1
	$+L0\_W_{runmax}$	0.0001	8.9	48.1
	$+L1\_D_{sd}$	0.0001	5.9	53.9
Bare soil/rock	+% cover	0.0001	4.2	58.2
Debris in veg	+% cover	0.0001	3.0	61.2
Soil moisture	$+L0\_D_{sd}$	0.0001	2.3	63.4
	$+L0\_D_{runmin}$	0.0001	3.1	66.5
	$+L1\_Sat_{dur}$	0.0001	2.3	68.9
	$+L1\_W_{sd}$	0.0001	2.1	71.0
	$+L1\_W_{runmax}$	0.0001	2.8	73.8
	$+L0\_W_{sd}$	0.0001	2.1	75.9
	$+L0\_Sat_{dur}$	0.0001	1.5	77.4
Substratum	+% cover	0.0002	0.9	78.3
Debris on ground	+% cover	0.0035	0.7	79.0

[1] Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.
[2] Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.

- These results suggest a strong relationship between soil moisture (as well as other environmental factors) and vegetation composition at this site.

An ordination of the fitted model given by the dbRDA plot in Figure 9.25shows that:

- Groups a and b, as the wettest groups, are clearly separate from the drier Groups d and e, with Group c between them along dbRDA1 (Figure 9.25a). This result is consistent with the spatial arrangement of vegetation communities at this site as discussed above.
- The bubble overlay of L1_Drunmin (Figure 9.25b), indicates clearly that soil moisture at plots with Groups d and e are significantly drier than those at Groups a and b.
- Some distinction between Groups a and b was also apparent along dbRDA2 (Figure 9.25c). The bubble overlay of L1_Dsd shows that soil moisture at plots supporting community Group a varied far less than at those in Group b during the dry season at a depth of 10-30 cm.
- Essentially, both minimum soil moisture and variation in soil moisture content over the dry season are important environmental factors accounting for differences in vegetation communities at this site.
- These results substantiate the notion that vegetation communities at T6_1b are closely linked to differences in soil moisture.

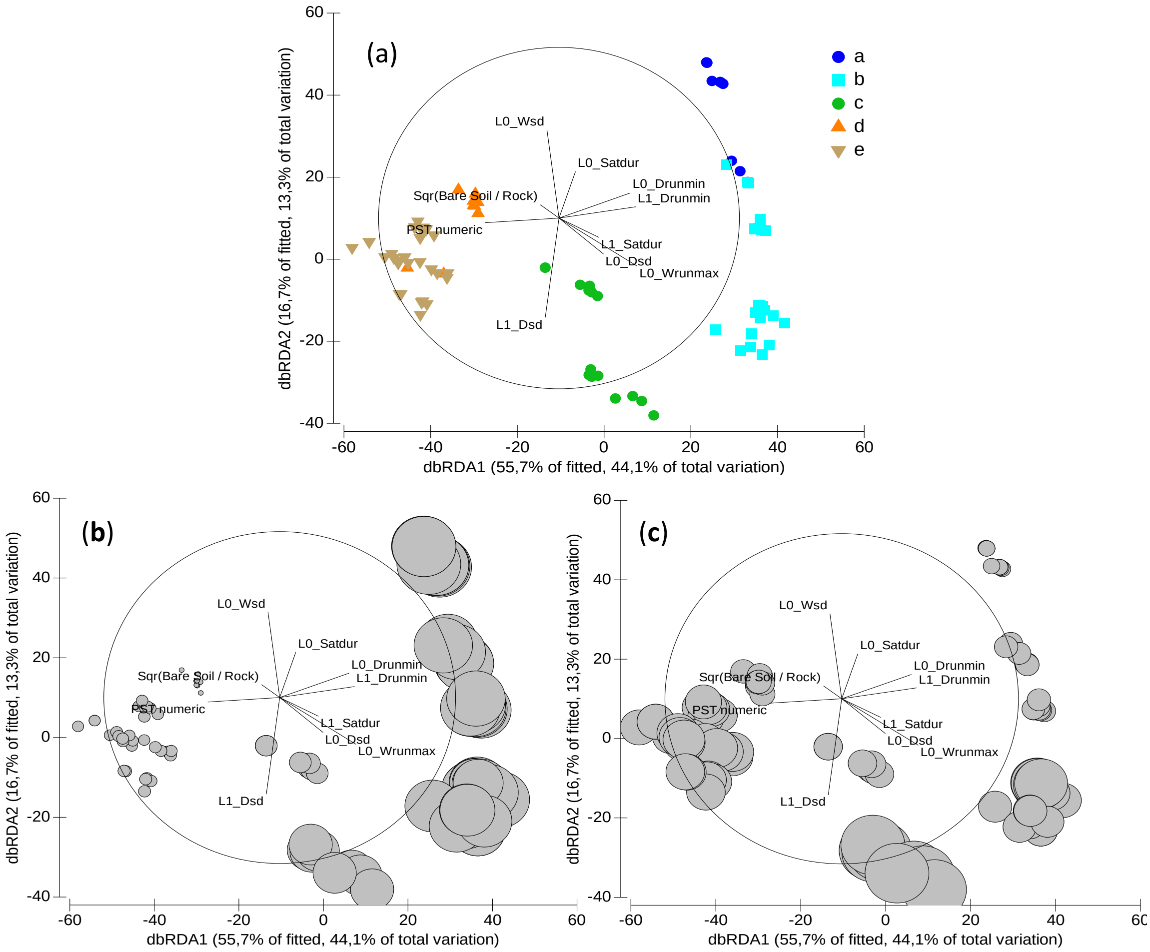


Figure 9.25 dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at T6_1b. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) gives the distribution of data represented by the groups identified in the hierarchical cluster analysis. Bubble overlays of b) L1_Drunmin, c) L1_Dsd show a relationship between plant communities and soil moisture - the larger the bubble, the greater the soil moisture content.

Considering the strong links between soil moisture and plant community structure at this site, it is likely that changes in soil moisture (particularly between 10-30 cm depth) will be reflected by a shift in the plant communities identified.

9.2.7.3 Year-on-year comparison of monitoring plots

The % similarity of individual plots is summarised for each of the plant communities identified at T6_1b (Figure 9.26). On average, the year-on-year similarities of plots belonging to Groups a and b were high (about 75% similarity) indicating stability flora within the wetter central areas of the seep, or at least slow rates of change. Plots representing Group e showed the greatest variability in year-on-year similarity. Only three plots were associated with similarities on or below 40% (T2_32b in Group e and T1-41a and b in Group c). The shifts in species in these plots suggest a slight drying along the southern end of T1 (reduction in *F. distans* and *E. asperiflora*; increase in *Ehrharta ramosa* and *E. setacea*), and somewhat wetter conditions at the end of T2 (increases in moss, *Chrysitrix capensis* and *Cassytha ciliolata* in T2_32b).

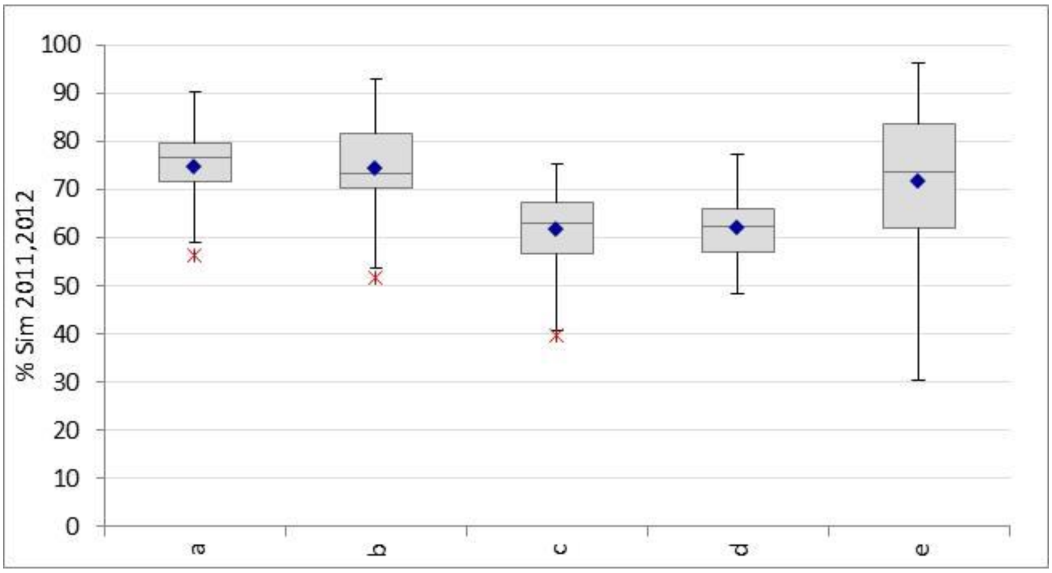


Figure 9.26 Percentage similarity in species composition between individual plots monitored in 2011 and 2012 summarised by the plant community (Group) affiliation of each plot at T6_1b.

9.2.7.4 Inter-annual change in the height of dominant species

A comparison of the average height of the tallest species in each plot between 2011 and 2012 shows that some species declined in the percentage of plots for which they were one of the three tallest s (Table 9.20). In particular, *Ficinia distans* was the tallest species in 19% of plots in 2011 but was only one of the tallest species in 2% of plots in 2012. By contrast, some species such as *Psoralea fleta* increased in its representation as one of the tallest species from only 25% in 2011 to 32% in with an average increase in height of 0.47m over the annual period. This suggests a change or shift in the canopy community over time at T6_1b.

Table 9.20 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T6_1b. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	181	Total N:	491	#Plots:	186	Total N:	520
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Anthochortus graminifolius	12	6.63	0.47	0.12	15	8.06	0.62	0.17
Anthochortus crinalis	1	0.55	3.00					
Aristida junciformis					1	0.54	0.70	
Cassytha ciliolata					8	4.30	1.20	0.23
Chrysitrix capensis					2	1.08	0.50	0.00
Chrysitrix dodii	6	3.31	1.12	0.84	4	2.15	0.88	0.32
Cliffortia gamine	13	7.18	1.02	0.17	10	5.38	0.99	0.20
Corymbium glabrum					1	0.54	0.50	
Cyathocoma hexandra	18	9.94	1.07	0.32	12	6.45	1.19	0.37
Diospyros glabra	2	1.10	1.10	0.14	4	2.15	0.78	0.45
Ehrharta ramosa	90	49.72	1.02	0.18	81	43.55	0.96	0.18
Ehrharta ramosa dead					1	0.54	0.20	
Ehrharta setacea subsp. scabra	44	24.31	0.79	0.47	65	34.95	0.51	0.24
Elegia asperiflora	8	4.42	0.84	0.25	2	1.08	0.90	0.14
Elegia thyrsifera	65	35.91	1.58	0.19	73	39.25	1.76	0.32
Epischoenus gracilis	5	2.76	0.72	0.11				
Epischoenus quadrangularis/villosus complex	6	3.31	0.85	0.18	11	5.91	0.95	0.15
Festuca scabra	1	0.55	0.20					
Ficinia distans	34	18.78	0.58	0.42	4	2.15	0.30	0.08
Ficinia elatior	1	0.55	0.50					
Ficinia nigrescens	2	1.10	0.45	0.07				
Ficinia sp. nov1					4	2.15	0.10	0.00
Ficinia trichodes	29	16.02	0.31	0.07	31	16.67	0.21	0.12
Geochloa rufa					1	0.54	0.30	
Helichrysum cf. petiolare	1	0.55	2.60					
Leucadendron salicifolium					2	1.08	0.75	0.35
Metalasia cephalotes	1	0.55	0.20		2	1.08	0.30	0.14
Metrosideros angustifolia	4	2.21	1.55	0.26	6	3.23	2.15	0.68
Metrosideros angustifolia (dead)	3	1.66	4.53	0.81				
Micranthus junceus	7	3.87	0.26	0.08				
Moss					6	3.23	0.03	0.02
Osmitopsis afra	1	0.55	0.20		1	0.54	0.30	
Othonna quinquedentata	11	6.08	3.55	5.46	18	9.68	2.07	0.57
Oxalis big green hairy	3	1.66	0.10	0.00				
Pentameris colorata	1	0.55	0.60		1	0.54	0.70	
Pentameris curvifolia	5	2.76	0.64	0.15	3	1.61	0.40	0.00
Pentameris thuarii	12	6.63	1.28	0.47	11	5.91	1.72	0.22
Prismatocarpus diffusus	1	0.55	0.50					
Pseudolago spuria	3	1.66	0.33	0.23				
Psoralea fleta	45	24.86	1.83	0.49	61	32.80	2.30	0.83
Restio curviramis	7	3.87	0.31	0.07	10	5.38	0.27	0.05
Restio perplexus					2	1.08	0.40	0.00
Restio triticeus	2	1.10	1.00	0.00	1	0.54	1.20	
Senecio speciosissimus	8	4.42	1.08	0.14	11	5.91	1.54	0.29
Seriphium cinereum	10	5.52	0.24	0.05	25	13.44	0.36	0.14
Staberoha distachyos	3	1.66	0.47	0.15	3	1.61	0.47	0.06
Struthiola myrsinites					5	2.69	0.94	0.19
Tetraria exilis	5	2.76	0.38	0.11	3	1.61	0.33	0.06
Thamnochortus lucens					1	0.54	0.30	
Ursinia paleacea	10	5.52	0.32	0.09	10	5.38	0.62	0.06
Widdringtonia nodiflora	8	4.42	1.00	0.53	6	3.23	1.55	0.58
Widdringtonia nodiflora dead	2	1.10	4.25	0.35				
Zyrphelis lasiocarpa	1	0.55	0.20		2	1.08	0.25	0.07

9.2.8 Ecoseep T6_4

9.2.8.1 Plant communities

Three distinct plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes and extrapolated to all but 12 plots of the full data set.

The diagrammatic representation of all plots along the three sampling transects, colour coded according to the plant community Group that each represents (Figure 9.27) indicates that Group b was associated with the wetter central portion of the seep, with Group c adjacent to Group b and Group a along the drier margins of the seep. A comparison between the spatial arrangement of these plant communities (Figure 9.27) and the animation of temporal changes in soil moisture over the site given in Section 7 suggests a strong link between soil moisture and the arrangement of plant communities at T6_4. These links are addressed in more detail in the next section. Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a : *Ehrharta ramosa* – facultative wetland species

Group b: *Anthochortus graminifolius* – obligate wetland species

Group c: *Ehrharta setacea* subsp. *scabra* – facultative wetland species

The average abundance (% cover) of each of these key indicator species is shown in Figure 9.28.

Given the coincidence of perennial soil moisture in the portion of the seep represented by Group b plots, it is not surprising that this group is defined by the presence of obligate wetland species, while both facultative and obligate wetland species characterise Group c. Group a is dominated entirely by the grass *Ehrharta ramosa,* typical of marginal wetland habitat. (See Appendix 1 for a detailed description of these communities.)

Although Group a formed a plant community that was distinctly different from the other two groups at T6_4, this group was less coherent than Groups b and c, as indicated by the higher within-group similarity for the latter two groups (Table 9.21). Nevertheless, Groups a and b, representative of the drier margins and the wetter central portion of the seep respectively, shared the least similarity (only 15%) and are therefore distinctly different from each other (Table 9.21).

Table 9.21 Average similarity within and between plant groups at T6_4.

	a	b	c
a	51		
b	15	65	
c	25	40	61

9.2.8.2 Key environmental drivers of plant community structure

DistLM analysis was used to determine which variables best described variability in plant community structure. Soil moisture variables analysed were only those for the surface and 30 cm depths as the soils at this site were generally shallow. From the analysis (Table 9.22) it was evident that:

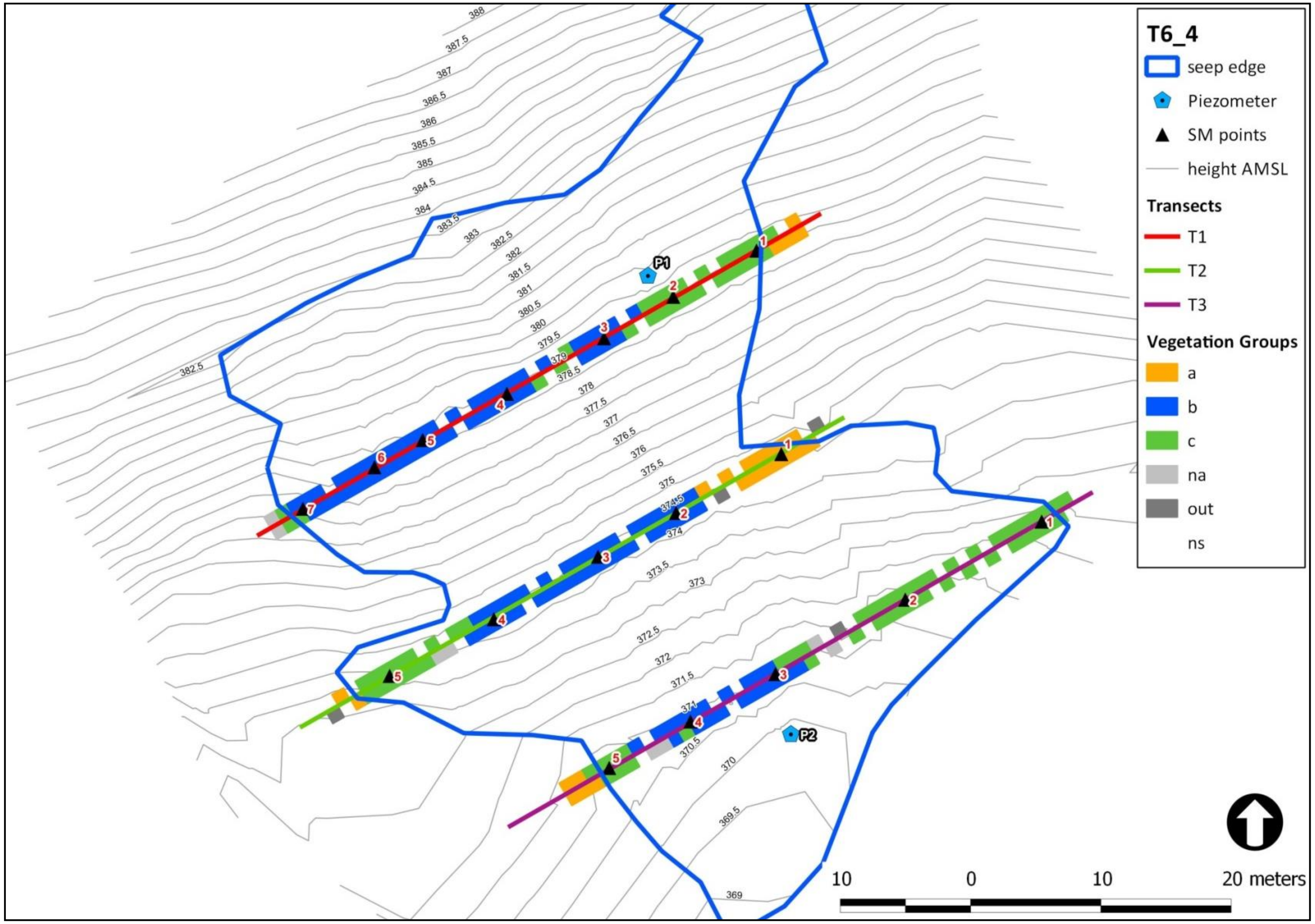


Figure 9.27 Diagrammatic representation showing the position of all plots at T6_4, colour coded according to the plant group that each represents. The light grey plots (na) represent those that could not be assigned to a plant community through extrapolation. The dark grey plots represent outliers (out) that were substantially different from all groups. Gaps in plots along the transect (ns) are plots that are not sampled as part of the monitoring programme.

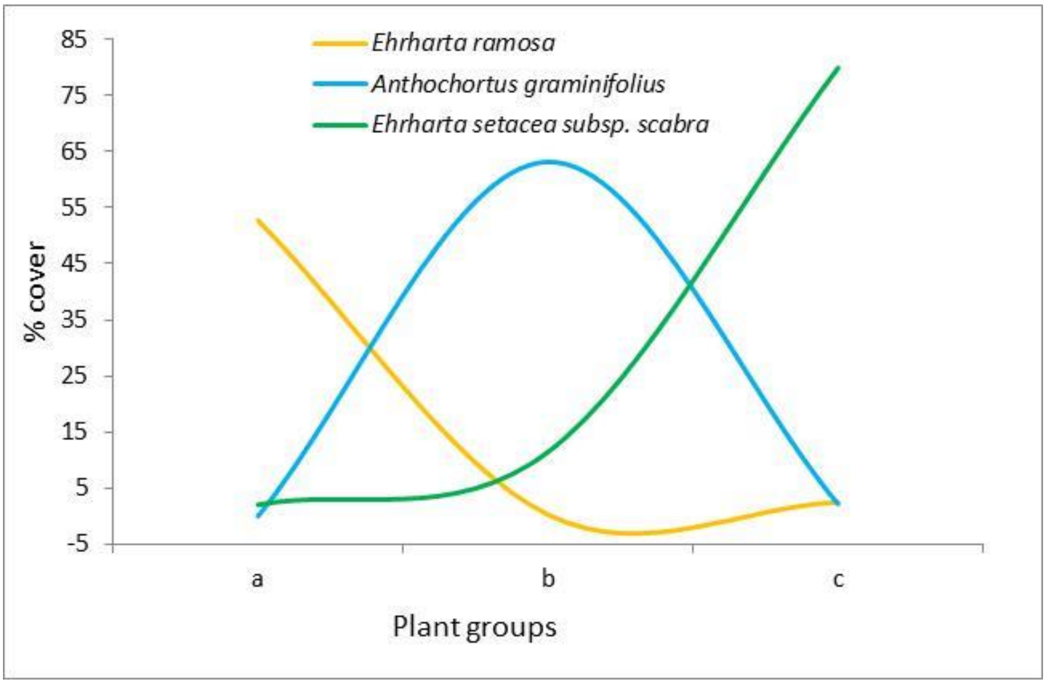


Figure 9.28 Average abundance (% cover) of indicator species for plant groups identified at T6_4.

- The standard deviation in soil moisture during the wet season between 10-30 cm (L1_Wsd) was the single best predictor of variability in plant composition at this site, accounting for 35% of the observed variability in plant community composition when considered alone (Table 9.22: marginal tests).
- The duration of saturation between 10-30 cm (L1Satdur) also accounted for a substantial portion of the variability (i.e. 32%) in vegetation composition (Table 9.22: marginal tests).
- A combination of nine soil moisture parameters, together with substratum type explained over 70% of the variability in vegetation composition (Table 9.22: sequential test).

An ordination of the fitted model given in the dbRDA in Figure 9.29 shows that:

- Although there is some overlap between plots in Groups a and c, all three groups were largely distinct from each other (Figure 9.29a). In particular, there is a clear distinction between Group a (typical of the seep margin) and Group b (characteristic of the central seep) along dbRDA 1 (Figure 9.29a).
- A bubble overlay of L1_Wsd which explained most of the variation in community composition (Table 9.22), shows a gradation of increased variation in wet season soil moisture variation with Group b plots being the least variable and Group a plots being the most variable in terms of soil moisture (Figure 9.29b).
- Also, duration of saturation of plots in Group b during the wet season was substantially greater than those within Group a.

These results suggest that there is a substantial link between soil moisture and the arrangement of plant communities at T6_4. It is therefore likely that changes in soil moisture, particularly at a depth between 10-30 cm during the wet season, would result in a change in these communities.

Table 9.22 Relationship between plant species composition for the subset of data associated with soil moisture and environmental variables at Site T6_4. '% variation explained' indicates the percentage of variation in plant species composition by each variable alone. 'Cumulative % variation explained" is the cumulative percentage variation explained for each additional co-variate in the sequential tests.

Environmental variable	Parameter	p	% variation explained	Cumulative % variation explained
MARGINAL TESTS[1]				
Soil moisture	$L0\_Sat_{dur}$	0.0001	15.7	
	$L0\_D_{ave}$	0.0001	19.9	
	$L0\_W_{ave}$	0.0001	11.3	
	$L0\_W_{runmin}$	0.0001	9.1	
	$L0\_D_{runmax}$	0.0001	27.5	
	$L0\_W_{runmax}$	0.0001	16.1	
	$L1\_Sat_{dur}$	0.0001	31.7	
	$L1\_D_{sd}$	0.0001	22.7	
	$L1\_W_{sd}$	0.0001	34.9	
	$L1\_W_{runmin}$	0.0001	25.6	
	$L1\_D_{runmax}$	0.0001	17.7	
	$L1\_W_{runmax}$	0.0162	3.3	
Substratum type	% cover	0.0001	21.2	
Vegetation canopy cover	% cover	0.0001	9.9	
SEQUENTIAL TESTS[2]	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Soil moisture	$+L1\_W_{sd}$	0.0001	34.86	34.86
	$+L1\_Sat_{dur}$	0.0001	11.28	46.14
	$+L0\_W_{ave}$	0.0001	4.78	50.93
	$+L1\_W_{runmin}$	0.0001	6.45	60.74
	$+L1\_D_{runmax}$	0.0001	1.69	62.43
Substratum type	+% cover	0.0025	1.65	64.08
Soil moisture	$+L0\_W_{runmin}$	0.0007	3.31	67.39
	$+L0\_W_{sd}$	0.0001	1.22	68.61
	$+L0\_Sat_{dur}$	0.0023	1.46	70.07
	$+L0\_D_{ave}$	0.0010	1.06	71.13

[1] Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.
[2] Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.

9.2.8.3 Year-on-year comparison of monitoring plots

The % similarity of individual plots is summarised for each of the plant communities identified at T6_1b (Figure 9.30). On average, the year-on-year similarities of plots belonging to all three groups were greater than 65% suggesting little change in the community composition of individual plots over the annual period. A very small number of plots recorded year-on-year similarities in below 50%. The lowest was one of the plots that remained unassigned to any community grouping (during extrapolation of the PRIMER analysis). Here dissimilarity between years was the result of a fairly high turnover, with many 2011 species recorded at low cover values no longer present in 2012, e.g. small *Ficinia* spp., *Bobartia, Restio curviramus, Staberoha, Tetraria*, suggesting that in future the plot might establish a more defined flora and group with one of the identified communities.

9.2.8.4 Inter-annual change in the height of dominant species

A comparison of averaged height of the tallest species in each plot between 2011 and 2012 (Table 9.23) shows that several species declined in the percentage of plots for which any given species was

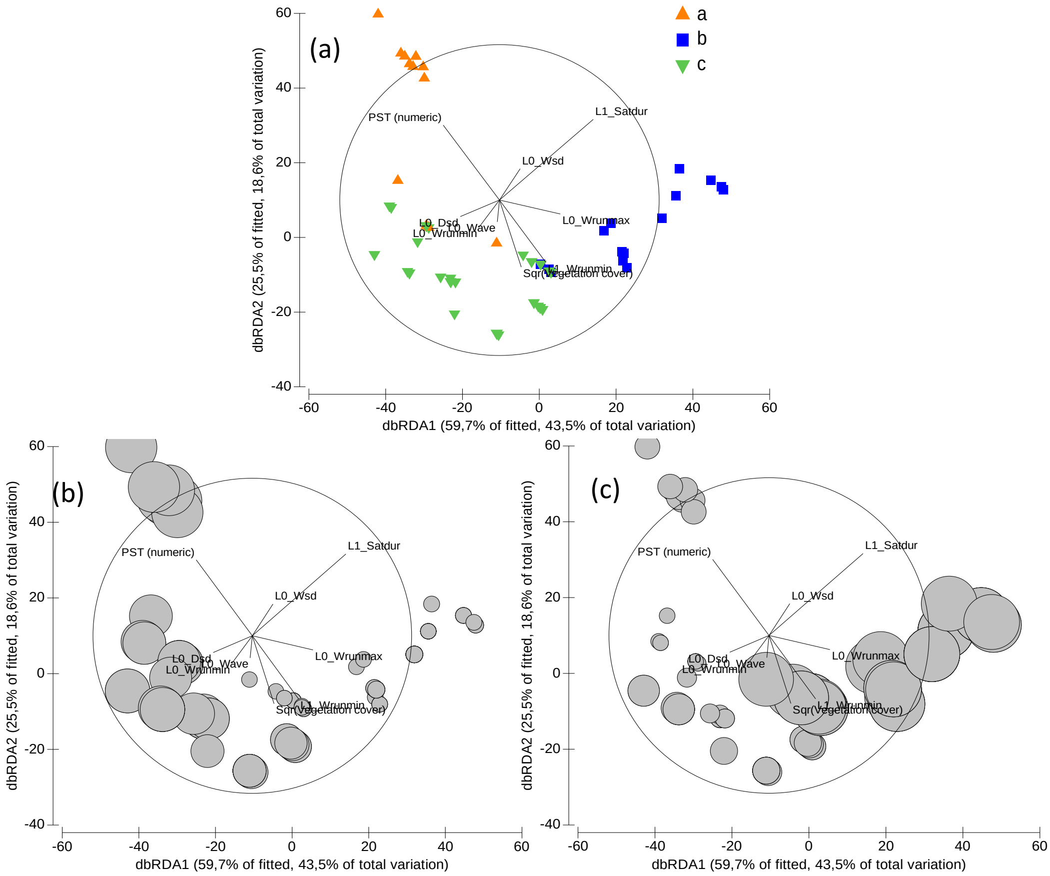


Figure 9.29 **dbRDA ordination of plant species represented by the subset of data associated with soil moisture probes at T6_4. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) gives the distribution of data represented by the plant communities identified in the hierarchical cluster analysis. Bubble overlays of b) L1_Wsd and c) L1_Satdur - the larger the bubble, the greater the soil moisture content.**

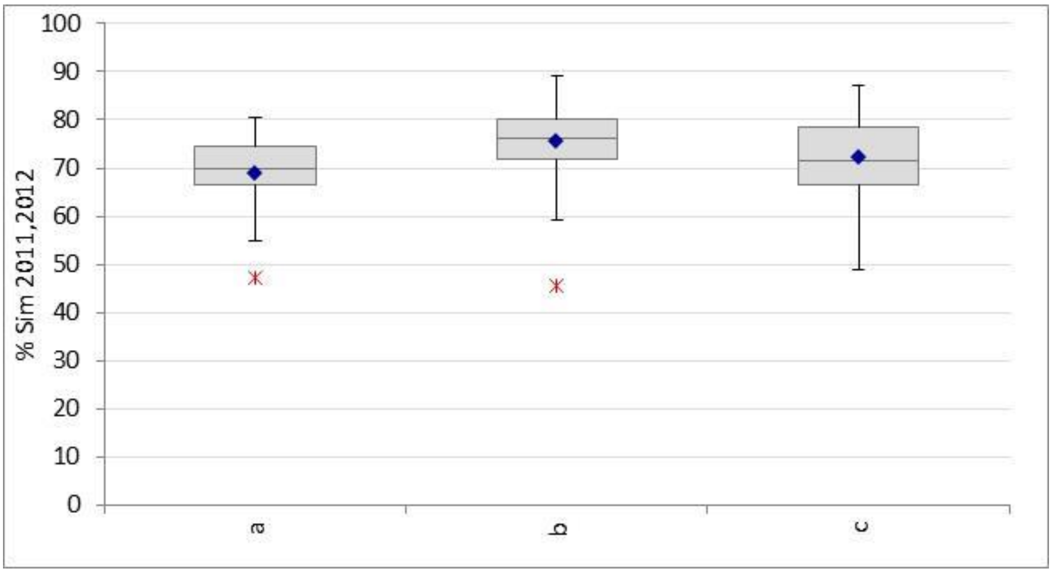


Figure 9.30 **Percentage similarity in species composition between individual plots monitored in 2011 and 2012 at T6_4, summarised by plant community (Group) affiliation of each.**

one of the three tallest . For example, *Anthochortus graminifolius* was the tallest species in 32% of plots in 2011 but was only one of the tallest species in 24% of plots in 2012, despite an average increase in height from 0.34m to 0.49m over this period (Table 9.23). Similarly, *Ehrharta setacea* subsp. *scabra* was the tallest species in 43% of plots in 2011 but this declined to 26% in 2012. By contrast, some species such as *Osmitopsis asteriscoides* and *Psoralea fleta* increased in their representation as one of the tallest species between 2011 and 2012. These temporal changes in the height of the tallest species in each plots suggests that there may be subtle changes in the canopy community at T6_4.

Table 9.23 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T6_4. The number of plots and the percentage of the total number of plots represented by each species are also given..

Species	2011				2012			
	#Plots:	220	Total N:	625	#Plots:	218	Total N:	636
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Anthochortus graminifolius	70	31.82	0.34	0.07	52	23.85	0.49	0.17
Capeobolus brevicaulis					2	0.92	0.10	0.00
Cassytha ciliolata					15	6.88	7.67	10.17
Chrysitrix dodii					2	0.92	0.85	0.21
Corymbium glabrum	2	0.91	0.55	0.21	1	0.46	1.80	
Cyathocoma hexandra	70	31.82	1.33	0.24	55	25.23	1.16	0.25
Disparago ericoides	1	0.45	0.10					
Ehrharta ramosa	32	14.55	0.95	0.13	27	12.39	0.99	0.20
Ehrharta rupestris subsp. *tricostata*	9	4.09	0.59	0.15	2	0.92	0.40	0.00
Ehrharta setacea subsp. *scabra*	95	43.18	0.58	0.20	56	25.69	0.60	0.25
Elegia asperiflora	2	0.91	0.70	0.42	2	0.92	1.00	0.00
Elegia thyrsifera	122	55.45	1.47	0.22	141	64.68	1.61	0.32
Epischoenus gracilis	5	2.27	0.60	0.25	5	2.29	1.02	0.18
Epischoenus quadrangularis					1	0.46	0.80	
Epischoenus villosus	2	0.91	0.40	0.00				
Ficinia distans					1	0.46	4.00	
Ficinia trichodes	3	1.36	0.37	0.12	4	1.83	0.20	0.08
Gibbaria ilicifolia	2	0.91	0.50	0.14	2	0.92	0.40	0.14
Leucadendron salicifolium					13	5.96	1.10	0.24
Moss					5	2.29	0.01	0.00
Neesenbeckia punctoria	16	7.27	1.43	0.32	22	10.09	1.75	0.24
Osmitopsis asteriscoides	65	29.55	1.19	0.27	80	36.70	1.46	0.34
Oxalis lanata	1	0.45	0.10					
Pentameris colorata	6	2.73	0.63	0.27	3	1.38	0.67	0.29
*Pinus pinaster****	2	0.91	8.00	0.00				
Platycaulos callistachyus	3	1.36	1.03	0.21	2	0.92	1.25	0.07
Psoralea fleta	95	43.18	1.82	0.37	120	55.05	2.48	0.68
Pteridium aquilinum	14	6.36	0.41	0.14	6	2.75	0.67	0.31
Pteridium aquilinum - dead	1	0.45	0.30		6	2.75	0.43	0.12
Restio bifidus	1	0.45	0.80		1	0.46	0.80	
Restio curviramis					1	0.46	0.20	
Restio triticeus	1	0.45	1.10		2	0.92	0.70	0.71
Schizaea tenella	1	0.45	0.20		1	0.46	0.20	
Seriphium cinereum					1	0.46	0.30	
Staberoha distachyos	1	0.45	0.40					
Tetraria bromoides					1	0.46	2.40	
Tetraria flexuosa	1	0.45	1.00					
Ursinia paleacea	1	0.45	0.30		1	0.46	0.50	
Wachendorfia thyrsiflora	1	0.45	1.00					
Widdringtonia nodiflora					2	0.92	1.20	0.28
Zyrphelis lasiocarpa					1	0.46	0.20	

9.2.9 Ecoseep T8_2b

9.2.9.1 Plant communities

Four plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots that were linked to soil moisture probes and extrapolated to all but five plots of the full data set.

The colour-coded diagrammatic representation of all plots along the three sampling transects in (Figure 9.31), shows that Group a was associated with the lower, central portion of the seep. The animation of temporal changes in soil moisture over the site given in Section 7, Figure 7.55, shows that the only area remaining saturated year-round was a small patch at SM4 on Transect 3. Around this, the wettest, albeit seasonal to near-perennially moist soils correspond well with the distribution of Group a plots. Other areas along and between Transects 2 and 3 had more variable patterns in drying, but the soil moisture data show that the upper portion of the seep, from midway between Transect 2 and Transect 1 is seldom saturated throughout the soil profile. Thus correspondence with the other plant community groups identified by PRIMER is unclear. The links between soil moisture and plant communities are addressed in more detail below.

Key indicator species representing each of these groups (described in Appendix 1) are:

Group a : *Carpha glomerata* – obligate wetland species

Group b: *Berzelia lanuginosa* – facultative wetland species

Group c: *Struthiola myrsinites* – facultative wetland species

Group d: *Pentameris macrocalycina*

The average abundance (% cover) of each of these key indicator species is shown in Figure 9.32.

As the contours in Figure 9.31 show, Group a plots nestle at the low-lying shallow bowl of the lower portion of the seep, where a spring is associated with organic soils and the community defined by the obligate hydrophyte, *Carpha glomerata* (Figure 9.32). The eastern margin of the seep was characterised by plots belonging to plant community Group c (Figure 9.31), arranged over a slight ridge separating the base of the seep from the stream channel to the east. Further upslope and along the western edge of the seep, from Transect 2 upwards, the plots all formed the Group b community (Figure 9.31). Although both groups were dominated by *Pteridium aquilinum* which accounted for most of the within-group similarity in each case (see Appendix 1), the distinguishing species were *Berzelia lanuginosa* in the case of Group b and both *Struthiola myrsinites* and *Neesenbeckia punctoria* in Group c (see Appendix 1 for a description of plant communities).

Group a had the greatest similarity among plots (i.e. 54% similarity between the plots within this group), followed by Group c (i.e. 52% similarity between plots), and then Group b (i.e. 47% similarity between plots (Table 9.24). The lowest within-group similarity was given for Group d (i.e. 44% similarity). These results suggest that the vegetation communities represented by the “wet” plant communities were more coherent than those belonging to the drier wetland margin. As expected, Group a and Group d shared the least similarity (i.e. 11% similarity) as the two vegetation communities representative of contrasting habitats in terms of soil moisture (Table 9.24).

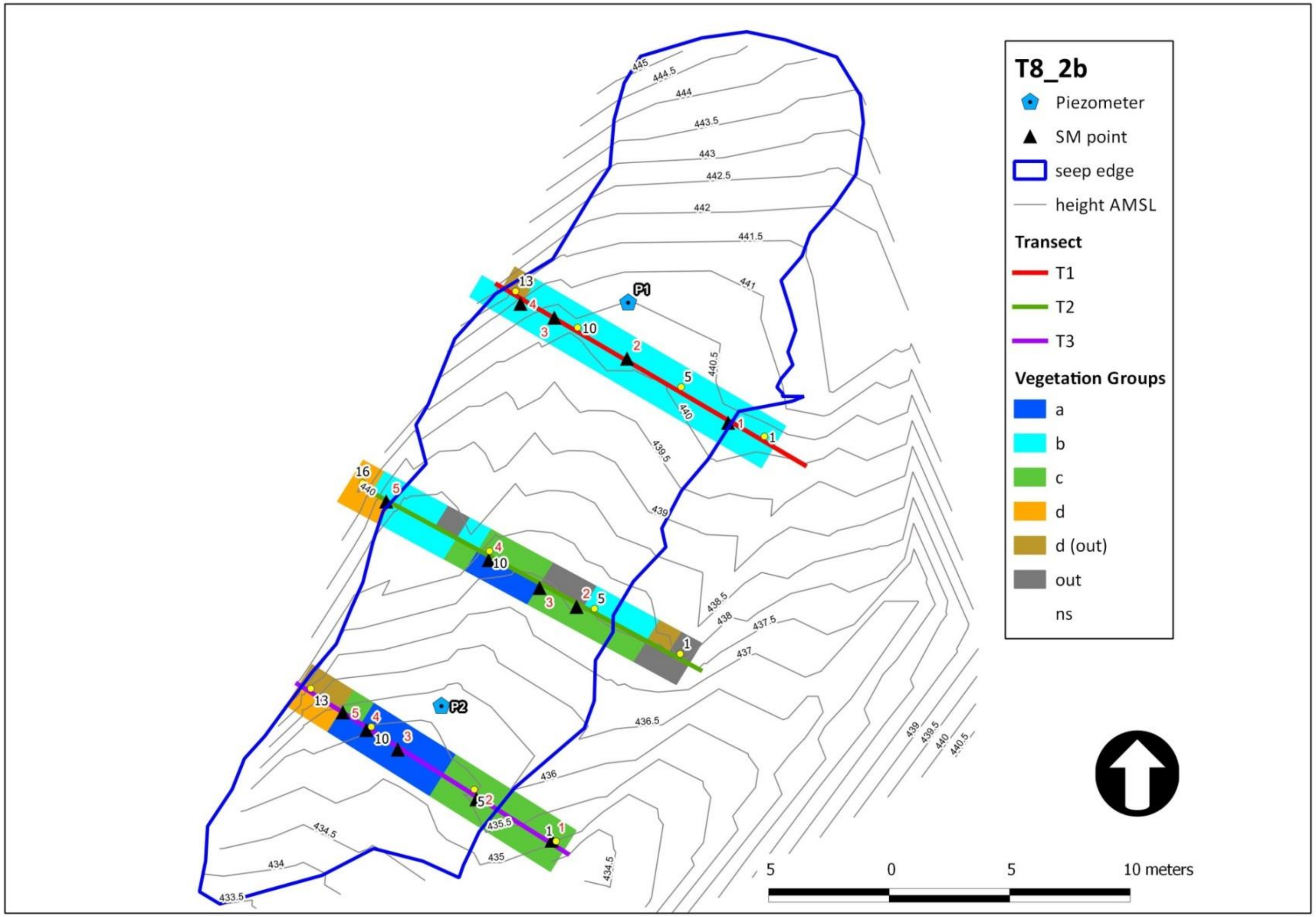


Figure 9.31 **Diagrammatic representation showing the position of all plots at T8_2b, colour coded according to the plant group that each represents. The dark grey plots represent outliers (out) that were substantially different from all groups. Gaps in plots along the transect (ns) are plots that are not sampled as part of the monitoring programme.**

Table 9.24 Average similarity within and between plant groups at T8_2b.

	a	b	c	d
a	54			
b	22	47		
c	33	40	52	
d	11	27	15	44

9.2.9.2 Key environmental drivers of community structure

DistLM analysis was used to determine with variables best described variability in plant community structure. Soil moisture parameters included only variables from the shallow soil profile (i.e. up to 30 cm depth) because the soils were generally shallow and deeper measurements could not be taken in many instances. The results of the analysis are as follows:

- Only a small proportion of the variation in vegetation community structure was explained by any single measured environmental factor at T8_2b (Table 9.25: marginal tests).
- Nevertheless, the wet season average soil moisture at a depth of 10-30 cm (L1_Wave) was the single best individual predictor of plant community structure at this site, describing 16% of the variability (Table 9.25: marginal tests).
- Several soil moisture parameters, as well as the cover of debris, the proportion of bare rock or soil and substratum type, together explained only 41 % of the total variability in plant community structure across the site.

Despite the tentative link between soil moisture and plant community structure at this site, an ordination of the fitted model given by the dbRDA plot (Figure 9.33) shows some separation of the plant communities based on the links between environmental factors and plant community structure. The ordination plots show that:

- Plots belonging to Groups a and c grouped closely, and separated from Group c plots along dbRDA1 (Figure 9.33a). There is a gradation of lowest average wet season soil moisture (L1Wave) along dbRDA1 indicating that L1_Wave was greater among plots in plant community Group c and a than in Group b with the lowest average wet season soil moisture in plots belonging to Group d (Figure 9.33b). This is consistent with the species' characteristics of the groups.
- Plots within Group a, however, had a higher average dry season surface soil moisture content (i.e. L0_Dave), relative to those in Group c and this distinction is largely evident along dbRDA 2 in the bubble overlay presented in (Figure 9.33c).
- Plots within Group d had a much lower % cover of debris on the ground as shown in Figure 9.33d, suggesting that some of the distinction between vegetation communities represented by Group d and the other groups might be attributed to factors other than soil moisture.

Although there is evidence to suggest that plant communities at T8_2b are linked to differences in soil moisture content across the seep, evidence from the DistLM to this effect is fairly weak, with a relatively low percentage of variability explained by soil moisture variables. Part of the reason for this could be attributed to only having the shallow soil moisture data, because of the rocky nature of the site: similar constraints on the power of the analysis have been shown for other rocky sites like K_6.

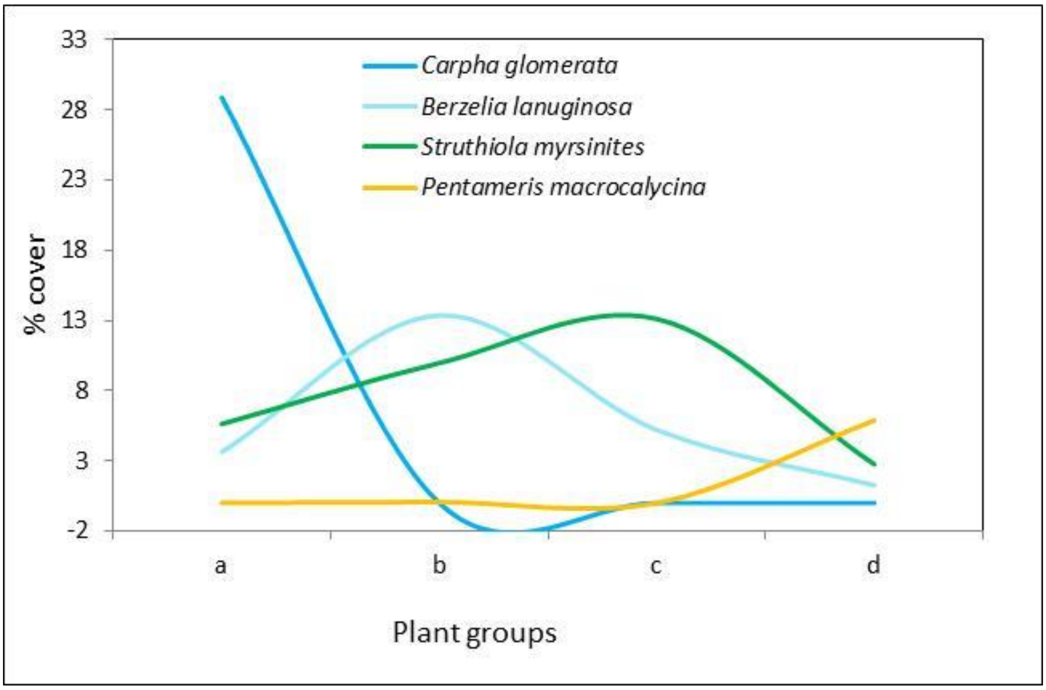


Figure 9.32 Average abundance (% cover) of indicator species for plant groups identified at T8_2b.

Table 9.25 Relationship between plant species composition for the subset of data associated with soil moisture and environmental variables at Site T8_2b. '% variation explained' indicates the percentage of variation in plant species composition by each variable. 'Cumulative % variation explained" is the cumulative percentage variation explained for each additional co-variate in the sequential tests.

Environmental variable	Parameter	*p*	% variation explained	
MARGINAL TESTS[1]				
Soil moisture	$L0\_Sat_{dur}$	0.0027	3.8	
	$L0\_D_{ave}$	0.0006	5.3	
	$L0\_W_{runmax}$	0.0006	4.6	
	$L1\_Sat_{dur}$	0.0001	10.9	
	$L1\_W_{ave}$	0.0001	16.3	
	$L1\_D_{sd}$	0.0001	11.8	
	$L1\_W_{runmax}$	0.0001	14.8	
Debris on ground	% cover	0.0006	5.0	
Debris in vegetation	% cover	0.0058	3.5	
Substratum type	% cover	0.0001	9.0	
Vegetation canopy cover	% cover	0.0082	3.4	
Bare Soil / Rock	% cover	0.0012	4.5	
SEQUENTIAL TESTS[2]	**Parameter**	***p***	**% variation explained**	**Cumulative % variation explained**
Soil moisture	$+L1\_W_{ave}$	0.0001	16.327	16.3
	$+L0\_W_{runmax}$	0.0001	4.6717	21.0
Debris on ground	+% cover	0.0001	4.4115	25.4
Bare Soil / Rock	+% cover	0.0013	2.8874	28.3
Soil moisture	$+L1\_D_{sd}$	0.0054	2.3424	30.6
	$+L0\_D_{ave}$	0.0001	3.7323	34.4
	$+L1\_W_{runmax}$	0.0014	2.4961	36.9
Substratum type	+% cover	0.0004	2.605	39.5
Soil moisture	$+L1\_Sat_{dur}$	0.0096	1.9134	41.4

[1] Marginal tests show how much variation each variable explains when considered alone, ignoring other variables.
[2] Sequential tests explain the cumulative variation attributed to each variable fitted to the model in the order specified, taking previous variables into account.

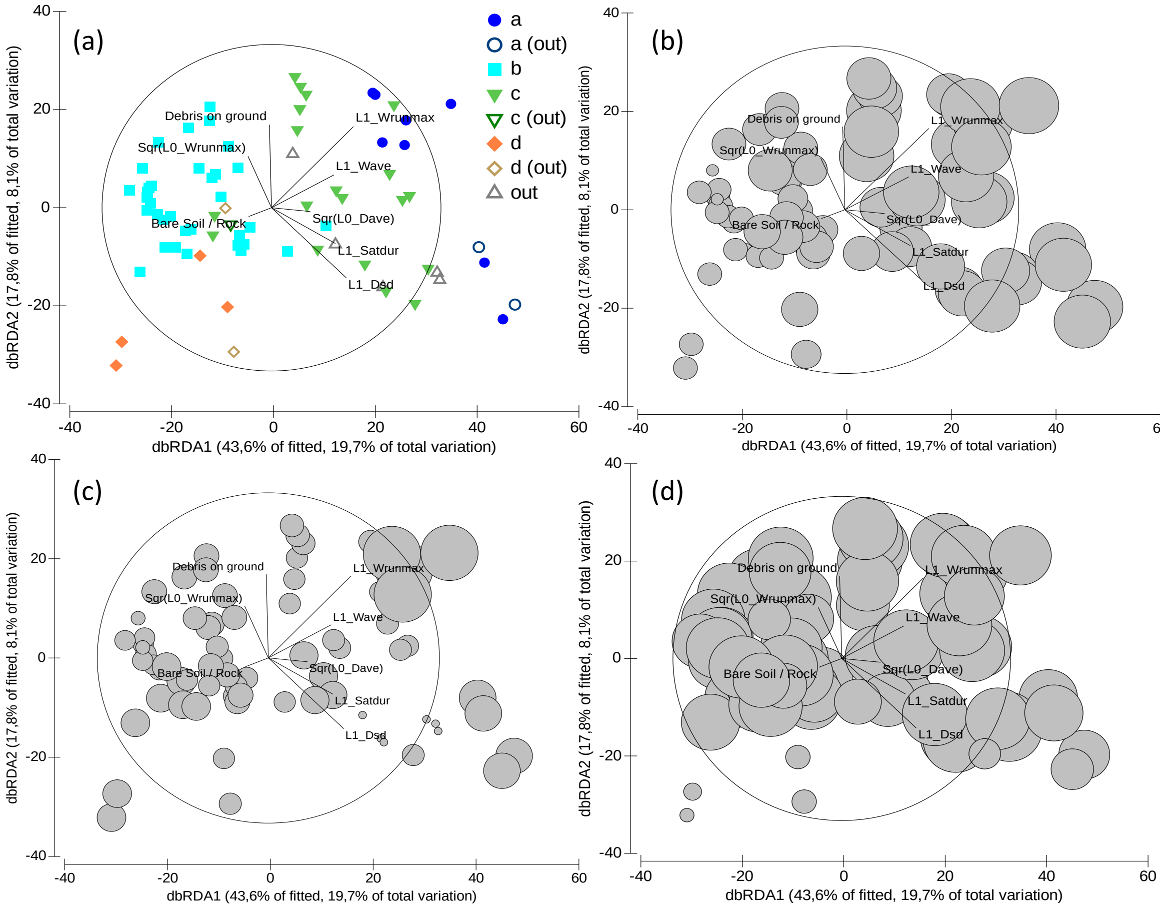


Figure 9.33 dbRDA ordination of plant species represented by the subset of data at T8_2b. The vectors show the Spearman correlation between environmental variables and dbRDA axes 1 and 2. a) gives the distribution of data represented by the plant communities identified in the cluster analysis. Bubble overlays of b) L1_Wave, c) L0_Dave and d) % cover of debris on the ground are also given - the larger the bubble, the greater the soil moisture content or % cover.

9.2.9.3 Year-on-year comparison of monitoring plots

The % similarity of individual plots is summarised for each of the plant communities identified at T8_2b (Figure 9.34). On average, the year-on-year similarities of plots belonging to Group a were relatively high (about 70% similarity) suggesting that the vegetation composition of plots within the wetter central areas of the seep are more conservative. Plots representing Groups b and c showed the greatest variability in inter-annual similarities between plots with some plots only showing less than 30% similarity between 2011 and 2012. The changes in species composition in these highly variable plots (over the two years) were, among other things, a decline in *Berzelia* in the Group b plots and of *Struthiola* in the Group c plots – defined in the previous section as their key indicator species for the respective groups. Drivers of these changes were not clear, however.

9.2.9.4 Inter-annual change in the height of dominant species

A comparison of the average height of the tallest species in each plot between 2011 and 2012 shows a general increase in height of the canopy species from 2011 to 2012 (Table 9.26). Interesting, *Pteridium aquilinum* and dead *P. aquilinum* increased substantially in the number of plots were was the tallest.

Considering that P aquilinum is a disturbance indicator, this suggests that the vegetation at this site may be recovering from some or other disturbance event Some species, such as *Restio paniculatus* and *Struthiola myrsinites* declined considerably in the percentage of plots for which they were one of the three tallest species (Table 9.26). This suggests a change or shift in the canopy community over time at T8_2b.

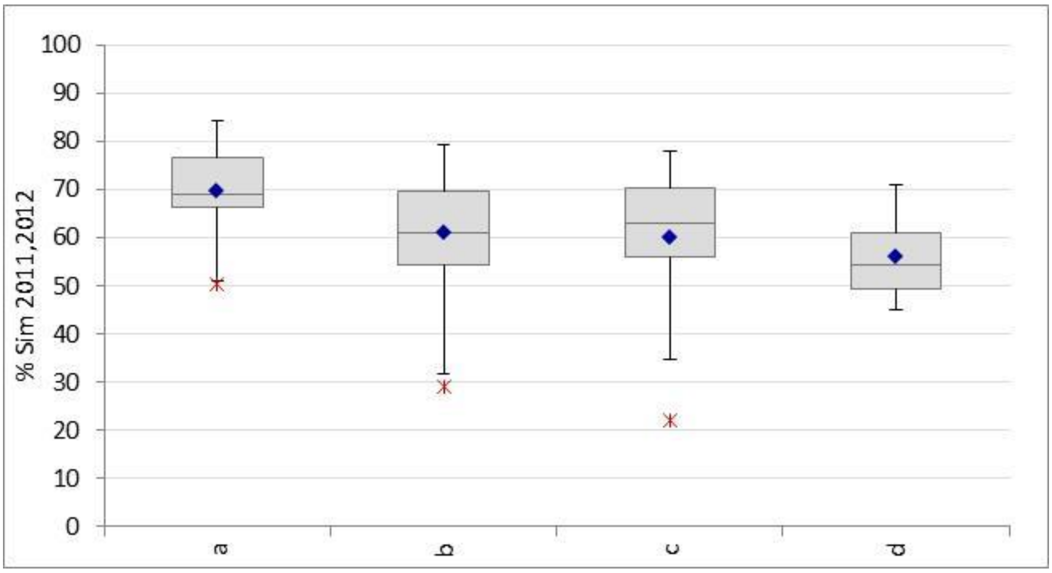


Figure 9.34 Percentage similarity in species composition between individual plots monitored in 2011 and 2012 summarised by the plant community (Group) affiliation of each plot at T8_2b.

9.2.9.5 Inter-annual change in the height of dominant species

A comparison of the average height of the tallest species in each plot between 2011 and 2012 shows a general increase in height of the canopy species from 2011 to 2012 (Table 9.26). Interesting, *Pteridium aquilinum* and dead *P. aquilinum* increased substantially in the number of plots were was the tallest. Considering that P aquilinum is a disturbance indicator, this suggests that the vegetation at this site may be recovering from some or other disturbance event Some species, such as *Restio paniculatus* and *Struthiola myrsinites* declined considerably in the percentage of plots for which they were one of the three tallest species (Table 9.26). This suggests a change or shift in the canopy community over time at T8_2b.

9.2.10 Ecochannel H8_3a

9.2.10.1 Plant communities

Four distinct plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

The colour-coded diagrammatic representation of all plots along the three sampling transects in Figure 9.35 shows that Groups a and b, which were defined by obligate wet bank or in-channel species (see Appendix 1 for details), were located in and along the main channel, as well as the secondary channel situated to the east. The floodplain and upper river banks were characterised by plots belonging to Groups c and d, which were largely dominated by facultative wetland species (Appendix 1).

The key indicator species reppresenting each of these groups are described in Appendix 1 and are:

Group a : *Pseudobaeckea africana* – obligate wet bank species along the channel and channel margins

Group b: *Isolepis digitata* – obligate wet bank species along the channel and channel margins

Group c: *Ehrharta ramosa* – facultative wetland species

Group d: *Restio dispar* – obligate wetland species

Table 9.26 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T8_2b. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	86	Total N:	248	#Plots:	84	Total N:	235
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Anthochortus graminifolius	4	4.65	0.45	0.26	5	5.95	0.38	0.29
Anthospermum aethiopicum	2	2.33	1.80	0.00				
Arctotis discolor	1	1.16	0.30		2	2.38	0.95	0.21
Aristea capitata	1	1.16	1.30		3	3.57	1.20	0.44
Berzelia lanuginosa	22	25.58	1.55	0.55	17	20.24	2.06	0.61
Blechnum capense	2	2.33	0.50	0.00				
Blechnum punctulatum	1	1.16	1.10		1	1.19	0.30	
Brachylaena neriifolia	3	3.49	2.50	0.00	4	4.76	3.00	0.00
Cannomois virgata	1	1.16	1.20					
Carpacoce spermacocea	5	5.81	0.80	0.27	2	2.38	1.05	0.49
Carpha glomerata	8	9.30	1.04	0.30	7	8.33	1.14	0.54
Carpha glomerata dead					2	2.38	0.70	0.00
Cassytha ciliolata	2	2.33	1.50	0.00	3	3.57	1.67	0.97
Centella eriantha	12	13.95	0.67	0.36	11	13.10	0.51	0.38
Diospyros glabra	2	2.33	1.75	0.35	2	2.38	1.55	0.92
Ehrharta setacea subsp. *uniflora*	1	1.16	0.30		3	3.57	0.43	0.15
Elegia thyrsifera					1	1.19	1.30	
Erica calyx	1	1.16	1.20					
Erica hispidula	3	3.49	0.73	0.31	7	8.33	0.99	0.47
Erica perspicua	1	1.16	0.70					
Erica pinea	2	2.33	1.60	0.14	1	1.19	1.60	
Ficinia acuminata					2	2.38	0.10	0.00
Ficinia trichodes	12	13.95	0.20	0.09	12	14.29	0.21	0.12
Gibbaria ilicifolia	3	3.49	0.63	0.42	1	1.19	1.00	
Helichrysum patulum					2	2.38	0.30	0.00
Indigofera filifolia	2	2.33	1.60	0.28				
Leucadendron xanthoconus / salificolium ?	27	31.40	2.30	0.57	18	21.43	2.82	0.88
Metrosideros angustifolia	1	1.16	0.80					
Neesenbeckia punctoria	11	12.79	1.74	0.30	6	7.14	1.60	0.78
Oxalis cf. truncatula	1	1.16	0.10		2	2.38	0.06	0.06
Penaea mucronata	2	2.33	1.50	0.71	2	2.38	1.30	0.14
Pentameris macrocalycina	1	1.16	0.80					
Psoralea monophylla	2	2.33	0.20	0.00	2	2.38	0.15	0.07
Pteridium aquilinum	47	54.65	0.99	0.33	55	65.48	1.30	0.91
Pteridium aquilinum - dead					33	39.29	0.93	0.39
Restio curviramus	1	1.16	0.30					
Restio gaudichaudianus	1	1.16	1.00		1	1.19	0.60	
Restio paniculatus	13	15.12	1.95	0.63	4	4.76	2.13	0.44
Restio paniculatus - dead					2	2.38	2.20	0.28
Restio triticeus	3	3.49	1.07	0.51	1	1.19	0.30	
Seriphium cinereum	10	11.63	0.90	0.53	3	3.57	1.20	0.44
Struthiola myrsinites	32	37.21	1.70	0.44	12	14.29	2.14	0.52
Tetraria cf. bromoides	2	2.33	0.75	0.35	2	2.38	0.45	0.21
Tetraria exilis	1	1.16	1.00		1	1.19	0.10	
Thesium strictum	1	1.16	1.50		1	1.19	2.80	
Todea barbara	1	1.16	1.80		1	1.19	0.90	
Tribolium brachystachyum					1	1.19	0.40	

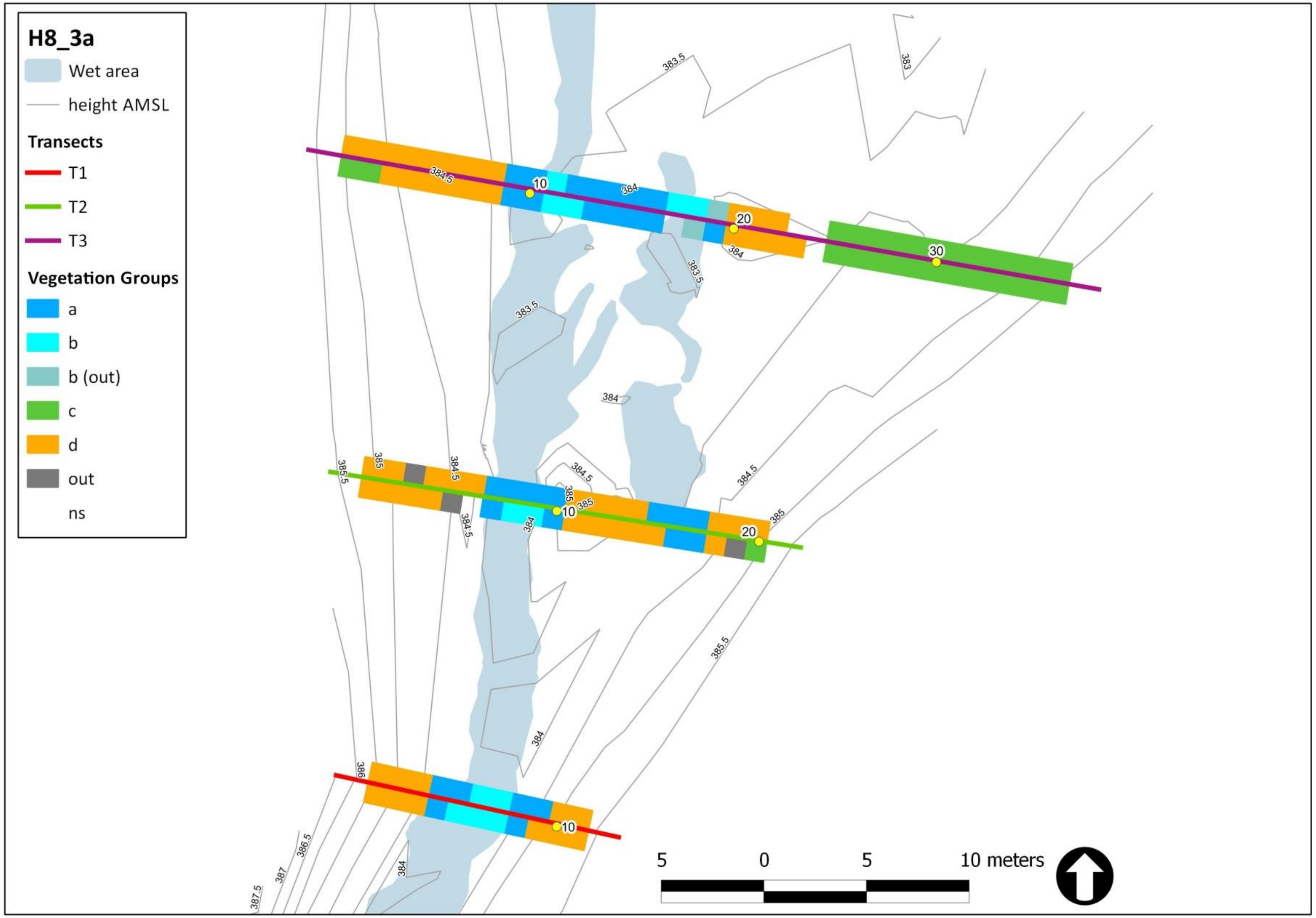


Figure 9.35 **Diagrammatic representation of the position of all plots at H8_3a , colour coded according to the plant group that each represents. The dark grey plots represent outliers (out) that were substantially different from all groups. Gaps in plots along the transect (ns) are plots that are not sampled as part of the monitoring programme.**

The average abundance (% cover) of each of these key indicator species at H8_3a is shown in Figure 9.36.

Group b was distinctly different from all other groups: plots had a high within-group similarity (60%, Table 9.27), was only 11% similar to Group a, and had zero similarity shared with Groups c and d (Table 9.27). These features are clearly linked to the dominance there of in-channel species, chiefly *Isolepis digitata*, which forms dense mats in the channel plots. Group a, although fairly uncohesive (within-group similarity of only 30%) represents the wetbank and channel bar vegetation, which is diverse along the bedrock-dominated channel, but differentiated from other community groups by the relative abundance of the obligate wetland species *Pseudobaeckea africana*. Dispersion among plots within the drier upper bank and floodplain areas (Groups c and d) was relatively high as indicated by the low within-group similarity. Nevertheless, groups were distinctly different from each by the prevalence of *Restio dispar* closer to the edge of the main channel (Group d plots) with *Ehrharta ramosa* being better adapted to the outer floodplain margins (Figure 9.35).

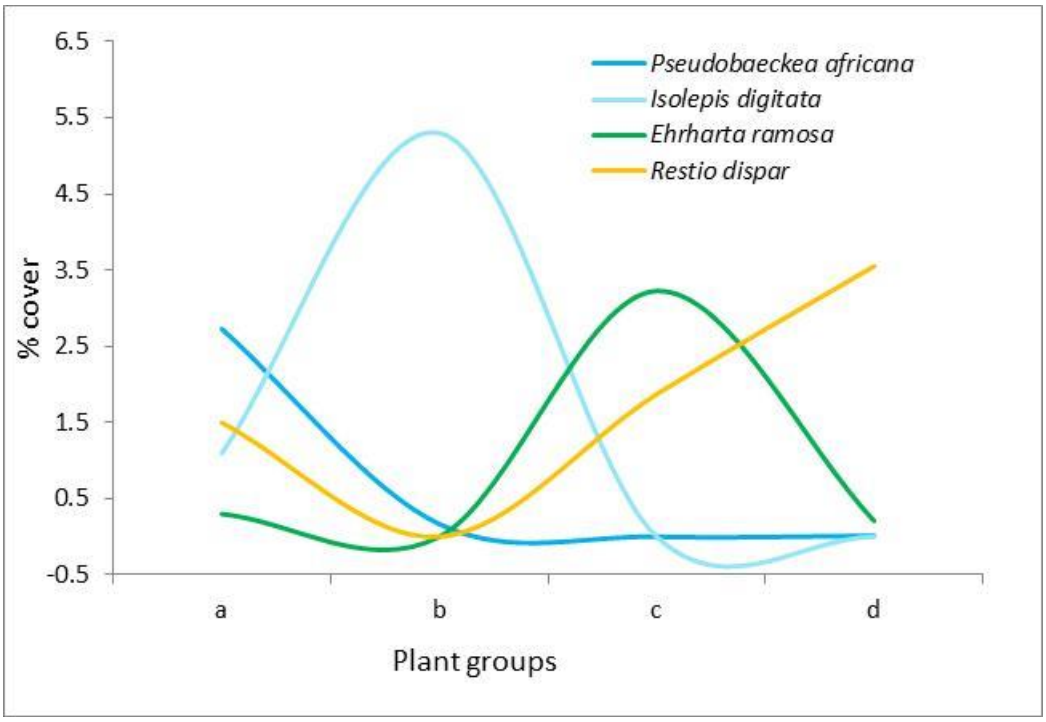


Figure 9.36 Average abundance (% cover) of indicator species for plant groups identified at H8_3a.

Table 9.27 Average similarity within and between plant groups at H8_3a.

	a	b	c	d
a	30			
b	11	60		
c	6	0	29	
d	11	0	15	28

In summary:

- These results suggest a relationship between plant community structure and soil moisture along a perpendicular gradient from the centre of the channel outward.
- The plant communities identified in this analysis therefore provide a framework for evaluating change in plant species composition based on monitoring plots in future sampling events.

9.2.10.2 Year-on-year comparison of monitoring plots

The % similarity in vegetation composition between individual plots is summarised by the plant community affiliation of each plot (Figure 9.37). On average, the year-on-year similarities of plots belonging to Groups a and b were relatively high (about 60% and 70% similarity respectively) suggesting that the plant community composition of the channel and channel margins did not change considerably between 2011 and 2012. Nevertheless, some plots represented by these groups did change substantially over the annual period as indicated by the variability around the average in Figure 9.37 for these groups. By contrast, vegetation composition of most plots representing Groups c and d changed considerably between 2011 and 2012.

Lower values for year-on-year comparisons in Group a plots were chiefly related to increases in cover values, for example at plot T2_17a and T2_10b, where species such as Platycaulos cascadensis, restio dispar *Pseudobaeckea* and *Isolepis* increased marginally, illustrating continued growth in wetbank vegetation after the fires of two years back. For Groups c and d, most of the year-on-year plot changes occurred along Transect 3, on both sides of the main channel. Here the year-on-year changes are magnified where starting plant densities are low – the changes for the most part represented the new record (in most cases) or loss of species (in fewer cases) but the change being at very low cover values.

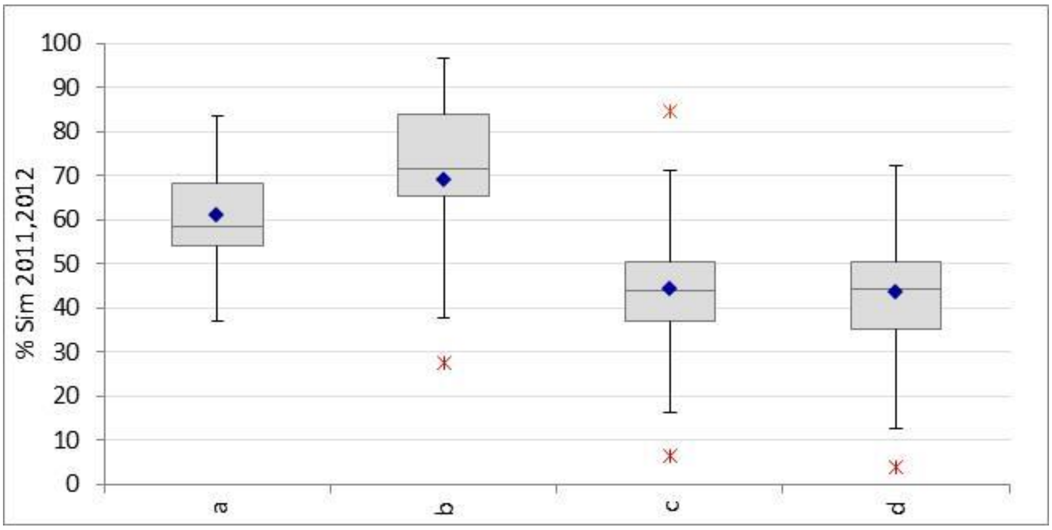


Figure 9.37 Percentage similarity in species composition between individual plots monitored in 2011 and 2012, summarised by the plant community (Group) affiliation of each plot at H8_3a.

9.2.10.3 Inter-annual change in the height of dominant species

A comparison of the average height of the tallest species per plot in 2011 and 2012 shows there were some changes in the canopy community over the annual period (Table 9.28). Besides a general increase in height of most of the canopy species from 2011 to 2012 (Table 9.28), a number of species declined in their representation as the tallest species while others increased. In particular, the grass, *Ehrharta ramosa* was one of the tallest species in 21% of plots in 2011 but this representation declined to 15%, despite an average increase in the growth of this species. Also, *Platycaulos cascadensis* was represented by 43% of plots as one of the tallest species in 2011 but was not recorded in a single plot as one of the tallest species in 2012. By contrast*, Restio dispar* was present as one of the tallest species in only 5% of plots but this representation increased to 55% in 2012. T*his* suggests a significant shift in the canopy community over time at H8_2a, which mirrors the patterns in year-on-year similarities described above.

Table 9.28 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at H8_3a. The number of plots and the percentage of the total number of plots represented by each species are also given..

Species	2011				2012			
	#Plots:	136	Total N:	389	#Plots:	136	Total N:	366
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Agathosma crenulata	2	1.47	1.30	0.00	1	0.74	1.20	
Anthospermum galioides	2	1.47	0.18	3.54				
Aristea racemosa var. *inflata /* var. *racemosa*	1	0.74	0.40					
Berzelia alopecuroides					1	0.74	1.10	
Berzelia lanuginosa	13	9.56	0.75	44.04	6	4.41	0.95	0.35
Brachylaena neriifolia	13	9.56	0.95	48.92	10	7.35	1.13	0.29
Brachylaena neriifolia - dead					1	0.74	0.40	
Carpacoce spermacocea					2	1.47	0.30	0.14
Centella difformis	4	2.94	0.14	4.35	14	10.29	0.18	0.16
Centella sessilis					2	1.47	0.15	0.07
Cliffortia atrata	7	5.15	0.30	14.72	5	3.68	0.46	0.27
Cliffortia atrata - dead					3	2.21	0.53	0.06
Clutia alaternoides					1	0.74	0.30	
Corymbium africanum subsp. *scabridum* var. *gramineum*	2	1.47	0.18	10.61				
Corymbium cf. laxum subsp. *bolusii*					1	0.74	0.30	
Corymbium glabrum	1	0.74	0.30		1	0.74	0.30	
Cyathocoma hexandra	3	2.21	0.57	11.55	4	2.94	0.68	0.17
Diospyros glabra	5	3.68	0.43	26.83	2	1.47	0.40	0.00
Disparago ericoides	1	0.74	0.20					
Drosera capensis					1	0.74	0.10	
Ehrharta ramosa	28	20.59	0.51	13.79	20	14.71	0.56	0.15
Elegia deusta	7	5.15	0.99	15.92	3	2.21	1.03	0.06
Elegia hookeriana	3	2.21	1.03	15.28	1	0.74	0.60	
Elegia mucronata	5	3.68	1.06	34.35	5	3.68	1.34	0.27
Elegia persistens	3	2.21	0.73	46.19	2	1.47	0.70	0.00
Epischoenus lucidus					1	0.74	0.40	
Epischoenus quadrangularis/villosus complex	5	3.68	0.68	25.64	5	3.68	0.66	0.15
Erica coccinea	5	3.68	0.44	16.73	5	3.68	0.58	0.26
Erica corifolia	1	0.74	0.30					
Erica equisetifolia					7	5.15	0.24	0.14
Erica hispidula	2	1.47	0.60	14.14	2	1.47	0.45	0.07
Erica intervallaris					2	1.47	0.45	0.07
Erica labialis					3	2.21	0.23	0.06
Erica pulchella					2	1.47	0.25	0.07
Erica serrata					3	2.21	0.20	0.10
Erica sitiens	4	2.94	0.51	39.02	8	5.88	0.46	0.26
Ficinia oligantha	1	0.74	0.15					
Ficinia zeyheri					1	0.74	0.20	
Gibbaria ilicifolia	3	2.21	0.27	11.55				
Grubbia rosmarinifolia	2	1.47	0.93	31.82				
Hypodiscus aristatus	2	1.47	0.65	7.07	1	0.74	6.60	
Hypodiscus willdenowia	1	0.74	0.40					
Isolepis digitata	15	11.03	0.40	13.50	12	8.82	0.28	0.14
Lanaria lanata	2	1.47	0.30	0.00	1	0.74	0.30	
Lichen					1	0.74	0.01	
Lobelia pinifolia	1	0.74	0.20					
Mastersiella digitata	2	1.47	0.43	10.61	8	5.88	0.46	0.09
Merxmuellera rufa	3	2.21	0.27	12.58	1	0.74	0.10	
Metalasia densa	9	6.62	0.32	10.90	4	2.94	0.50	0.08
Microdon dubius	1	0.74	0.15					
Moss					2	1.47	8.00	5.66
Neesenbeckia punctoria	4	2.94	1.10	0.00	2	1.47	1.15	0.21
Nevillea obtusissima	15	11.03	0.55	15.41	12	8.82	0.60	0.10
Othonna quinquedentata	6	4.41	0.49	31.05	3	2.21	1.20	0.46

Cont.

Species	2011				2012			
	#Plots:	136	Total N:	389	#Plots:	136	Total N:	366
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Pentameris colorata	2	1.47	0.45	7.07				
Phaenocoma prolifera	1	0.74	0.25					

Platycaulos cascadensis	59	43.38	0.92	43.96				
Platycaulos compressus	4	2.94	0.78	26.30	3	2.21	0.97	0.06
Prionium serratum	14	10.29	0.50	21.35	18	13.24	0.59	0.27
Pseudobaeckea africana	18	13.24	0.86	24.59	15	11.03	0.83	0.24
Raspalia microphylla	7	5.15	0.69	30.06	7	5.15	0.66	0.26
Restio bifarius	4	2.94	0.98	9.57	3	2.21	1.00	0.00
Restio bifidus	2	1.47	0.55	21.21	3	2.21	0.53	0.15
Restio burchellii					6	4.41	0.55	0.10
Restio capensis	3	2.21	0.38	17.56	3	2.21	0.47	0.06
Restio curviramis	7	5.15	0.19	3.45	6	4.41	0.25	0.05
Restio dispar	7	5.15	0.96	49.62	75	55.15	1.11	0.41
Restio dispar - dead					1	0.74	0.90	
Restio fusiformis					1	0.74	0.70	
Restio pedicellatus					2	1.47	0.40	0.00
Restio purpurascens	6	4.41	1.05	35.07	4	2.94	1.25	0.31
Restionaceae juveniles	3	2.21	0.27	10.41				
Senecio umbellatus	1	0.74	0.40					
Seriphium cinereum	1	0.74	0.40		9	6.62	0.43	0.19
Seriphium spirale	1	0.74	0.35		3	2.21	0.33	0.12
Soroveta ambigua					2	1.47	0.25	0.07
Syncarpha speciocissima	15	11.03	0.39	10.26	12	8.82	0.52	0.12
Tetraria bromoides	2	1.47	0.38	10.61				
Tetraria compar	2	1.47	0.70	28.28	3	2.21	0.67	0.06
Tetraria exilis					1	0.74	0.60	
Tetraria flexuosa	18	13.24	0.82	23.89	10	7.35	1.08	0.71
Tetraria microstachys	1	0.74	0.25					
Tetraria pillansii					1	0.74	0.50	
Thamnochortus gracilis	2	1.47	0.45	7.07				
Thamnochortus lucens					1	0.74	0.30	
Thamnochortus sp					3	2.21	0.43	0.06
Ursinia paleacea	20	14.71	0.43	12.08				
Ursinia paleacea - dead	4	2.94	0.35	4.08	2	1.47	0.35	0.07
Willdenowia teres	1	0.74	0.30					

9.2.11 Ecochannel K_2a

9.2.11.1 Plant communities

Eight plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

The colour-coded diagrammatic representation of all plots along the three sampling transects in Figure 9.38 shows that Groups a and b, which were defined by obligate wet bank species (see Appendix 1 for details) in the main channel and channel margins but extended beyond this across the woody floodplain.

Plant communities comprising Groups c to h appear as the bank slopes upward (seen clearly from the contours in Figure 9.38), but were distinctly different on the left vs. right bank at K_2a (Figure 9.38). Groups c, d, e and f were located on the steep left bank slopes, with Group d closest and Group c furthest from the channel, this bank densely vegetated and associated with the shales of the northern portion of Oudebos valley. Groups g and h were associated with the dry sandy terrace forming the right bank of the river (Figure 9.38). Details of species composition of these groups are provided in Appendix 1.

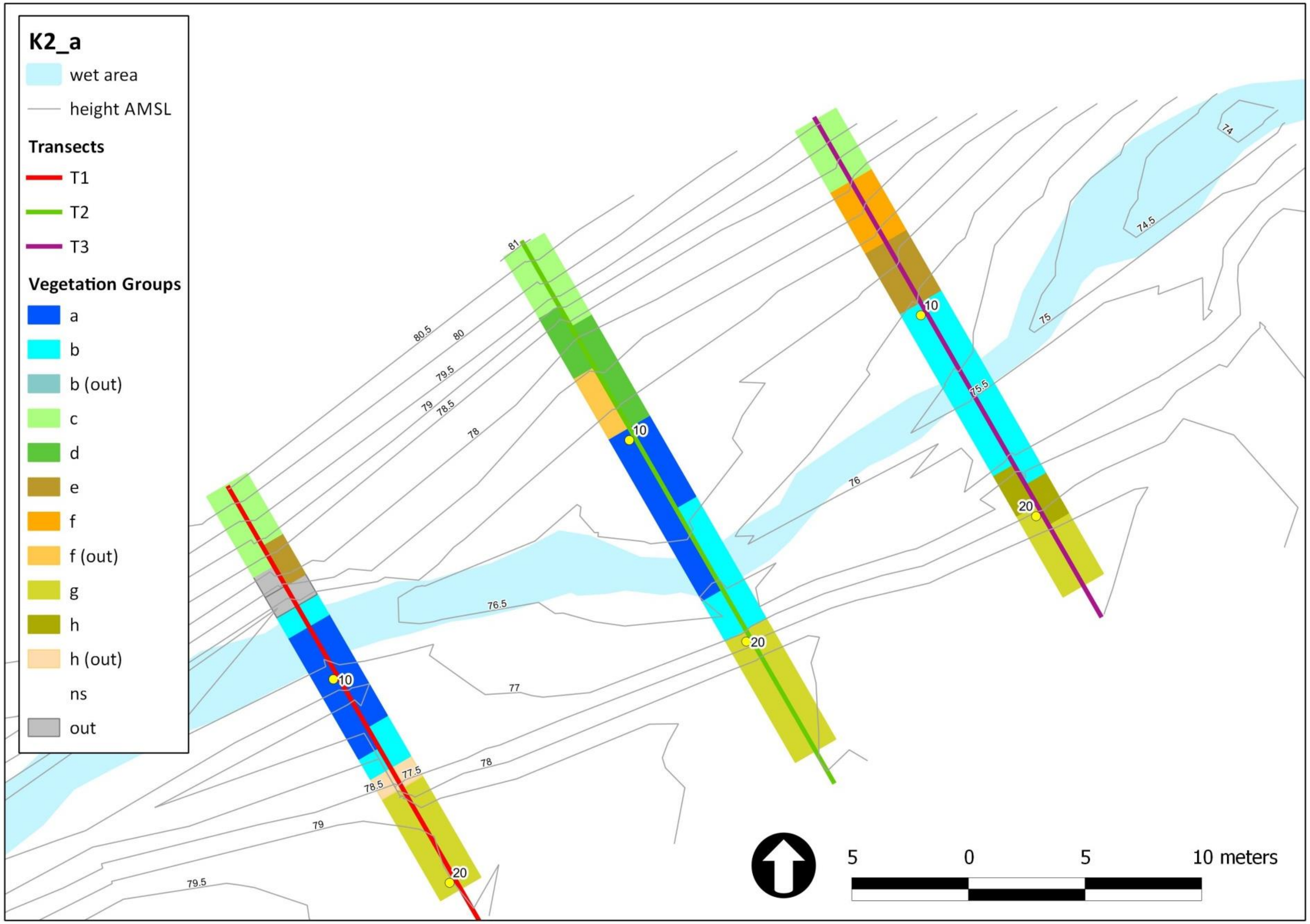


Figure 9.38 Diagrammatic representation of all plots at K_2a colour coded according to the plant community that each represents. The gaps represent plots not sampled and the grey plots represent outliers.

The key indicator species of each of these groups are described in Appendix 1 and summarised as follows**:**

Group a : *Metrosideros angustifolia* – obligate wet bank species

Group b: *Prionium serratum* – obligate wet bank species

Group c: *Aristea capitata* –

Group d: *Myrsine africana* – obligate wet floodplain species

Group e: *Restio subverticillatus*

Group f: *Brachylaena neriifolia*

Group g: *Erica muscosa*

Group h: *Brabejum stellatifolium* – mature specimens may denote historical wetbank / riparian zones in incised channels

The average abundance (% cover) of each of these key indicator species at T8_2b is shown in Figure 9.39. The average similarity within-group similarity matrix (Table 9.29) shows that dispersion among plots within each group was relatively high with similarities within each of the eight groups ranging between 40% and 50%. Nevertheless, groups were distinctly different from each other as indicated by the very low similarity shared between groups. In particular, Group g, typical of the dry bank was distinctly different from all groups with between three and six percentage similarity shared with any other group (Table 9.29).

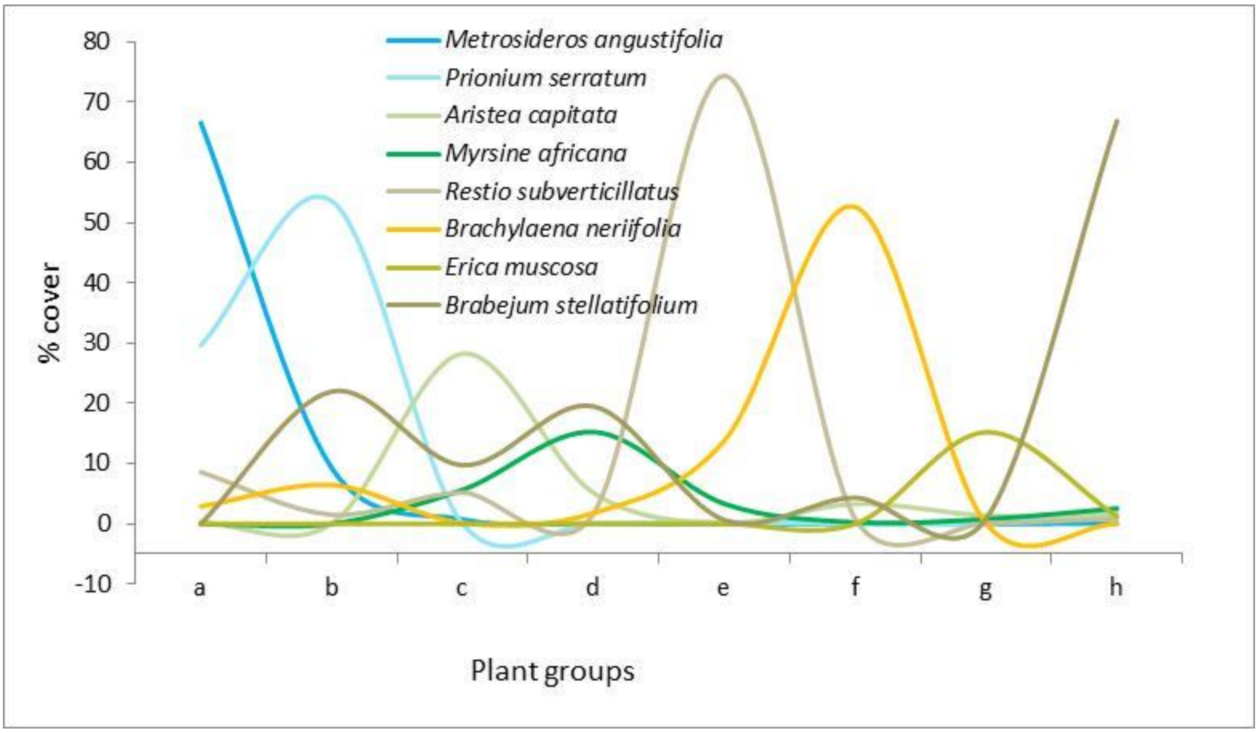


Figure 9.39 Average abundance (% cover) of indicator species for plant groups identified at K_2a.

In summary:

- A clear distinction in plant communities between the channel and floodplain and the banks was evident at this site suggesting a relationship between plant community structure and soil moisture.
- The plant communities identified in this assessment therefore provide a framework for evaluating change in plant species composition based on monitoring plots in future sampling events.

Table 9.29 Average similarity within and between plant groups at K_2a.

	a	b	c	d	e	f	g	h
a	50							
b	31	49						
c	4	6	41					
d	5	10	28	40				
e	12	15	13	15	51			
f	8	16	16	21	20	45		
g	4	3	6	6	3	3	40	
h	9	19	15	19	10	11	19	47

9.2.11.2 Year-on-year comparison of monitoring plots

The % similarity in vegetation composition between individual plots is summarised by the plant community affiliation of each plot in Figure 9.40. The average year-on-year similarities of plots among plant communities varied considerably, with the greatest similarity evident between plots belonging to Groups a, b, c and e. By contrast, vegetation composition in plots affiliated to Group f changed considerably between 2011 and 2012 (Figure 9.40). Low values here were the result of a possibly spurious and very large difference in cover values recorded in 2011 and 2012 for *Brachylaena neriifolia* and *Laurophyllus capensis*. Both of these are small trees, and would probably overhang a number of plots. The differences in recorded cover are more likely related to recorder-inconsistency than real change.

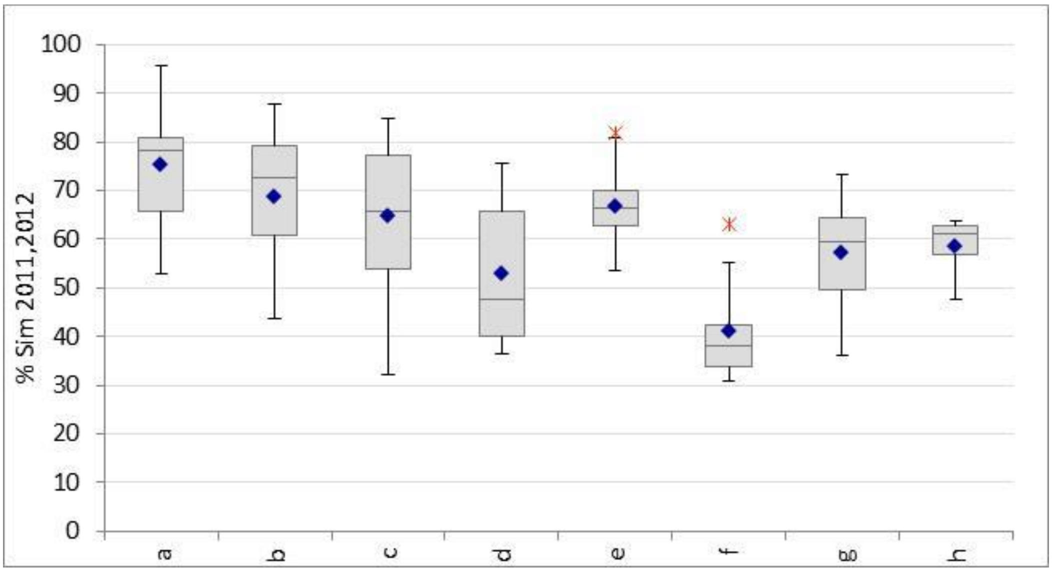


Figure 9.40 Percentage similarity in species composition between individual plots monitored in 2011 and 2012, summarised by the plant community (Group) affiliation of each plot at K2_a.

9.2.11.3 Inter-annual change in the height of dominant species

A comparison of the average height of the tallest species in each plot between 2011 and 2012 shows little change or shift in the canopy community at K_2a (Table 9.30). *Brachylaena neriifolia* was present as one of the tallest species in 21% of plots in 2011 but this representation increased to 32% in 2012 (Table 9.30) – a result that confirms that the low cover values recorded in some plots in Group f in 2012 are likely to be errors. *Thesium strictum* was also present as one of the tallest species in only 5% of plots in 2011 but this representation increased to 14% in 2012 (Table 9.30). By contrast, *Pteridium aquilinum* was overtaken by other species as one of the tallest because its representation as a canopy species changed from 12% in 2011 to 3% in 2012 (Table 9.30). These observations all suggest, as expected, the continued growth and densification of the riparian zone following the fires in 2010.

Table 9.30 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at K_2a. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots: 136		Total N: 360		#Plots: 136		Total N: 399	
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Arctotis discolor					1	0.74	0.60	
Aristea capitata	18	13.24	0.98	0.45	13	9.56	1.24	0.23
Aspalathus excelsa	3	2.21	0.73	0.25	2	1.47	1.15	0.21
Asparagus rubicundus	1	0.74	0.80		1	0.74	1.20	
Berzelia lanuginosa	9	6.62	2.81	1.24	11	8.09	2.69	0.90
Blechnum capense	24	17.65	1.25	0.32	24	17.65	1.43	0.25
Brabejum stellatifolium	23	16.91	2.94	1.03	29	21.32	3.00	1.14
Brachylaena neriifolia	29	21.32	2.48	1.06	44	32.35	41.95	34.60
Cannomois virgata	3	2.21	0.85	0.28	4	2.94	0.93	0.15
Carpha glomerata	4	2.94	1.20	0.54	5	3.68	1.56	0.70
Cassytha cilliolata					3	2.21	1.07	0.51
Centella eriantha	2	1.47	0.25	0.07	2	1.47	1.75	1.06
Cliffortia heterophylla	5	3.68	0.80	0.85	4	2.94	2.03	1.13
Cliffortia odorata	1	0.74	0.30		1	0.74	0.60	
Culumia setosa var. setosa	2	1.47	0.40	0.00	6	4.41	0.75	0.32
Diospyros glabra	1	0.74	0.80		6	4.41	2.08	1.50
Dipogon lignosus	1	0.74	1.40					
Drosera capensis	1	0.74	0.20		1	0.74	0.10	
Ehrharta ramosa	1	0.74	1.00		1	0.74	1.10	
Ehrharta rupestris subsp. rupestris	1	0.74	0.40					
Ehrharta setacea subsp. uniflora	1	0.74	25.00		4	2.94	0.78	0.52
Erica caffra	1	0.74	1.20		2	1.47	1.40	0.00
Erica muscosa	4	2.94	1.66	2.89	8	5.88	0.43	0.12
Euryops cf. abrotinifolius					3	2.21	1.03	0.25
Ficinia acuminata	5	3.68	0.34	0.08	3	2.21	0.40	0.10
Ficinia trichodes	1	0.74	0.30					
Gibbaria ilicifolia	1	0.74	0.50					
Halleria lucida					1	0.74	1.00	
Hermas villosa	4	2.94	0.55	0.17	3	2.21	0.80	0.52
Isolepis digitata	2	1.47	0.18	0.04				
Kiggelaria africana	1	0.74	0.60		2	1.47	0.75	0.07
Laurophyllus capensis	7	5.15	2.17	1.30	11	8.09	2.69	0.78
Leucadendron salicifolium	2	1.47	2.20	0.42	3	2.21	2.53	1.33
Lobelia capilifolia	9	6.62	0.29	0.12	6	4.41	0.47	0.10
Maytenus acuminata	1	0.74	1.50					
Metrosideros angustifolia	31	22.79	2.65	0.67	32	23.53	2.89	0.95
Montinia caryophallacea	7	5.15	0.71	0.35	5	3.68	0.52	0.11
Moss					1	0.74	0.01	
Muraltia divaricata					1	0.74	0.60	
Muraltia paludosa	1	0.74	0.20		1	0.74	0.20	
Myrsine africana	9	6.62	1.01	0.63	6	4.41	1.18	0.97
Neesenbeckia punctoria	1	0.74	1.10					
Notobubon galbaniopse	2	1.47	1.35	0.21	1	0.74	1.30	
Olea capensis L. subsp. capensis	6	4.41	3.60	1.02	13	9.56	2.72	1.13
Othonna quinquedentata	10	7.35	0.92	0.33	16	11.76	1.60	0.57
Oxalis incarnata	4	2.94	1.36	2.43	1	0.74	0.10	
Platycaulos compressus					2	1.47	1.35	0.07
Podalyria calyptrata	11	8.09	2.24	1.86	6	4.41	3.33	1.33
Prionium serratum	43	31.62	1.46	0.22	38	27.94	1.51	0.31

Cont.

Species	2011				2012			
	#Plots: 136		Total N: 360		#Plots: 136		Total N: 399	

	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Protea leptocarpodendron	5	3.68	2.78	1.16	2	1.47	1.45	0.21
Pseudoselago spuria	2	1.47	0.35	0.07				
Pteridium aquilinum	16	11.76	1.16	0.39	5	3.68	1.34	0.44
Pteridium aquilinum (dead)					5	3.68	2.34	1.67
Restio capensis	1	0.74	0.45		1	0.74	0.50	
Restio subverticillatus	16	11.76	1.65	0.37	16	11.76	1.78	0.44
Restio subverticillatus (dead)					2	1.47	1.15	0.07
Restionanceae juvenile					1	0.74	0.20	
Rhyncosia capensis	1	0.74	5.00					
Searsia angustifolia					2	1.47	2.50	0.00
Searsia lucida	4	2.94	2.05	0.25	2	1.47	2.20	0.28
Searsia tomentosa	5	3.68	2.66	1.51	5	3.68	2.38	1.33
Senecio rigidus	1	0.74	1.60					
Stoebe capitata	1	0.74	0.20		3	2.21	0.40	0.00
Struthiola myrsinites					2	1.47	1.15	0.92
Thamnochortus cf sporadicus					2	1.47	0.80	0.28
Thesium strictum	7	5.15	0.94	0.22	19	13.97	1.21	0.26
Todea barbara					1	0.74	1.60	
Tritoniopsis lata	2	1.47	0.93	0.39				
Ursinia chrysanthemoides	5	3.68	0.46	0.25				
Watsonia borbonica	1	0.74	0.60		1	0.74	1.60	
Widdringtonia nodiflora					3	2.21	2.50	1.73

9.2.12 Ecochannel K_5a

9.2.12.1 Plant communities

Eight plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

The colour-coded diagrammatic representation of all plots along the three sampling transects in Figure 9.41 shows Groups c, e and f located along the main channel (northerly withint he broad valley bottom) and the secondary channels that remain wet year-round. The plots comprising Groups a and b communities were on the sandier terraces and floodplain, including dry or seldom inundated channels and flats. Group d pots were located in a discrete area on the upper slopes above the valley bottom, along Transect 1 (Figure 9.41).

Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a: *Ehrharta setacea* subsp. *uniflora* – – seeps on lower slopes, threatened status VU (SANBI)
Group b: *Ehrharta ramosa* – facultative wetland species
Group c: *Prionium serratum* – obligate wet bank species
Group d: *Erica muscosa*
Group e: *Platylophus trifoliatus* – obligate wet bank species;
Group f: *Metrosideros angustifolia* – obligate wet bank species

The average abundance (% cover) of each of these key indicator species is shown in Figure 9.42.

The slopes and terrace along the left bank was dominated by Group a, defined by *Ehrharta setacea* subsp. *uniflora* (Figure A9.15b) – this species being an indicator at K_5b, as an indicator of moist hillslope seeps.

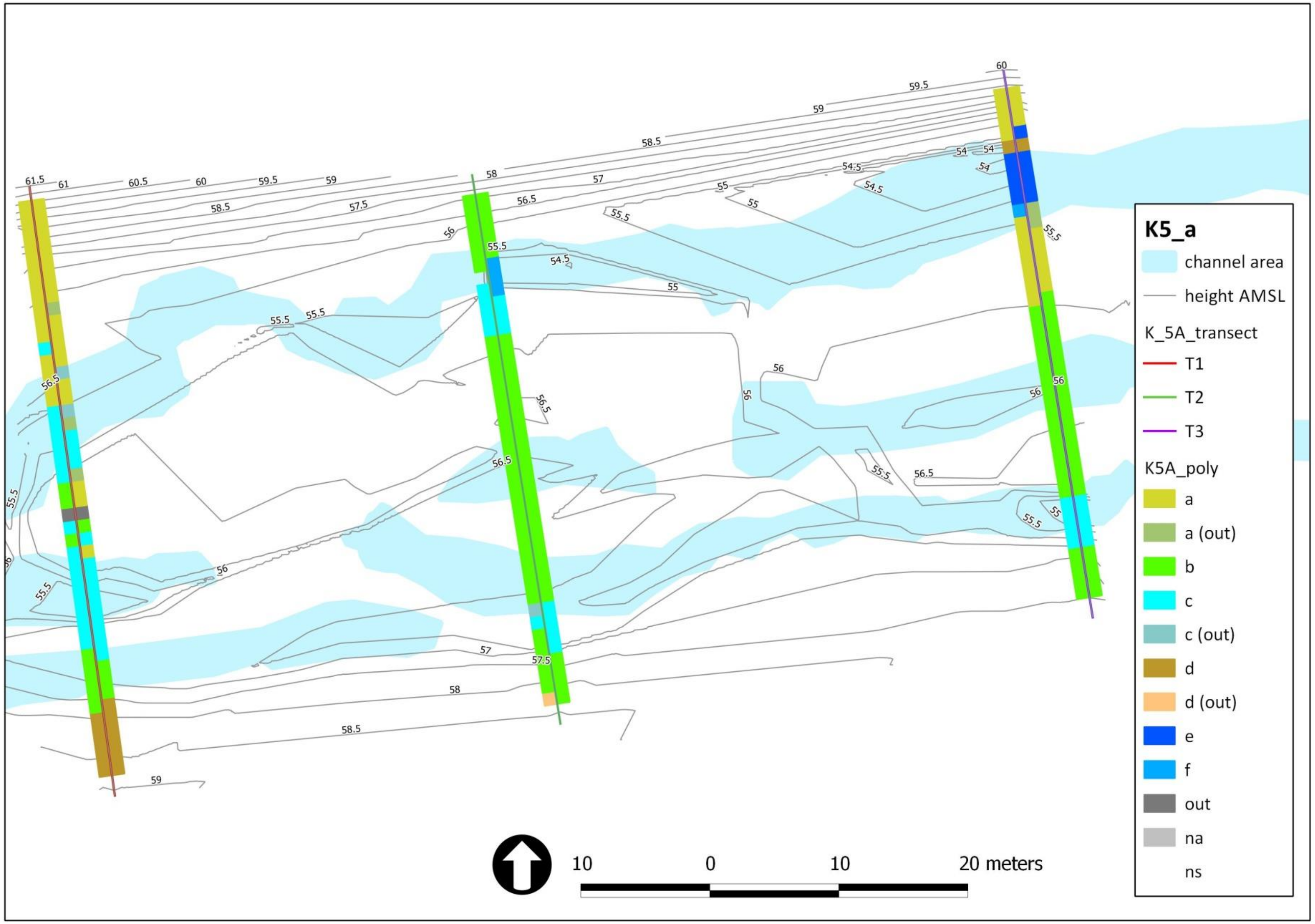


Figure 9.41 Diagrammatic representation of all plots at K_5a during spring 2012 colour coded according to the plant community that each represents. The gaps represent plots not sampled and the grey plots represent outliers.

Although their habitats both included the outer margins of the stream and portions of the floodplain, Group a and Group b communities were only 9% similar in composition (Table 9.31). The key species differentiating Group b from the other communities was the facultative wetland grass, *Ehrharta ramosa,* indicating that this community inhabits the drier portions of the floodplain, with Group a and c dominating the wetter areas. Group b was not only the most widespread plant community group, but also the least coherent, with a within-group similarity among plots of 32 %, reflecting the fact that the floodplain is topographically diverse. A further contributing factor is the recent burn there, so recovery in the drier areas would be slower, and vegetation typically more patchy.

Differentiating between the three obligate wet groups associated with the channel, *Prionium serratum* was the signature species defining Group c plots, whilst Groups e and f were defined by *Platylophus trifoliatus* and *Metrosideros angustifolia* respectively – these groups being restricted to a woody forested portion of the main channel abutting the steep rocky banks on the northern edge of the valley (see Appendix 1 for detailed descriptions of communities). Group d representing the dry bank community above the valley floor was particularly different from all other groups with zero similarity between this group and the wet bank communities typical of the channel (i.e. Groups e and f) (Table 9.31). The key species defining this community was *Erica muscosa*, which was also the key descriptor of the driest community at K_2a, on the terraced slopes above the floodplain there (see section 9.2.11).

Table 9.31 Average similarity within and between plant groups at K_5a.

	a	b	c	d	e	f
a	35					
b	9	32				
c	10	14	41			
d	1	10	1	37		
e	3	1	1	0	54	
f	6	4	10	0	18	36

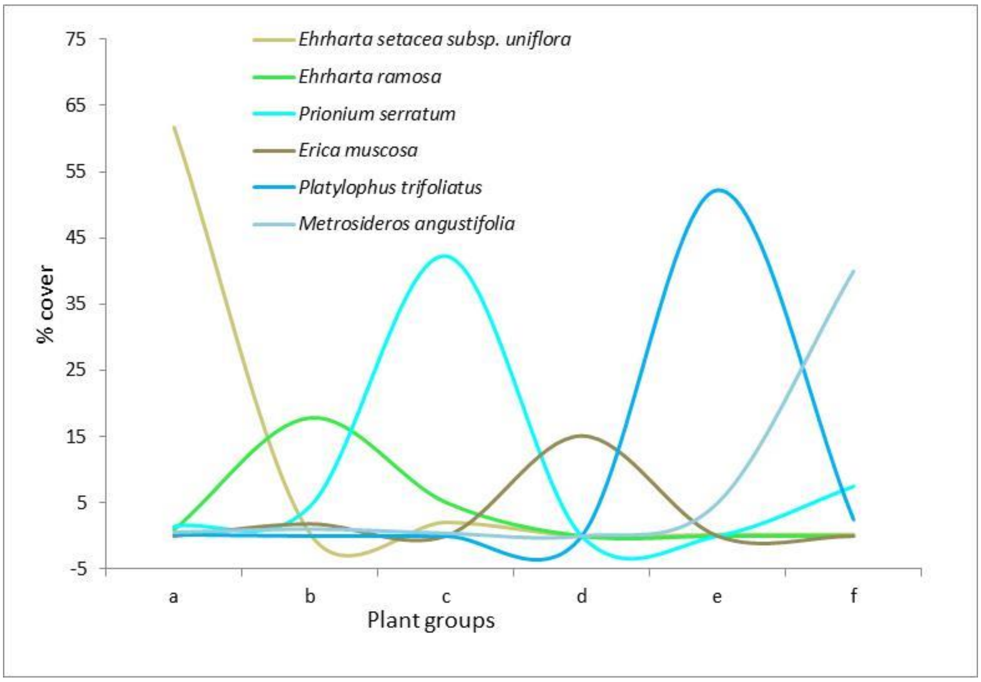


Figure 9.42 Average abundance (% cover) of indicator species for plant groups identified at K_5a.

In summary:

- A clear distinction in plant communities between the wet banks characterising the channels and channel margins and the drier banks and terrace was evident at this site suggesting a relationship between plant community structure and soil moisture.
- The plant communities identified in this assessment therefore provide a framework for evaluating change in plant species composition based on monitoring plots in future sampling events.

9.2.13 Ecochannel T4_Pal1

9.2.13.1 Plant communities

Seven plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

A colour-coded diagrammatic representation of all plots along the three sampling transects in this the Palmiet River, is shown in Figure 9.43. Group a plots formed a longitudinal band spanning the main channel including the boulder-strewn floodplain, a very clear indication of the channel and wetbank areas. This community gave way to two very different Group c, on the steeper southern slopes above the river, whilst Group b and d plots lined the outer edges of the channel to the north (Figure 9.43). The couple of plots constituting Group f were all situated in a deeper pool / run and these were mostly barren or comprised trailing roots of riparian species (see Appendix 1 for a detailed description of plant communities).

Key indicator species representing each of these groups are described in Appendix 1 and are summarised as:

Group a: *Prionium serratum* – obligate wet bank species
Group b: *Brachylaena neriifolia*
Group c: *Elegia caespitosa*
Group d: *Cliffortia atrata*
Group e: *Erica hispidula*
Group f: no clear indicator but largely barren with roots from wet bank species present
Group g: *Protea neriifolia*

The average abundance (% cover) of each of these key indicator species at T4_Pal1 is shown in Figure 9.44. Dispersion among plots within plant communities at this site was high with almost all groups sharing only about 30% similarity (Table 9.32). As expected, Group f shared the least similarity with any of the groups. Most groups were fairly distinct from the other with less than 20% similarity shared between any group (Table 9.32). The vegetation was distinctly different on opposite sides of the channel, with Groups b – g restricted to one side only. It is noteworthy, however, that Group e and Group g, were most similar of all the groups, in pair-wise comparisons. These groups were largely dominated by terrestrial species (refer to Appendix 1 for details of communities).

The main channel Group a, discriminated from other groups by the dominance of *Prionium serratum*, was closest in composition to Group b and then to Group c (Table 9.32), which represented the high-energy rocky outer floodplain on the left bank and the steeper, bedrock slopes of the right bank respectively. Group b was differentiated from the other plant communities by *Brachylaena neriifolia,* a species typical of the tree-shrub zone of rocky streams, although *Restio subverticillatus* also featured in this community as a typical component riparian zones in rocky mountain streams (refer to Appendix 1 for details). In contrast, *Elegia caespitosa, Berzelia lanuginosa* and *Restio perplexus* were important in Group c. *Prionium serratum* did also feature in Group c, as did *Protea neriifolia* (Figure 9.44) making this community a transitional one between the channel vegetation and the upper terrestrial slopes (Figure 9.43).

Groups d and e, represent relatively dry plant communities, Group d being transitional between the rocky outer floodplain and the fynbos slopes on the left bank and discriminated from other groups by the presence of *Cliffortia atrata*, while Group e was dominated by *Erica hispidula* (Figure 9.44).

In summary:

- Plant communities at this site appear to be structured according to their proximity to the active, wetted channel suggesting a link between plant species composition and moisture.
- The plant communities identified in this assessment therefore provide a framework for evaluating change in vegetation species composition of monitoring plots in future sampling events

Table 9.32 Average similarity within and between plant groups at T4_Pal1.

	a	b	c	d	e	f	g
a	35						
b	16	44					
c	11	9	30				
d	9	16	9	30			
e	5	11	11	18	33		
f	6	1	2	0	0	54	
g	5	8	15	11	18	0	34

9.2.13.2 Inter-annual change in the height of dominant species

With the exception of a few species, for example *Berzelia lanuginosa*, which grew from 1.58m to 1.81m on average, there was little evidence of significant growth in the canopy at this site between 2011 and 2012 (Table 9.33). Twelve new species were recorded as being tallest in some of the plots, e.g. *Cassytha ciliolata Grubbia tormentosa, Restio egregius, Restio parvispiculus: t*his implies that all these showed sufficient growth over the year to register among the canopy species in the monitoring plots. Compared with other site, the small degree of change over the year suggests that the riparian community at this site has reached or is close to maturity, since the last fire disturbance was in 1999.

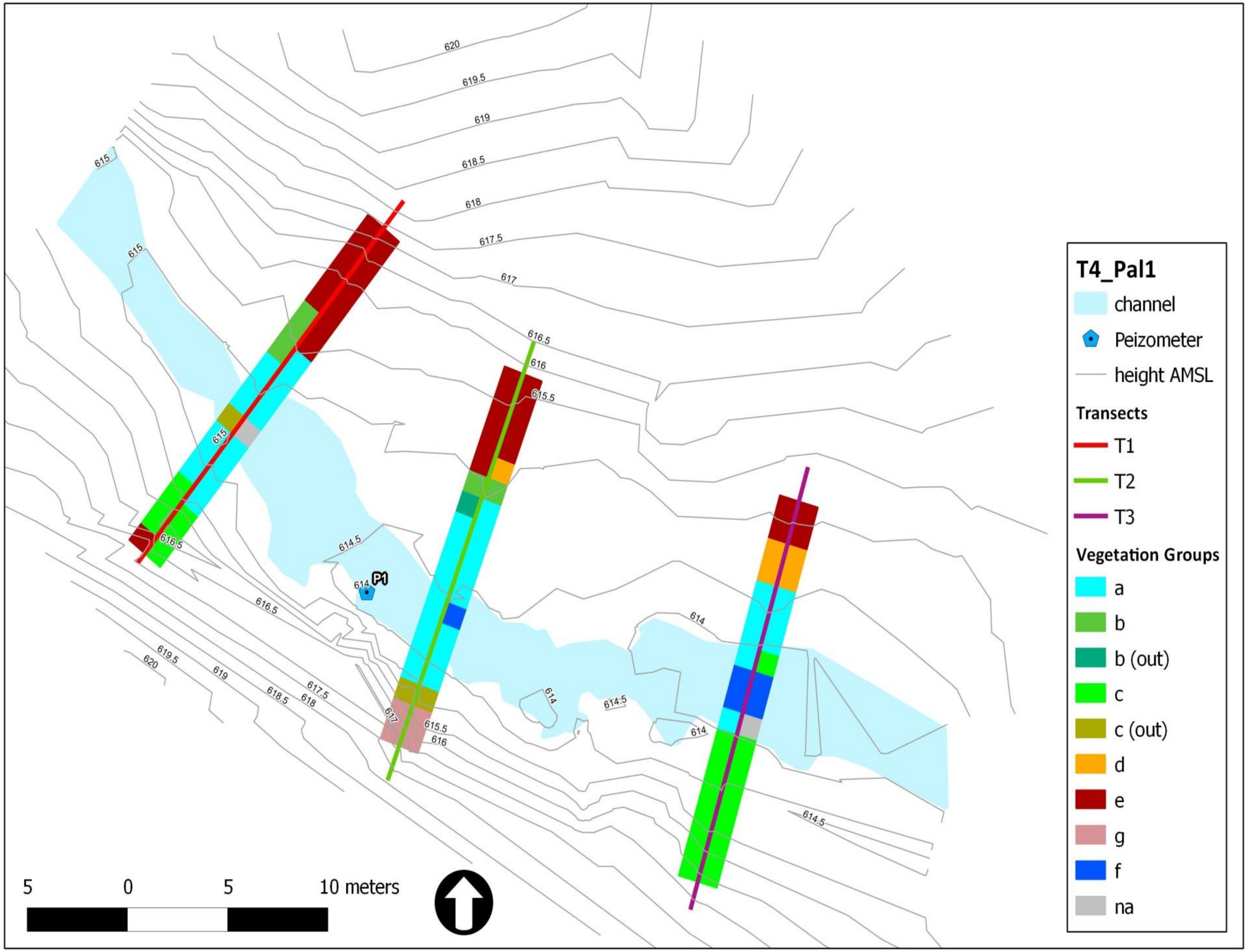


Figure 9.43 Diagrammatic representation of all plots at T4_Pal1 colour coded according to the plant community that each represents. The grey plots represent those that had zero vegetation cover (na) and were therefore excluded from all plant communities.

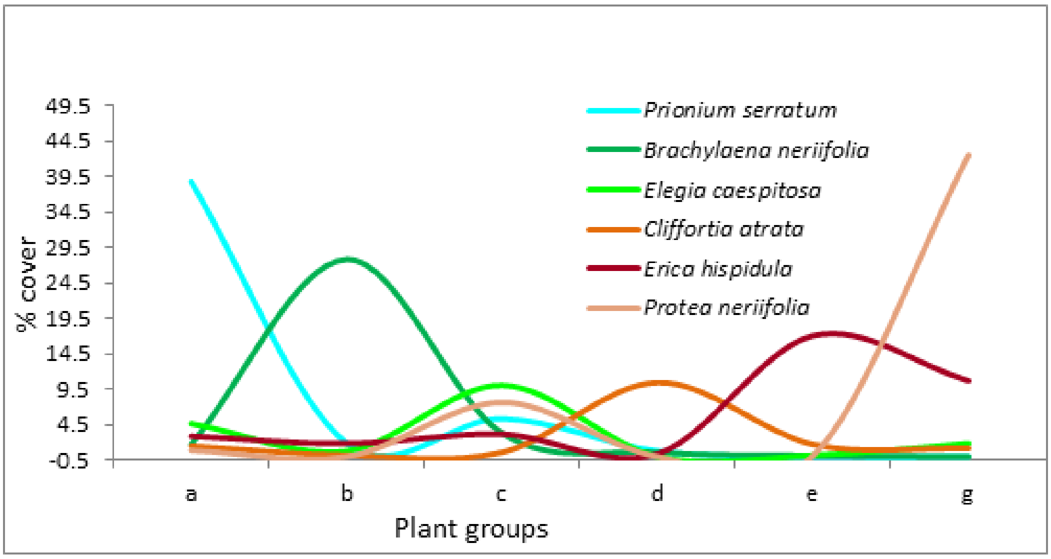


Figure 9.44 Average abundance (% cover) of indicator species for plant groups identified at T4_Pal1.

Table 9.33 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T4_Pal1. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	110	Total N:	263	#Plots:	108	Total N:	241
	No.	%	AveHeight	StdDev	No.	%	AveHeight	StdDev
Berzelia lanuginosa	4	3.64	1.58	0.78	7	6.48	1.81	0.23
Berzelia squarrosa	1	0.91	1.70		2	1.85	1.30	0.14
Brachylaena neriifolia	8	7.27	1.14	0.44	9	8.33	1.16	0.35
Cassytha ciliolata					1	0.93	0.80	
Ceratocaryum argenteum	1	0.91	1.80		1	0.93	1.50	
Cliffortia atrata	8	7.27	0.96	0.54	6	5.56	0.85	0.46
Cliffortia odorata	1	0.91	0.60		2	1.85	0.60	0.14
Clutia alaternoides	2	1.82	1.30	0.42				
Corymbium glabrum	1	0.91	0.40		2	1.85	0.30	0.00
Cyathacoma hexandra	7	6.36	0.69	0.44	3	2.78	0.60	0.26
Ehrharta cetaceae					1	0.93	0.10	
Ehrharta ramosa	3	2.73	0.47	0.12	1	0.93	0.40	
Elegia caespitosa	20	18.18	1.31	0.24	15	13.89	1.21	0.26
Elegia deusta	6	5.45	1.12	0.24	5	4.63	1.04	0.21
Elegia neesii					1	0.93	1.10	
Elegia racemosa	1	0.91	2.00		2	1.85	1.40	0.14
Epischoenus gracilis	1	0.91	0.50		1	0.93	0.20	
Epischoenus quadrangularis/villosus	3	2.73	0.60	0.26	3	2.78	0.70	0.10
Erica caffra	2	1.82	0.75	0.49	4	3.70	0.50	0.22
Erica curvirostris					1	0.93	0.60	
Erica hispidula	18	16.36	0.91	0.28	18	16.67	0.93	0.29
Erica intervallaris					1	0.93	0.60	
Erica labialis	8	7.27	0.86	0.24	11	10.19	0.80	0.15
Erica lutea	4	3.64	0.65	0.25	2	1.85	0.45	0.07
Euryops abrotanifolius	1	0.91	0.30					
Grubbia rosmarinifolia	1	0.91	1.20		1	0.93	1.20	
Grubbia tomentosa					4	3.70	1.10	0.08
Hypodiscus aristatus	4	3.64	1.23	0.19	5	4.63	1.08	0.13
Isolepis digitata	4	3.64	0.18	0.05	1	0.93	0.20	
Leucadendron laureolum	3	2.73	2.27	0.25	3	2.78	1.90	0.10
Leucadendron salicifolium	11	10.00	2.04	0.37	9	8.33	1.83	0.36

Cont.

Species	2011				2012			
	#Plots:	110	Total N:	263	#Plots:	108	Total N:	241
	No.	%	AveHeight	StdDev	No.	%	AveHeight	StdDev
Merxmuellera cincta					2	1.85	1.10	0.14
Muraltia heisteria	1	0.91	1.20		1	0.93	1.20	
Penaea mucronata	3	2.73	1.33	0.31	6	5.56	0.77	0.48
Pentameris caulescens	7	6.36	0.29	0.11	1	0.93	0.10	
Pentameris colorata					3	2.78	0.30	0.00
Pentameris macrocalycina	1	0.91	0.40		5	4.63	0.54	0.17
Phaenocoma prolifera					2	1.85	0.10	0.00
Phylica balls	1	0.91	0.30		1	0.93	0.60	
Platycaulos cascadensis	1	0.91	1.00					
Prionium serratum	31	28.18	0.51	0.21	35	32.41	0.60	0.26
Protea neriifolia	10	9.09	1.78	0.53	8	7.41	1.59	0.58
Pseudobaeckea africana	1	0.91	0.40		1	0.93	0.40	
Psoralea cf. pinnata	2	1.82	1.50	0.00	1	0.93	2.00	
Restio bifarius	3	2.73	1.13	0.21				
Restio bifurcus	1	0.91	0.80		1	0.93	0.90	
Restio debilis var. subulatus	1	0.91	0.40		1	0.93	0.30	
Restio dispar	15	13.64	1.13	0.32	5	4.63	1.22	0.46
Restio egregius					6	5.56	1.17	0.38
Restio nudiflorus	1	0.91	0.40					
Restio parvispiculus					2	1.85	0.90	0.42
Restio perplexus	2	1.82	0.35	0.07	4	3.70	0.35	0.21
Restio purpurascens	5	4.55	1.26	0.28	3	2.78	1.27	0.68
Restio subtilis	2	1.82	0.30	0.00	1	0.93	0.20	
Restio subverticillatus	19	17.27	1.16	0.49	12	11.11	1.03	0.34
Schizaea pectinata	1	0.91	0.30					
Seriphium plumosum	1	0.91	0.40		2	1.85	0.20	0.00
Staberoha distachyos	1	0.91	0.40		1	0.93	0.30	
Struthiola myrsinites	1	0.91	1.40		2	1.85	1.00	0.71
Tetraria bromoides	2	1.82	2.50	0.71	4	3.70	2.10	0.41
Tetraria capillacea	2	1.82	0.80	0.14	3	2.78	0.70	0.20
Tetraria flexuosa					1	0.93	0.50	
Tetraria thermalis	4	3.64	0.85	0.29	4	3.70	0.80	0.16
Thamnochortus gracilis	3	2.73	0.70	0.17	1	0.93	0.80	

9.2.14 Ecochannel T4_Pal 3

9.2.14.1 Plant communities

Seven plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

The colour-coded diagrammatic representation of all plots along the three sampling transects in Figure 9.45 shows that the wetted channel was characterised variously between transects by plots within Groups b, c and g, with Group a plots flanking these. Although these groups were distinctly different from the other plant groups (refer to Cluster analysis in Appendix 1) they were not well differentiated according to standard topographical units (i.e. channel, banks, slopes etc.). This is probably the result of a number of factors:

- The topography is highly irregular, with huge clasts; the stream channel in places disappears under boulders or curves at right angles to the main direction of flow; habitat diversity is high.
- The stream supports a riparian thicket, with a closed canopy, and denser vegetation in portions where cobble and small boulder dominate (corresponding with Group c plots), but is more open and bare in the large boulder and bedrock sections (Group b plots – bedrock run; Group a plots – bedrock pool and margins; and Group g plots rocky boulder cluster over the narrow channel).
- The dominance of bare rock and sparse vegetation increases variability in the multivariate analysis,

as is evidenced by Group g which had <1% cover.

Adjacent to these channel communities, Group d, e and f plots were all characteristic of different riparian / floodplain areas: Group d the steeper bank slope on the outer margins of the canopied section (Transect 1), Group e the rockier scour areas and Group f the flat sandy flood terraces predominantly on the left bank (Figure 9.45). Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a: *Ehrharta rupestris subsp. tricostata* – obligate wetland species

Group b: *Isolepis digitata* – obligate lower wetbank species

Group c: *Brachylaena neriifolia* – riparian species

Group d: *Restio subverticillatus*

Group e: *Erica equisetifolia*

Group f: *Seriphium cinereum*

Group g: no clear indicator because plots were largely barren.

The average abundance (% cover) of each of these key indicator species at T4_Pal3 is shown in Figure 9.46. Groups a, b and c were characterised by obligate riverine or wet bank species, most notably *Isolepis digitata, Ehrharta rupestris* and *Brachylaena neriifolia*.

Dispersion among plots within plant communities at this site was high but varied between groups (Table 9.34). Groups c and d were the most coherent groups, with 43 and 45% within-group variability respectively (Table 9.34). However, these groups also had considerably greater percentage cover per plot than any other group (see Appendix 1, but also densities of the indicator species in Figure 9.46). Plant communities at this site appear to be broadly structured according to their proximity to the active, wetted channel, as well as the substratum characteristics at this site.

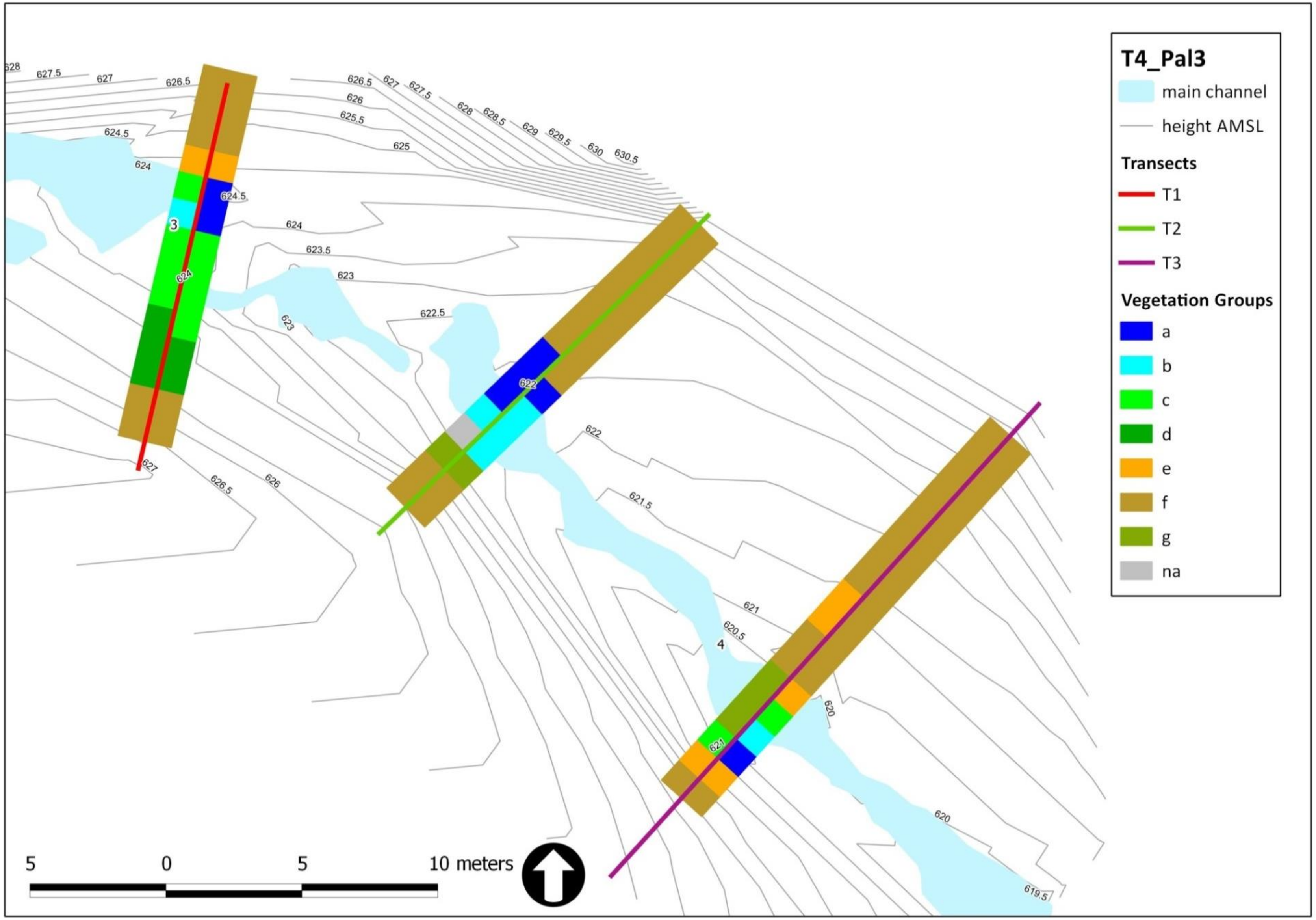


Figure 9.45 Diagrammatic representation of all plots at T4_Pal3, colour coded according to the plant community that each represents. The grey plots represent those that had zero vegetation cover (na) and were therefore excluded from all plant communities.

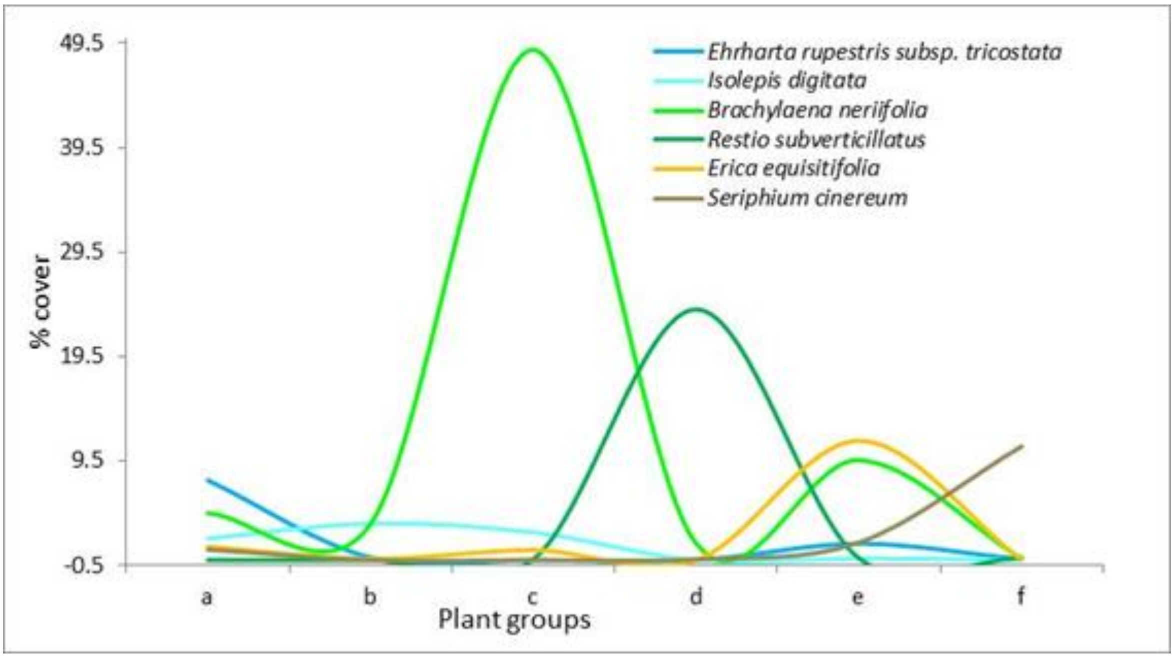


Figure 9.46 Average abundance (% cover) of indicator species for plant groups identified at T4_Pal3.

Table 9.34 Average similarity within and between plant groups at T4_Pal3.

	a	b	c	d	e	f	g
a	32						
b	11	34					
c	16	20	43				
d	7	2	8	46			
e	21	11	19	12	33		
f	11	2	4	12	22	37	
g	4	7	5	1	8	2	41

9.2.14.2 Year-on-year comparison of monitoring plots

The % similarity in vegetation composition between individual plots is summarised by the plant community affiliation of each plot in Figure 9.47. On average, plots within Group c had the greatest year-on-year similarities (>70% similarity), although individual plot similarities were mostly greater than 50% (Figure 9.47). Low year-on-year similarities in some of the Group e and f plots (floodplain) were generally associated with increases in species diversity within the plot, but off a very low base. For example, plot T3_12a (19% year-on-year similarity) comprised just eight species, all recorded at cover values <3%: any small change, such as the appearance of juvenile restio seedlings, will be magnified in the analysis because of the low richness and densities.

Low year-on-year similarities for plots within Group b with (e.g. T2_11a and T2_10b) (Figure 9.47) was a result of on the one hand a loss of some species like Isolepis digitata, which could easily have been removed during flooding, and on the other hand a substantial recruitment of species including *Anthochortus crinalis*, moss, *Erica intervallensis* and *Ehrharta rupestris*. This suggests Group b plots may experience considerable flux due to their position in the centre of the channel.

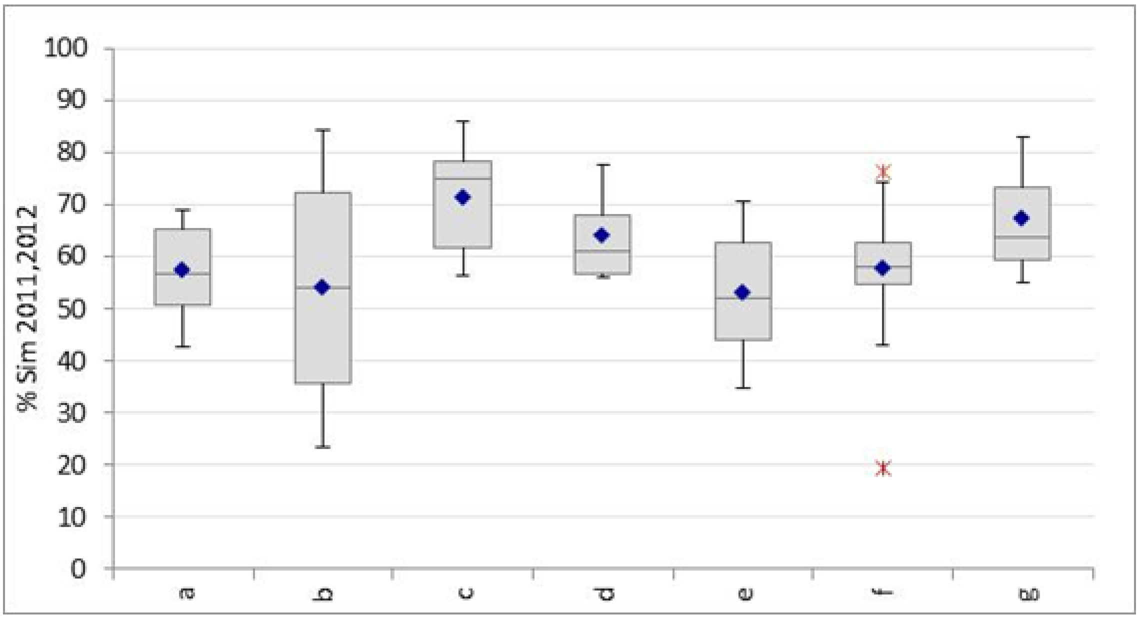


Figure 9.47 Percentage similarity in species composition between individual plots monitored in 2011 and 2012, summarised by the plant community (Group) affiliation of each plot at T4_Pal3.

9.2.14.3 Inter-annual change in the height of dominant species

Table 9.35 provides a summary of the height and representation of the tallest three individuals measured in each plot in 2011 and 2012. No significant increase in height of the canopy community was evident between 2011 and 2012. Nevertheless, some species such as *Ehrharta ramosa* and *Restio di*spar declined in their representation as the tallest species, while others such as *Metalasia densa* increased in the number of plots where it was one of the tallest. Although some species disappeared from the canopy, and others appeared as the tallest species, this change only occurred in a small proportion of plots. Essentially, these data show that there was little change or shift in the canopy community at this site.

Table 9.35 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T4_Pal3. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	**94**	**Total N:**	**231**	**#Plots:**	**94**	**Total N:**	**220**
	N	**%**	**AveHeight**	**StdDev**	**N**	**%**	**AveHeight**	**StdDev**
Agathosma crenulata	3	3.19	1.03	0.15	3	3.19	1.20	0.00
Anthochortus crinalis					1	1.06	0.20	
Argyrolobium lunare subsp. *sericeum*					1	1.06	0.40	
Berzelia squarrosa					2	2.13	2.05	0.07
Brachylaena neriifolia	16	17.02	2.20	1.12	17	18.09	1.64	1.07
Cassytha ciliolata	1	1.06	1.00					
Centella difformis	2	2.13	0.10	0.00	1	1.06	0.10	
Centella eriantha					2	2.13	0.25	0.07
Ceratocaryum argenteum	2	2.13	1.90	0.14	3	3.19	1.63	0.65
Chrysitrix capensis					1	1.06	0.70	
Chrysitrix flat leaf					2	2.13	0.35	0.07
Cliffortia atrata					2	2.13	0.80	0.00
Clutia alaternoides	1	1.06	0.40					
Coleonema juniperinium	3	3.19	0.50	0.10	2	2.13	0.65	0.49
Corymbium glabrum	11	11.70	0.34	0.05	5	5.32	0.34	0.09
Crassula capensis cf. var *capensis*	1	1.06	0.40					

Cont

Species	2011				2012			
	#Plots:	**94**	**Total N:**	**231**	**#Plots:**	**94**	**Total N:**	**220**

	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Dilatris viscosa	1	1.06	0.30					
Disa tripetaloides	2	2.13	0.20	0.14				
Ehrharta ramosa	20	21.28	0.63	0.22	14	14.89	0.76	0.22
Ehrharta rupestris subsp. tricostata	3	3.19	0.47	0.06	3	3.19	0.47	0.29
Elegia mucronata	2	2.13	1.40	0.57	3	3.19	1.90	0.17
Elegia racemosa	3	3.19	0.77	0.06	3	3.19	0.93	0.12
Epischoenus gracilis	1	1.06	0.40		3	3.19	0.43	0.15
Epischoenus quadrangularis/villosus complex	1	1.06	0.40		1	1.06	0.60	
Erica equisitifolia	7	7.45	0.36	0.31	4	4.26	0.30	0.14
Erica hispidula					1	1.06	0.40	
Erica intervallaris					1	1.06	0.10	
Ficinia zeyheri	1	1.06	0.20					
Gleichenia polypodioides					1	1.06	0.20	
Gnidia juniperifolia					1	1.06	0.20	
Grubbia rosmarinifolia					1	1.06	0.80	
Indigofera sarmentosa					1	1.06	0.20	
Isolepis digitata	4	4.26	0.18	0.10				
Metalasia cephalotes					4	4.26	0.33	0.05
Metalasia densa	8	8.51	0.41	0.12	13	13.83	0.44	0.17
Moss	1	1.06	0.01		3	3.19	0.21	0.34
Osmitopsis afra					1	1.06	0.10	
Othonna quinquedentata	7	7.45	0.90	0.77	1	1.06	1.00	
Pentameris caulescens	5	5.32	0.74	0.09				
Pentameris colorata	18	19.15	0.54	0.15	14	14.89	0.56	0.17
Pentameris curvifolia	6	6.38	1.07	0.16				
Pentameris macrocalycina	1	1.06	1.00		2	2.13	1.00	0.00
Pentameris obtusifolia	1	1.06	0.50		1	1.06	0.60	
Pentameris thuarii	2	2.13	1.50	0.00	2	2.13	1.30	0.00
Podalyria hirsuta	4	4.26	0.65	0.24	4	4.26	0.83	0.45
Prionium serratum	7	7.45	0.86	0.32	5	5.32	1.04	0.17
Protea cineroides	1	1.06	0.80		1	1.06	0.70	
Pseudobaeckea africana	7	7.45	0.91	0.34	7	7.45	0.89	0.37
Restio bifarius					2	2.13	1.20	0.00
Restio bifidus	2	2.13	1.00	0.85	2	2.13	0.45	0.07
Restio dispar	22	23.40	1.14	0.19	17	18.09	1.17	0.19
Restio egregius					1	1.06	1.00	
Restio parvispiculus					1	1.06	0.80	
Restio purpurascens	5	5.32	2.02	0.91	4	4.26	1.45	0.64
Restio subverticillatus	6	6.38	0.85	0.41	3	3.19	1.13	0.15
Restio triticeus	1	1.06	1.00					
Restionaceae juveniles					1	1.06	0.30	
Satyrium humile	1	1.06	0.10					
Schizaea pectinata	1	1.06	0.20					
Seriphium cinereum	17	18.09	0.32	0.09	32	34.04	0.46	0.18
Tetraria capillacea	11	11.70	0.79	0.43	4	4.26	0.90	0.34
Tetraria exilis	1	1.06	0.60		2	2.13	0.20	0.14
Tetraria flexuosa					1	1.06	1.00	
Tetraria thermalis	6	6.38	0.63	0.15	4	4.26	0.63	0.17
Thesium bathyschistum					2	2.13	0.70	0.42
Thesium carinatum					1	1.06	1.00	
Thesium strictum	3	3.19	1.03	0.29				
Ursinia chrysanthemoides					2	2.13	0.25	0.07
Ursinia dentata	1	1.06	0.30		4	4.26	0.43	0.05
Ursinia paleacea	1	1.06	0.30					

9.2.15 Ecochannel T6_1a

9.2.15.1 Plant communities

Eight plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

The colour-coded diagrammatic representation of all plots along the three sampling transects in Figure 9.48 shows that the wetted channel was characterised mostly by Group g which was dominated by *Metrosideros angustifolia* and *Cunonia capensis.* This reflects the dense canopy formed by riparian forest at this site, the large trees rooted along the right bank and shading most of the active channel. This feature, and the location of the boulder floodplain along the left bank of the channel, is a clear driver of plant community patterns at T6_1a (Figure 9.48).

Group f was representative of the instream and marginal vegetation, usually in contact with the flow during lowflow periods, and occurred, particularly along Transect 2. This group was defined by the dominance of *Prionium serratum*, an obligate wet bank species. The channel margins and parts of the floodplain adjacent to the wetted channel were characterised by Group h plots which were defined largely by the dominance of *Brachylaena neriifolia* (Figure 9.48). This species was recorded as the dominant at many other sites in similar habitats – vegetated portions of the rocky floodplain adjacent to scour channels (e.g. H8_3a, T4_Pal3). Other floodplain groups were Group d and e (Figure 9.48), which were dominated by gramminoids and probably more prevalent in sandier portions of the floodplain.

The dry bank communities representative of the left bank and the right bank were substantially different at this site, with Groups a and b along the upper terraces and dry sloping banks on the left of the floodplain, whilst, Group c was characteristic of the right bank, dominated by grasses and restios just beyond the riparian forest zone (Appendix 1) (Figure 9.48).

Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a: *Corymbium glabrum*
Group b: *Pentameris thuarii*
Group c: *Ehrharta ramosa*
Group d: *Anthochortus graminifolius*
Group e: *Askidiosperma paniculatum*
Group f: *Prionium serratum*
Group g: *Metrosideros angustifolia*
Group h: *Brachylaena neriifolia*

The average abundance (% cover) of each of these key indicator species at T4_Pal3 is shown in Figure 9.49. Group a, which formed a distinct dry community along the left bank had the highest within-group similarity, with Group b, also a dry community along the banks showing the least similarity (Table 9.36). Nevertheless, within-group similarities were generally low in all groups (Table 9.36). Some groups, such as Group f, in-channel and marginal vegetation, shared very little similarity with other groups as indicated by the very low similarity percentages in the matrix ranging from zero similarity with the Group a (i.e. the dry, left bank community) to 8% similarity to Group c (Table 9.36).

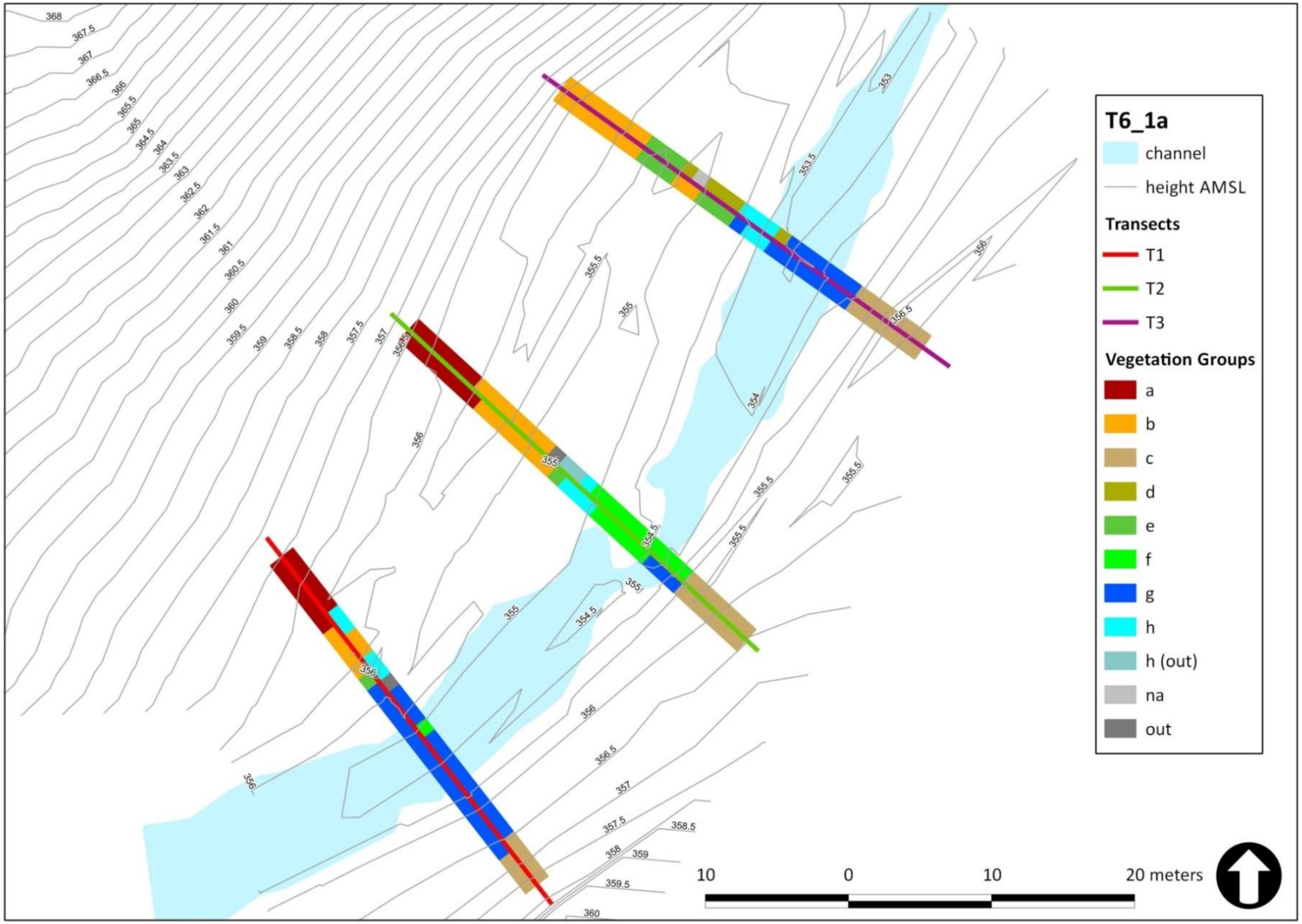


Figure 9.48 Diagrammatic representation of all plots at T6_1a, colour coded according to the plant community that each represents. The light grey plots represent those that had zero vegetation cover (na) and were therefore excluded from all plant communities. The dark grey plots represent outliers not affiliated to any particular group.

Table 9.36 Average similarity within and between plant groups at T6_1a.

	a	b	c	d	e	f	g	h
a	47							
b	14	33						
c	5	19	43					
d	3	9	5	42				
e	3	14	3	14	40			
f	0	3	8	3	2	39		
g	1	10	10	7	11	20	34	
h	4	12	11	12	8	12	17	41

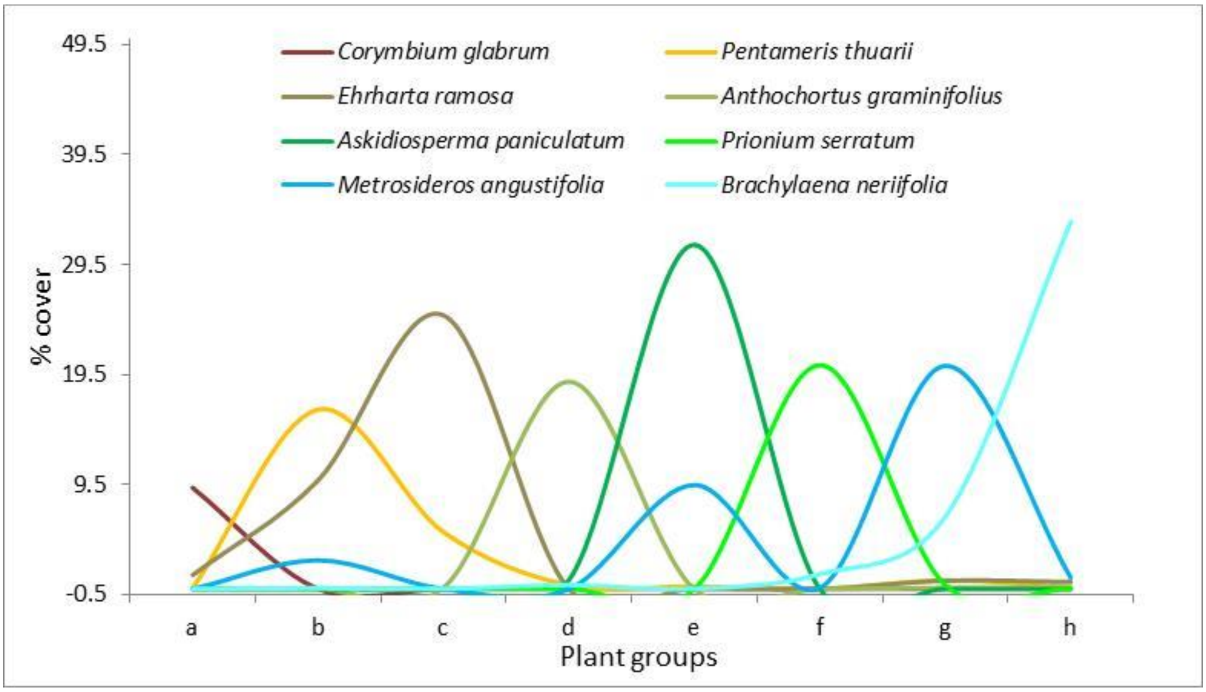


Figure 9.49 Average abundance (% cover) of indicator species for plant groups identified at T6_1a.

The distinction between plant communities associated with the channel, sloping bank and banks suggest a relationship between vegetation assemblage structure and moisture along a perpendicular gradient at this site. The plant communities identified in this assessment therefore provide a framework for evaluating change in vegetation species composition of monitoring plots in future sampling events.

9.2.15.2 Year-on-year comparison of monitoring plots

The % similarity in vegetation composition between individual plots is summarised by the plant community affiliation of each plot (Figure 9.51). The average year-on-year similarities of plots was generally high in all groups but Group d (Figure 9.51). Examination of these low-similarity plots indicated that the dominant species in 2011, *Anthochortus graminifolius*, indeed the species that defines this group (Table 9.37) was absent from the plots in 2012. Given that other species in these plots mostly also declined, it is likely that this represents a real species loss from these plots. Their location – plots 13 -15 on Transect 3 – places them on a vegetated bar, as mapped in the site maps in Volume 1: Monitoring Framework and Protocol, and suggests that these changes are the effects of flood disturbance.

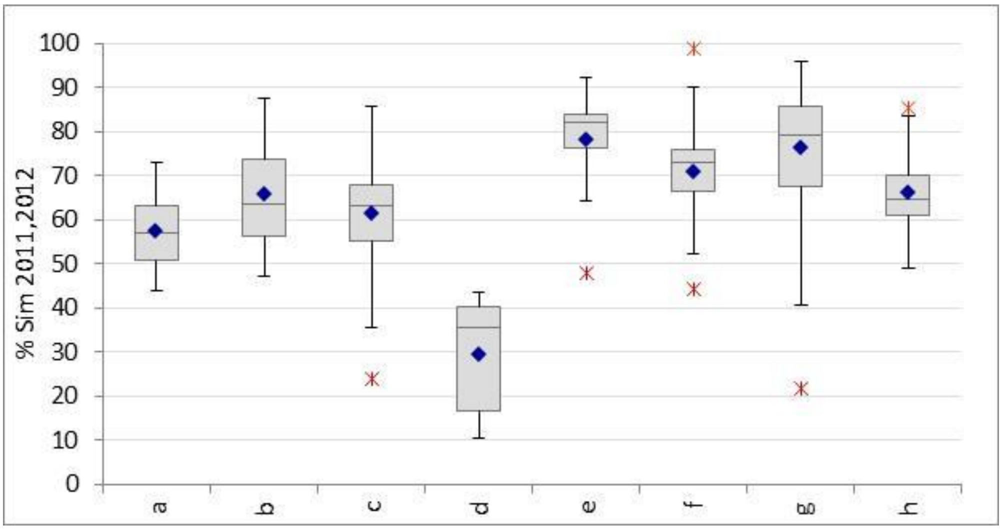


Figure 9.50 Percentage similarity in species composition between individual plots monitored in 2011 and 2012, summarised by the plant community (Group) affiliation of each plot at T6_1a.

9.2.15.3 Inter-annual change in the height of dominant species

A comparison of the average height of the tallest species in each plot between 2011 and 2012 shows there were few changes in the canopy community over the annual period (Table 9.37). Nevertheless, some species declined in their representation as the tallest species while others increased. In particular, the grass, *Ehrharta ramosa* was one of the tallest species in 32% of plots in 2011 but this representation declined to 24%, despite an average increase in the growth of this species. Similarly as was indicated in the year-on-year plot comparisons, *Anthochortus graminifolius* was apparently scoured from some plots, seemingly ones in which it was the tallest, as 2012 saw no representation in the canopy. By contrast*,* *Pentameris thuarii* was present as one of the tallest species in 18% of plots in 2011 but this representation increased to 22% in 2012 with an average increase in height of 0.5 m.

Table 9.37 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T6_1a. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	184	Total N:	480	#Plots:	185	Total N:	482
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Agathosma crenulata	2	1.09	1.65	0.21	2	1.08	1.65	0.21
Anaxeton laeve					3	1.62	0.17	0.06
Andropogon appendiculatus	2	1.09	0.70	0.42	2	1.08	1.05	0.35
Anthochortus graminifolius	7	3.80	0.87	0.24				
Aristea capitata	2	1.09	0.80	0.57	1	0.54	1.00	
Aristida junciformis	6	3.26	0.57	0.20	2	1.08	0.50	0.00
Askidiosperma paniculatum	10	5.43	1.43	0.22	9	4.86	1.46	0.24
Bobartia gladiata	1	0.54	0.70					
Brachylaena neriifolia	33	17.93	1.68	0.59	32	17.30	1.82	0.79
Carpha glomerata	1	0.54	0.80					
Centella restioides	3	1.63	0.43	0.12	2	1.08	0.40	0.00
Chrysitrix dodii	2	1.09	0.40	0.14	1	0.54	1.00	
Corymbium glabrum	14	7.61	0.50	0.15	12	6.49	0.35	0.11
Corymbium villosum	1	0.54	0.50					
Cunonia capensis	29	15.76	5.46	2.68	26	14.05	6.15	2.70

Cont.

Species	2011				2012			
	#Plots: 184		Total N: 480		#Plots: 185		Total N: 482	
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Diospyros glabra	2	1.09	0.75	0.35	1	0.54	0.60	
Ehrharta ramosa	59	32.07	0.91	0.22	45	24.32	1.01	0.98
Ehrharta rupestris subsp. *tricostata*	2	1.09	1.20	0.00				
Ehrharta setacea subsp. *scabra*	7	3.80	0.73	0.78	10	5.41	0.34	0.18
Elegia capensis	18	9.78	1.71	0.34	23	12.43	2.08	0.67
Epischoenus quadrangularis/villosus complex	1	0.54	1.00		1	0.54	1.00	
Erica caffra	15	8.15	2.59	1.40	10	5.41	2.85	1.12
Erica hispidula	2	1.09	0.15	0.07	1	0.54	0.10	
Erica labialis					1	0.54	1.00	
Festuca scabra	3	1.63	0.77	0.32	1	0.54	0.20	
Ficinia distans	3	1.63	0.30	0.00	1	0.54	0.60	
Ficinia nigrescens	8	4.35	0.44	0.27	3	1.62	0.40	0.00
Ficinia sp. nov1					2	1.08	0.50	0.00
Ficinia trichodes	6	3.26	0.33	0.08	2	1.08	0.15	0.07
Geissorhiza juncea	2	1.09	0.20	0.00				
Hippia pillosa	2	1.09	0.20	0.00				
Hypodiscus aristatus	4	2.17	1.10	0.48	3	1.62	1.00	0.00
Ilex mitis	9	4.89	9.00	1.41	14	7.57	8.00	0.00
Imperata cylindrica					1	0.54	0.30	
Isolepis digitata	5	2.72	0.18	0.04	8	4.32	0.36	0.43
Leucadendron salicifolium	4	2.17	1.60	0.94	6	3.24	0.62	0.64
Lobelia jasionoides	1	0.54	0.50					
Maytenus acuminata	3	1.63	0.90	0.17	1	0.54	1.00	
Metalasia cephalotes	1	0.54	0.20		3	1.62	0.57	0.38
Metrosideros angustifolia	40	21.74	3.38	2.63	48	25.95	4.10	2.88
Morella serrata	8	4.35	0.83	0.50	9	4.86	1.20	0.39
Moss	3	1.63	0.02	0.02	14	7.57	0.16	0.19
Othonna quinquedentata	1	0.54	0.30					
Pentameris curvifolia	1	0.54	0.40		1	0.54	0.40	
Pentameris thuarii	33	17.93	1.01	0.34	40	21.62	1.52	0.33
Platycaulos callistachyus	24	13.04	1.28	0.37	19	10.27	1.31	0.40
Platylophus trifoliatus	6	3.26	2.80	1.36	9	4.86	3.19	1.07
Podalyria calyptrata	3	1.63	1.93	0.95	5	2.70	1.60	1.02
Prionium serratum	9	4.89	0.71	0.27	8	4.32	0.55	0.14
Pseudobaeckea africana	2	1.09	0.70	0.42	1	0.54	1.30	
Pseudoselago spuria	1	0.54	0.40					
Psoralea fleta	3	1.63	1.20	0.79	7	3.78	2.50	0.52
Psoralea pinnata	2	1.09	1.10	0.85	6	3.24	1.33	1.24
Pteridium aquilinum	5	2.72	0.52	0.18	5	2.70	1.00	0.00
Restio curviramis	11	5.98	0.27	0.06	12	6.49	0.28	0.05
Restio paniculatus	3	1.63	1.07	0.51	1	0.54	0.20	
Restio pedicelatus	3	1.63	0.60	0.17				
Restio perplexus					4	2.16	0.20	0.00
Restio subverticillatus	19	10.33	0.85	0.30	21	11.35	0.75	0.37
Senecio pubigerus					1	0.54	1.00	
Seriphium cinereum	3	1.63	0.20	0.00	4	2.16	0.38	0.10
Seriphium plumosum	1	0.54	0.20					
Staberoha distachyos	1	0.54	0.40		2	1.08	0.30	0.00
Tetraria exilis	4	2.17	0.33	0.13	7	3.78	0.40	0.13
Thamnochortus gracilis	1	0.54	0.40		1	0.54	0.50	
Thamnochortus lucens	2	1.09	0.55	0.07	1	0.54	0.30	
Thesium strictum	1	0.54	1.10		4	2.16	1.98	0.37
Todea barbara	13	7.07	1.28	0.38	10	5.41	1.34	0.48
Trachyandra ciliata					1	0.54	0.60	
Ursinia paleacea	5	2.72	0.30	0.07	8	4.32	0.43	0.07
Widdringtonia nodiflora	2	1.09	1.60	0.00	2	1.08	2.50	0.71

9.2.16 Ecochannel T6_2a

9.2.16.1 Plant communities

Seven plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

A diagrammatic representation of all plots in Figure 9.51 shows that the wetted channel and a wide cobble bar at Transect 3, were comprised almost entirely of Group a plots, this Groups being dominated by the obligate riverine species, *Prionium serratum*. Flanking this Groups d, e and f, formed a wider riparian zone, with overlapping species complements, but important differences. Group e was located along the flatter riparian areas influenced by the valley bottom elements on both sides of the channel; Groups d and f associated with more rocky riparian banks typical of mountain streams. The discriminating species for these groups reflect these differences in location: *Pentameris thuarii* was the key indicator of Group e (Figure 9.51), whilst *Metrosideros angustifolia* differentiated Group f from all other communities (Figure 9.52). Group d was most distinguishable by the predominance of the pioneer *Pteridium aquilinum* – the area on the right hand side of Transect 2 and across the valley bottom beyond the river channel has deep dry sands that have taken time to recolonize after the hot fires of 2010. Detailed descriptions of these communities are given in Appendix 1.

The bank slopes on the right bank of the macro channel at Transects 1 and 2 was characterised by plant community Group c (Figure 9.51) No single species was a good discriminator of this community from the other groups, although the combination of both *Ehrharta ramosa* and *Pteridium aquilinum* seemed to define it best. Like Group d, this part of the valley still represents an early successional phase after the burn in the area.

On the opposite side of the channel, the shale mountain slopes that hug the channel here give rise to wetter conditions on the valley floor. Group b at the same elevation as Group c extended alongside the left bank of the macro channel at Transects 1 and 2 (Figure 9.51), just lateral to the Group e community. Its discriminating species was the facultative wetland grass prevalent in sandy areas, *Ehrharta ramosa*, but importantly, the obligate wetland species *Platycaulos callistachyus* was prevalent to both Group b and Group e.

Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a: *Prionium serratum* – obligate riverine species

Group b: *Ehrharta ramosa* – facultative wetland species

Group c: no single discriminator

Group d: *Pteridium aquilinum* – facultative wetland species

Group e: *Pentameris thuarii* with *Platycaulos callistachyus* -obligate wetland species

Group f: *Metrosideros angustifolia*- obligate wet bank species

Group g: *Restio perplexus*

The average abundance (% cover) of each of these key indicator species at T6_2a is shown in Figure 9.52. The sloping bank communities along the left bank (i.e. Groups b and g) shared the greatest within-group similarities and were therefore the most coherent of the plant communities identified at this site (Table 9.38). Communities characteristic of the floodplain (i.e. Groups c, d, e and f) were the least coherent as indicated by the low within-group similarities and the relatively high similarity between groups (Table 9.38).

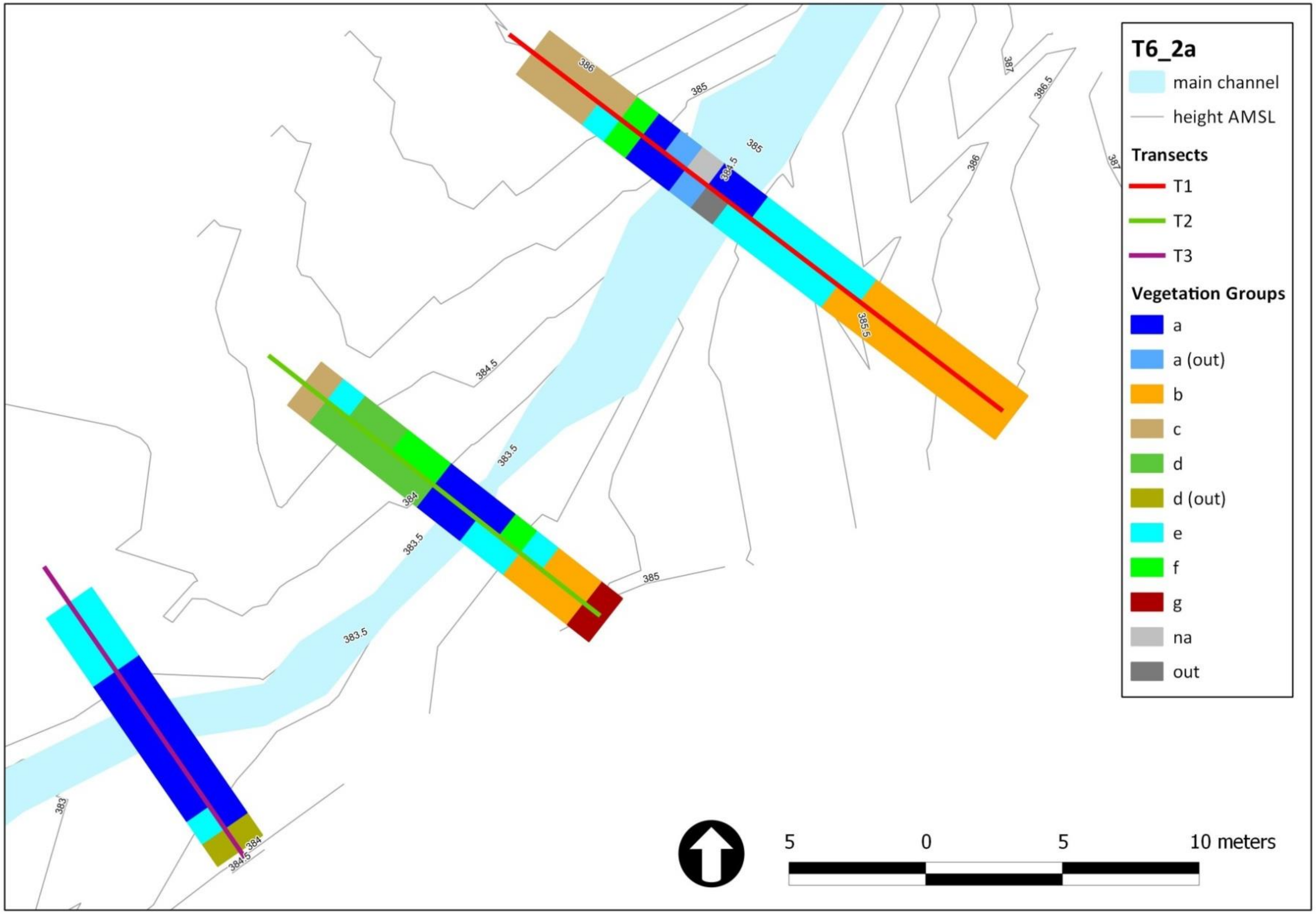


Figure 9.51 **Diagrammatic representation of all plots at T6_2a colour coded according to the plant community that each represents. The light grey plots represent those that had zero vegetation cover (na) and were therefore excluded from all plant communities. The dark grey plots represent outliers not affiliated to any particular group.**

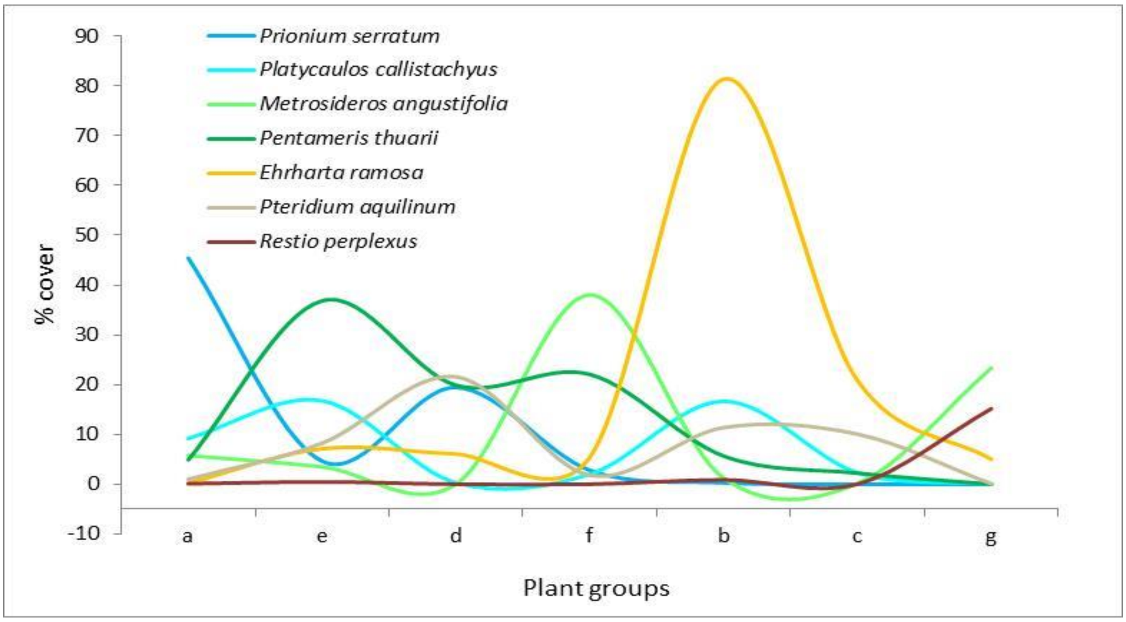


Figure 9.52 Average abundance (% cover) of indicator species for plant groups identified at T6_2a. The order of the groups on the x-axis follows the groups typical of the wetter central portions (left) to the drier outer margins (right).

Table 9.38 Average similarity within and between plant groups at T6_2a.

	a	b	c	d	e	f	g
a	43						
b	14	60					
c	5	35	47				
d	15	28	31	47			
e	22	33	20	30	45		
f	21	22	18	26	30	41	
g	5	15	17	13	8	19	53

Although a number of relatively dispersed communities characterised the flood plain at this site, there was a clear distinction between the drier riparian communities and those typical of the channel and channel margins. This distinction suggests a relationship between plant community structure and soil moisture along a perpendicular gradient at this site and thus provides a framework for evaluating change in vegetaiton communties that are potentially affected by change in soil moisture.

9.2.16.2 Year-on-year comparison of monitoring plots

The % similarity in vegetation composition between individual plots summarised by the plant community affiliation of each plot in Figure 9.54 shows that most plots were fairly similar between 2011 and 2012. The average year-on-year similarity of plots affiliated to Group b was high, suggesting that plots within this group remained relatively unchanged between 2011 and 2012. Plots affiliated to Group a, d and g also seemed relatively stable with averaged year-on-year similarities of greater than 60% (Figure 9.54). Groups c and d represented plots that appear to have changed the most with some plots showing about 40% from 2011 to 2012. These results suggest that temporal changes in community composition varied spatially across the site at T6_2a but that the vegetation composition of plots was fairly stable over the annual period.

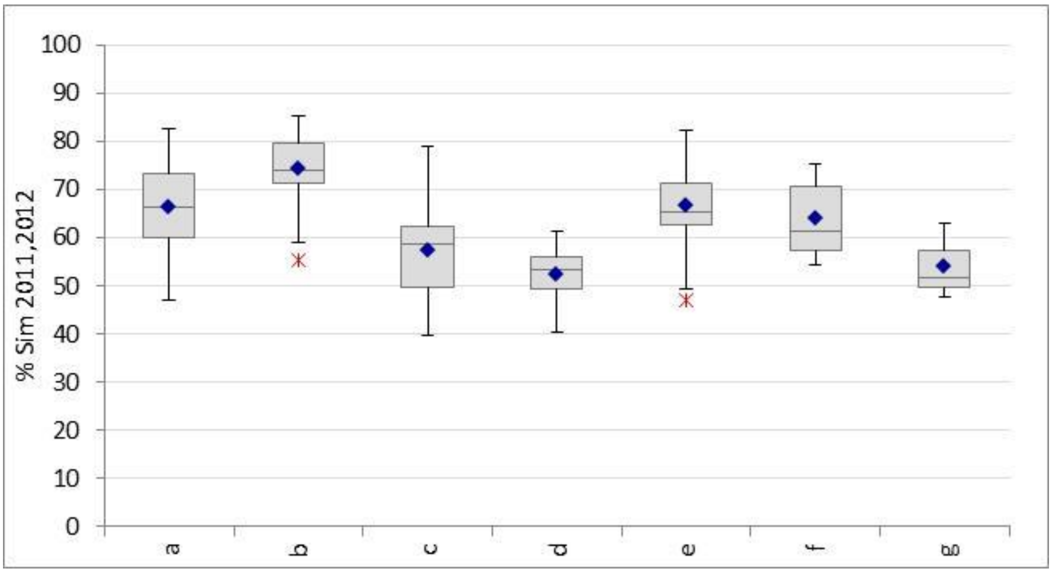


Figure 9.53 Percentage similarity in species composition between individual plots monitored in 2011 and 2012, summarised by the plant community (Group) affiliation of each plot at T6_2a.

9.2.16.3 Inter-annual change in the height of dominant species

Table 9.39 provides a summary of the height and representation of the tallest three individuals measured in each plot at T6_2a in 2011 and 2012. An increase in a few species representing the canopy community was evident. In particular, the tree species, *Brachylaena neriifolia*, grew from a height of 1.51 m to 2.13 m over the year (Table 9.39). Nevertheless, it did not seem to significantly replace other species representing the canopy community as indicated by the small change in the number of plots where it was recorded (i.e. 8 plots in 2011 and 9 plots in 2012) (Table 9.39). Nevertheless, some species such as *Ehrharta ramosa, Pentameris thuarii* and *Platycaulos callistachyus* were represented as the tallest species less in 2012 than 2011 (Table 9.39), suggesting that these species were outgrown by others over the annual period. However, a temporal change or shift in the characteristics of the canopy community at this site were not clear and may become more apparent with ongoing monitoring over time.

9.2.17 Ecochannel T8_2a

9.2.17.1 Plant communities

Seven plant communities were identified by PRIMER cluster analysis of the species data from the monitoring plots.

A diagrammatic representation of all plots in Figure 9.54 shows that Group a was confined to the wetted channel at Transects 2 and 3, while Group b was characteristic of the channel at Transect 1. Both Groups were characterised by obligate wetland species, typically found alongside or within stream channels. Details of the plant communities represented by these groups are provided in Appendix 1. Many of the outliers, which generally had sparse vegetation cover, as well as one plot with zero plant cover, were also situated within the wetted channel (Figure 9.54).

Table 9.39 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T6_2a. The number of plots and the percentage of the total number of plots represented by each species are also given.

Species	2011				2012			
	#Plots:	94	Total N:	263	#Plots:	94	Total N:	199
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Aristea capitata	3	3.19	0.67	0.31	1	1.06	0.30	
Aristida junciformis subsp. *junciformis*	1	1.06	0.40					
Aspalathus divaricata subsp. *divaricata*	2	2.13	0.25	0.07				
Blechnum capense	1	1.06	0.20					
Brachylaena neriifolia	8	8.51	1.51	0.46	9	9.57	2.13	0.92
Capeochloa cincta subsp. *cincta*	4	4.26	1.08	0.15	5	5.32	0.74	0.29
Centella affinis var *affinis*					1	1.06	0.10	
Corymbium glabrum	3	3.19	0.37	0.06	1	1.06	0.40	
Disa tripetaloides	1	1.06	0.10		1	1.06	0.10	
Drosera capensis					1	1.06	0.05	
Ehrharta ramosa	35	37.23	0.74	0.17	26	27.66	0.84	0.29
Ehrharta setacea subsp. *scabra*	1	1.06	0.30		2	2.13	0.20	0.00
Elegia asperiflora	1	1.06	0.80					
Elegia capensis	13	13.83	1.31	0.31	9	9.57	1.74	0.32
Epischoenus gracilis	4	4.26	0.38	0.05	1	1.06	0.60	
Erica sp.	1	1.06	1.00		1	1.06	1.30	
Euryops abrotanifolius	1	1.06	0.30					
Ficinia nigrescens	1	1.06	0.50					
Ficinia oligantha					1	1.06	0.10	
Gibbaria ilicifolia	4	4.26	0.70	0.36	4	4.26	0.58	0.26
Isolepis digitata	6	6.38	0.12	0.04	5	5.32	0.17	0.07
Leucadendron salicifolium					2	2.13	1.25	0.35
Metalasia cephalotes					1	1.06	0.40	
Metalasia densa					3	3.19	0.43	0.15
Metrosideros angustifolia	11	11.70	0.99	0.36	7	7.45	1.46	0.51
Moss					1	1.06	0.01	
Neesenbeckia punctoria	2	2.13	1.65	0.21				
Pentameris colorata	1	1.06	1.00		1	1.06	0.80	
Pentameris thuarii	39	41.49	0.95	0.41	30	31.91	1.40	0.42
Platycaulos callistachyus	36	38.30	1.15	0.43	25	26.60	1.38	0.25
Prionium serratum	29	30.85	0.93	0.42	14	14.89	0.86	0.28
Prionium serratum roots					1	1.06	0.70	
Pseudobaekia africana	4	4.26	1.18	0.24	2	2.13	1.50	0.00
Psoralea fleta	10	10.64	1.50	0.56	8	8.51	3.14	0.72
Pteridium aquilinum	21	22.34	0.49	0.10	23	24.47	0.87	0.30
Pteridium aquilinum dead	2	2.13	0.45	0.07	6	6.38	0.43	0.15
Restio curviramis	1	1.06	0.30		1	1.06	0.30	
Restio gaudichaudianus	4	4.26	0.45	0.13				
Restio perplexus	1	1.06	0.10					
Schizaea tenella	4	4.26	0.18	0.05				
Struthiola myrsinites	1	1.06	0.20					
Tetraria bromoides	4	4.26	0.65	0.24	2	2.13	1.10	0.71
Tetraria exilis					1	1.06	0.40	
Thesium strictum					2	2.13	1.75	0.35
Ursinia chrysanthemoides	1	1.06	0.40		1	1.06	0.50	
Widdringtonia nodiflora	2	2.13	0.60	0.14				

Plots adjacent to the wetted channel on both the left and right banks were characterised mostly by within Group d, where the riparian tree, Brabejum stellatifolium, was the key indicator that separated this group from the others.

Communities characterising the dry riparian banks differed between the left and right of the macro channel (Figure 9.54), although the facultative wetland grass, Ehrharta ramosa was common to all these dry communities, and indeed throughout all plot groups with the exception Group f. The right bank

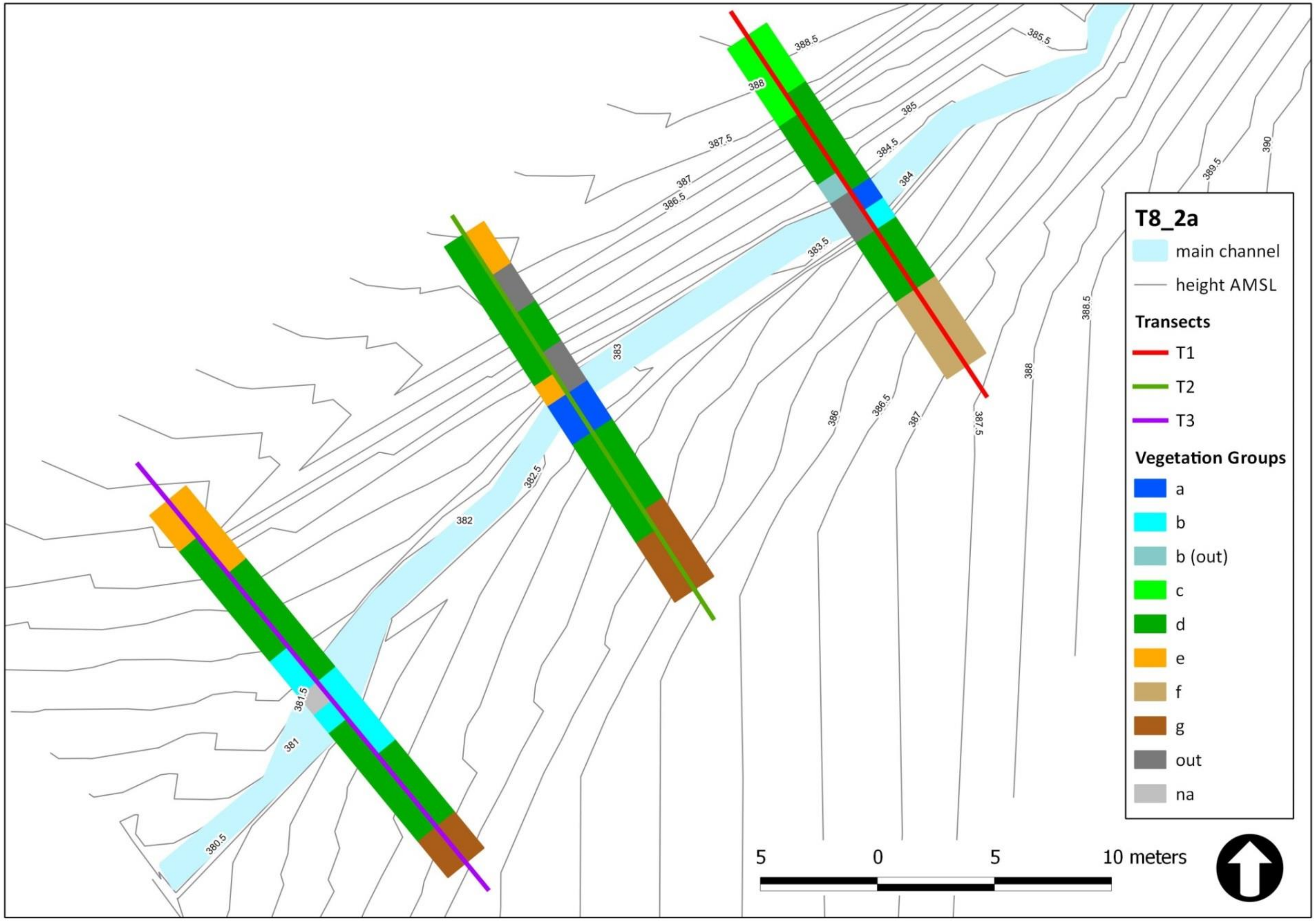


Figure 9.54 Diagrammatic representation of all plots at T8_2a during spring 2011 colour coded according to the plant community that each represents.

communities were characterised by Group c at Transect 1, but Group e characterised the banks at Transects 2 and 3 (Figure 9.54). Along the right bank, Group f characterised the dry riparian communities at Transect 1, while Group g was found along the outer banks of the macro channel at Transects 2 and 3 (Figure 9.54).

Key indicator species representing each of these groups are described in Appendix 1 and are summarised as follows:

Group a: *Todea barbara* – obligate wetland species

Group b: *Restio paniculatus* – obligate wetland species

Group c: *Ehrharta ramosa* – facultative wetland species

Group d: *Brabejum stellatifolium* – obligate wet bank species

Group e: *Osteospermum ciliatum*

Group f: *Tenaxia stricta*

Group g: *Restio perplexus*

The average abundance (% cover) of each of these key indicator species at T8_2a is shown in Figure 9.55. Dispersion among plots within each group was relatively high at this site with no single group sharing more than 46% similarity (Table 9.40). Groups a and b which represented the wetted channel communities were however distinctly different from Groups f and g along the dry riparian banks as indicated by the low percentage similarity between these groups (Table 9.40).

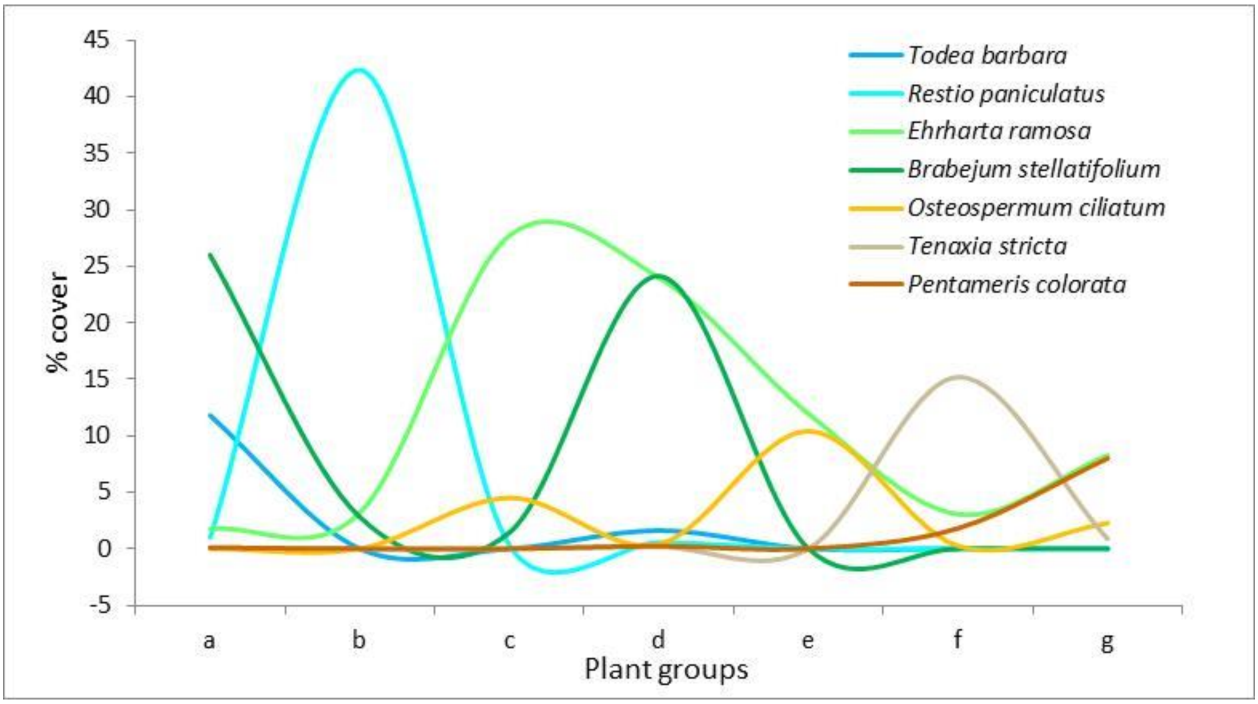


Figure 9.55 Average abundance (% cover) of indicator species for plant groups identified at T8_2a.

These results show that despite similarities in the plant communities represented by these groups, there was a clear distinction between the drier riparian communities and the those typical of the wetted channel at this sites. This distinction suggests a relationship between plant community structure and soil moisture along a perpendicular gradient at this site and thus provides a framework for evaluating change in plant communties in the future.

Table 9.40 Average similarity within and between plant goups at T8_2a.

	a	b	c	d	e	f	g
a	43						
b	16	43					
c	7	11	46				
d	24	26	25	42			
e	10	22	24	32	45		
f	4	10	12	14	15	42	
g	6	13	21	20	23	30	43

9.2.17.2 Year-on-year comparison of monitoring plots

The % similarity in vegetation composition between individual plots, summarised by the plant community affiliation of each plot in Figure 9.56 shows that the extent to which individual changed between 2011 and 2012 varied across the site. Low (<40%) year-on –year similarities were associated with both channel / riparian (e.g. Groups b and d) and dry bank groups (e.g. Groups e and g) and affected some 18 of the 113 plots at this site (Figure 9.56). As with the other sites, plots with few species, combined with very low cover values had low year-on-year similarities related mainly to their sparseness. An example is the two adjacent plots T2_11a (outlier) and T2_11b (Group e). These two plots sit in the middle of Group b plots on Transect 2 (Figure 9.54) and thus their species complement (some 4 species) does not reflect the zonation that would be expected.

Elsewhere, however, for example plots 11b and 12b on Transect 3 (Group b plots), the shift in community was the result of a reduction or loss in *Pteridium aquilinum, Searsia angustifolia, Restio paniculatus*, *Seriphium* and *Brachylaena*, suggesting flood disturbance in these channel plots.

In contrast, low year-on-year similarities in Group d (riparian zone, sloping banks) were generally associated with growth in cover of established species like *Brabejum stellatifolium*, or fluxes of species that were present at cover values of <2%.

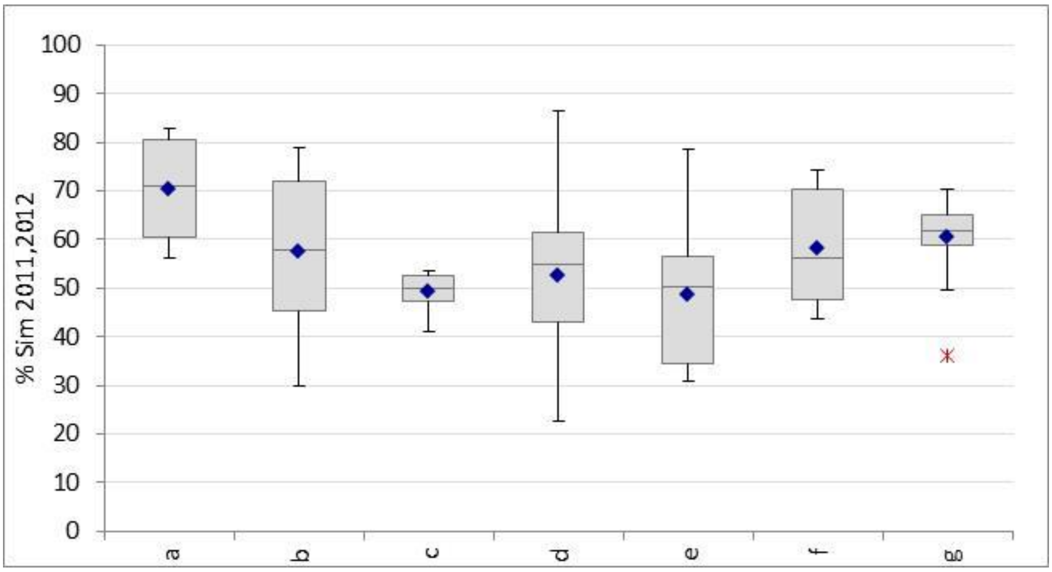


Figure 9.56 Percentage similarity in species composition between individual plots monitored in 2011 and 2012, summarised by the plant community (Group) affiliation of each plot at T8_2a.

9.2.17.3 Inter-annual change in the height of dominant species

Table 9.41 provides a summary of the height and representation of the tallest three individuals measured in each plot at T8_2a in 2011 and 2012. No significant growth in the dominant canopy species was evident at this site. Nevertheless, some species that were dominant species among the canopy community declined in their representation as the tallest species (Table 9.41). In particular, *Ehrharta ramosa* was represented as one of the tallest species in 53% of plots in 2011 but this representation decreased to only 21% in 2012, suggesting that individuals of this species were outgrown by others over the annual period. The average height of *Pteridium aquilinum* increased slightly between 2011 and 2012 and a slight increase in the representation of this species as one of the tallest was also evident (Table 9.41). Therefore a subtle shift or change in the canopy community was evident at this site.

Table 9.41 Average species height (m), based on the maximum height of the three tallest species in each plot, in 2011 and 2012 at T8_2a. The number of plots and the percentage of the total number of plots represented by each species are also given.

	2011				2012			
	#Plots:	110	Total N:	296	#Plots:	112	Total N:	296
Species	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Anthospermum galioides	4	3.64	0.30	0.00	2	1.79	0.20	0.00
Arctotis cf. discolor/flaccida - dead					2	1.79	0.50	0.00
Arctotis cf. incisa					1	0.89	0.10	
Arctotis flaccida/ discolor	5	4.55	0.70	0.24				
Aristea capitata	2	1.82	0.85	0.49	1	0.89	1.20	
Blechnum capense	4	3.64	0.38	0.15	3	2.68	0.67	0.40
Blechnum punctulatum	3	2.73	0.47	0.15	2	1.79	0.70	0.14
Bobartia filiformis	6	5.45	1.38	0.23	2	1.79	1.15	0.07
Bobartia gladiata	2	1.82	1.25	0.35				
Brabejum stellatifolium	37	33.64	2.09	1.76	34	30.36	1.76	0.52
Brachylaena neriifolia	1	0.91	1.80		2	1.79	2.30	0.14
Caesia contorta	2	1.82	0.30	0.14				
Carpha glomerata	1	0.91	1.20		1	0.89	2.00	
Cliffortia juniperina var. *juniperina*	2	1.82	1.10	0.14	4	3.57	1.45	0.37
Corymbium villosum	1	0.91	0.40					
Cyphia cf. bulbosa	3	2.73	0.20	0.17				
Diospyros glabra	1	0.91	1.00		2	1.79	0.70	0.28
Dipogon lignosus	1	0.91	0.20					
Disparago ericoides	1	0.91	0.20		1	0.89	0.40	
Ehrharta ramosa	58	52.73	0.51	0.20	23	20.54	0.67	0.35
Ehrharta ramosa - dead					18	16.07	0.26	0.11
Ehrharta rupestris subsp. *tricostata*					1	0.89	0.20	
Ehrharta rupestris subsp. *tricostata* - dead					6	5.36	0.13	0.05
Ehrharta setacea subsp. *uniflora* - dead	2	1.82	1.20	0.00	2	1.79	0.10	0.00
Elegia vaginulata	1	0.91	0.60		1	0.89	0.20	
Erica bergiana	1	0.91	0.40		3	2.68	0.40	0.10
Erica hispidula	2	1.82	0.40	0.14	6	5.36	0.43	0.12
Erica multumbellifera					1	0.89	0.40	
Euryops abrotanifolius					1	0.89	1.10	
Ficinia bergiana					1	0.89	0.10	
Ficinia distans	1	0.91	0.20					
Ficinia oligantha	3	2.73	0.20	0.00				
Ficinia trichodes	1	0.91	0.30		2	1.79	0.15	0.07
Helichrysum odoratissimum	2	1.82	0.30	0.14				
Leucadendron salicifolium					3	2.68	0.87	0.15
Leucadendron xanthoconus	2	1.82	0.80	0.28	1	0.89	0.70	
Maytenus oleoides	1	0.91	1.00		1	0.89	1.50	
Metrosideros angustifolia	1	0.91	1.80		1	0.89	2.00	
Montinia caryophyllacea	7	6.36	0.67	0.26	4	3.57	0.80	0.24

Cont.

Species	2011				2012			
	#Plots:	110	Total N:	296	#Plots:	112	Total N:	296
	N	%	AveHeight	StdDev	N	%	AveHeight	StdDev
Morella serrata	6	5.45	2.90	4.47	5	4.46	1.30	0.29
Neesenbeckia punctoria					2	1.79	1.05	0.64
Osteospermum ciliatum	3	2.73	0.37	0.06	5	4.46	0.30	0.16
Penaea mucronata	2	1.82	0.45	0.07				
Pentameris colorata	2	1.82	0.40	0.00	4	3.57	1.33	1.79
Pentameris thuarii	4	3.64	0.83	0.24	3	2.68	0.60	0.52
Phylica lasiocarpa	1	0.91	0.30		2	1.79	0.25	0.07
Podylaria hirsuta	2	1.82	1.30	0.99	1	0.89	1.10	
Pteridium aquilinum	48	43.64	0.85	0.36	53	47.32	0.99	0.35
Pteridium aquilinum - dead					29	25.89	0.84	0.36
Restio capensis					1	0.89	0.40	
Restio fusiformis					1	0.89	0.40	
Restio gaudichaudianus	1	0.91	0.40					
Restio paniculatus	12	10.91	2.23	0.88	9	8.04	2.20	0.96
Restio paniculatus - dead					1	0.89	1.70	
Restio pedicellatus	1	0.91	0.30		1	0.89	0.50	
Restio triticeus	4	3.64	0.73	0.21	4	3.57	1.40	1.74
Searsia angustifolia	18	16.36	1.73	0.49	16	14.29	1.58	0.62
Seriphium cinereum	3	2.73	0.57	0.21	5	4.46	0.78	0.33
Spiloxene cf. capensis	1	0.91	1.50					
Tenaxia stricta	2	1.82	0.65	0.35	1	0.89	1.00	
Tetraria bromoides	4	3.64	1.28	0.36	3	2.68	1.33	0.55
Tetraria capillacea/flexuosa	2	1.82	0.50	0.14	2	1.79	0.25	0.07
Tetraria flexuosa	1	0.91	0.40		1	0.89	0.70	
Thamnochortus fruticosus	1	0.91	0.80		1	0.89	0.60	
Todea barbara	3	2.73	1.43	0.21	4	3.57	1.53	0.41
Ursinia paleacea	1	0.91	0.80					
Wahlenbergia parvifolia	7	6.36	0.54	0.24	2	1.79	0.40	0.14
Wahlenbergia parvifolia - dead					1	0.89	0.50	
Watsonia cf. angusta	9	8.18	0.62	0.33	5	4.46	1.00	0.07
Watsonia cf. angusta - dead					2	1.79	0.80	0.28

10 AQUATIC MACROINVERTEBRATES

10.1 Introduction

The objective of the collection of aquatic macroinvertebrates data was to document the temporal variability of these communities in the ecochannels. These data provided an overall index of ecological integrity based on rapid biomonitoring techniques, and a baseline against which future data may be evaluated and contextualised.

Invertebrate samples were collected from two biotopes at each ecochannel. The annual macroinvertebrate data collected from each ecochannel were:

- Taxon lists, number of taxa, and abundance, used in multivariate analysis;
- Total SASS5 scores; average score per taxon, per site and per biotope

10.2 SASS

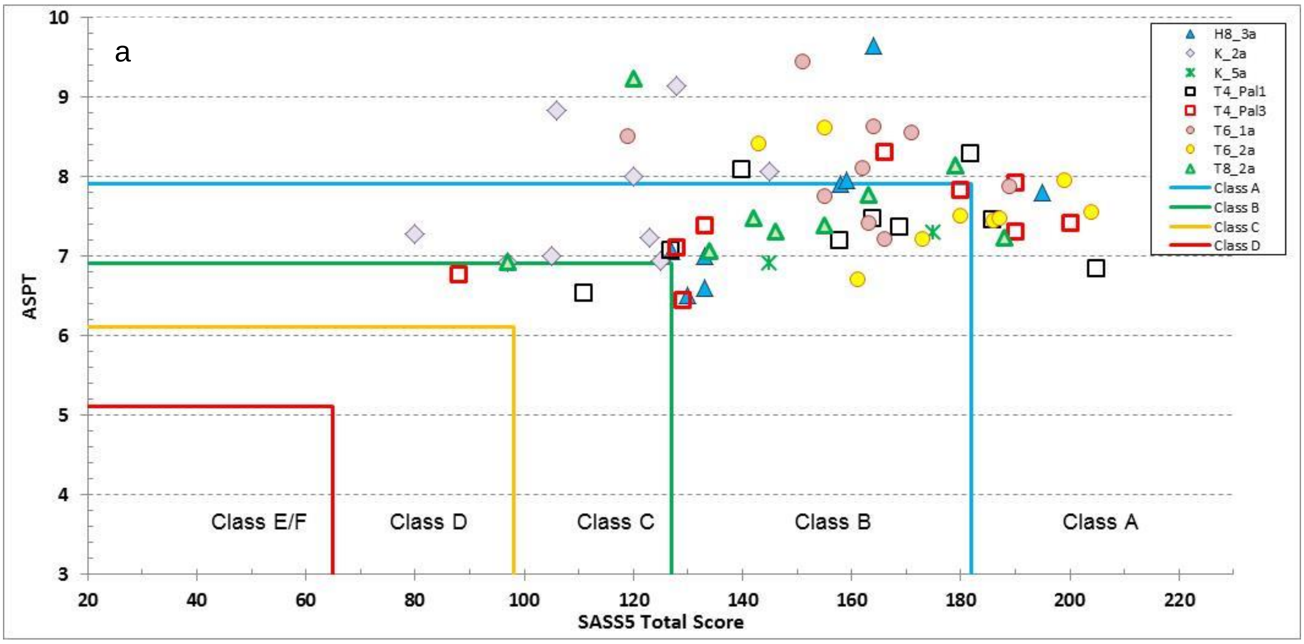
The SASS sample scores are usually interpreted by viewing them within the Ecostatus, or River Health Classes A – E/F (details in Volume 2: Method Statements), which assign a degree of naturalness to SASS scores, depending on the combination of SASS Total Score and Average Score per Taxon (ASPT). These classes are superimposed on the SASS scores recorded from the ecochannels over EPM1 and EPM2 (Figure 10.1a).

Despite the fact that the EPM2 ecochannels are all pristine or near pristine, their SASS / ASPT ratio scores ranged across values that in terms of the Ecostatus classification would fall into both Class A (natural) and Class B (largely natural) rivers, with a few values even falling within Class C (moderately modified). The reason for this is that thresholds for each of these Ecostatus classes are based on taking percentiles of all values recorded from all rivers within an ecoregion and equating the top ten percentile of scores as representative of unmodified (Class A) rivers, rather than using a static value to define the Class thresholds. What they suggest is that these systems periodically or occasionally experience a reduction in conditions conducive to supporting a wide diversity and / or fauna highly sensitive to water quality alteration.

Figure 10.1(b) shows the SASS/ASPT ratios for the March samples only, illustrating that a large proportion of the Class B scores were from samples collected in March (i.e. the plot of March only data excludes the bulk of the samples in the Class A category. Also, the lowest scores were recorded at T4_Pal1 and K_2a in March 2009 and at T4_Pal3 in March 2013 – indeed all the Class C scores were recorded in the month of March – late summer. As a period of the lowest flow in these mountain streams, the late summer period is often associated with the stresses of very low flow, dwindling habitat availability (e.g. of fast shallow riffles, as was shown in the analysis of flow-depth data). This is a useful finding, as it indicates the potential for using SASS data from late summer as a monitoring tool.

With respect to the 2013 year, Figure 10.2 shows the contribution of the Vegetation and Stones biotopes to overall SASS scores. Although the Stones biotope is often considered to be the most important, the Vegetation biotope was at times as or more important to the Total Scores than the Stones at most sites.

Inter-annual differences in the March scores were high at T4_Pal1, with the lowest scores recorded there in March 2009, which was after a fire in the Nuweberg area. K-2a recorded generally lower SASS scores than the other sites, although the ASPT there was not affected and indicates similar levels to the other ecosites.



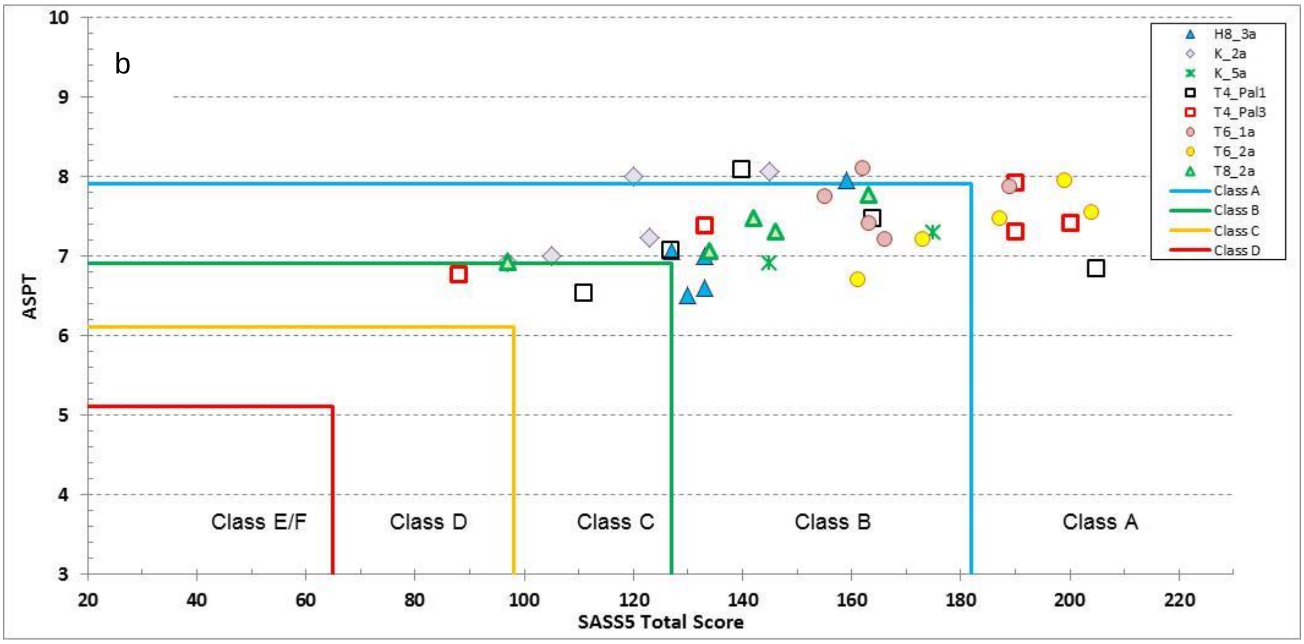


Figure 10.1. SASS results for EPM2 ecochannels (a) all samples from EPM1 and EPM2 and (b) March only samples, from EPM1 and EPM2 sampling periods.

10.3 Invertebrate taxa

10.3.1 Community composition

The Primer routines Cluster analysis and Multidimensional Scaling (MDS – see methods in Volume 2: Method Statements) were used to identify patterns of change in community composition over both EPM1 and EPM2 and across biotopes. These are shown in Figure 10.3 to Figure 10.10, alongside bar graphs showing overall invertebrate abundance (combining biotopes) and species richness, here presented simply as species count. In the discussion that follows, each site is treated separately.

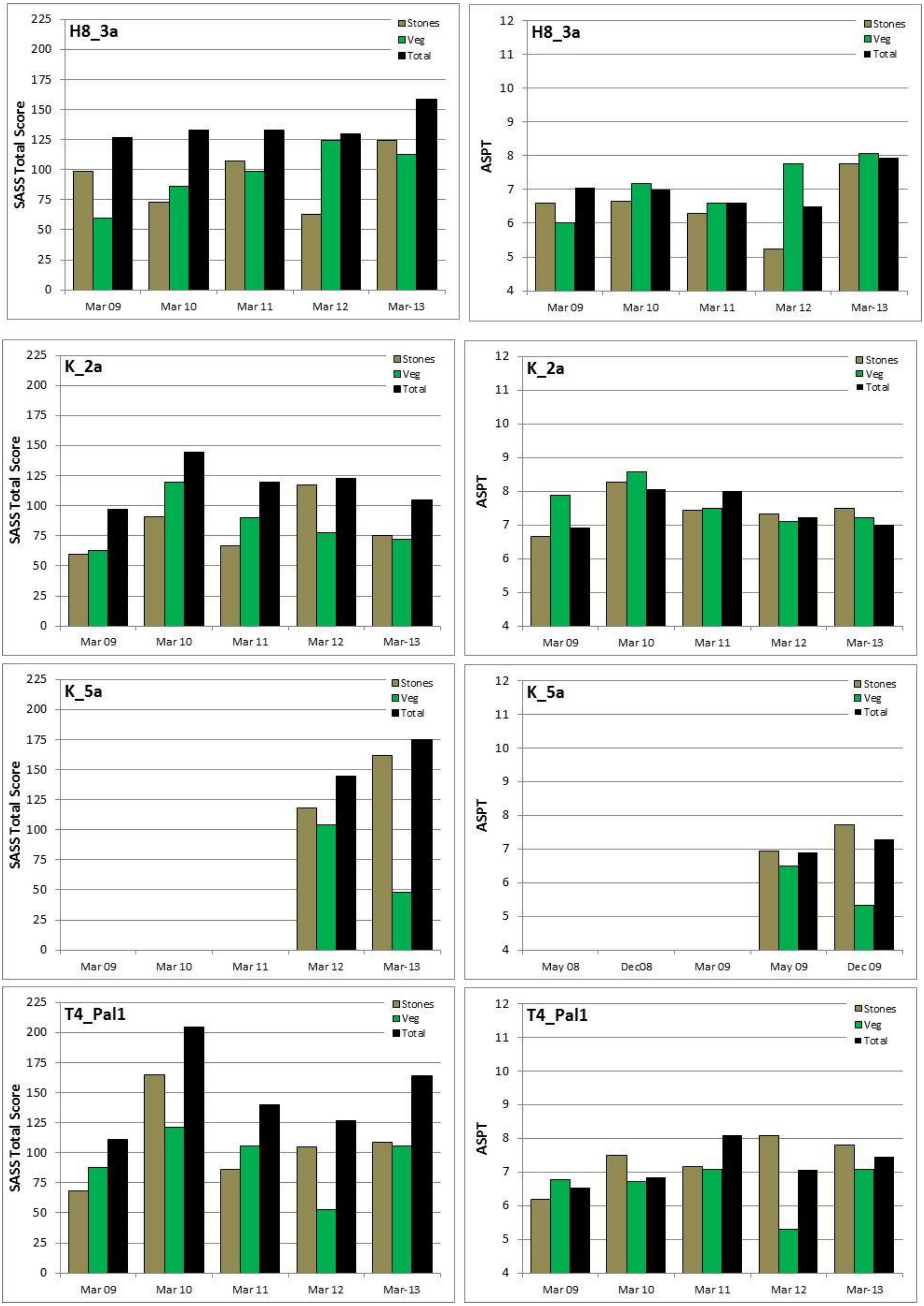


Figure 10.2. **SASS Total scores (right) and ASPT (left) separated by biotope (stones and vegetation) and for the site as a whole, March 2008 – 2013.**

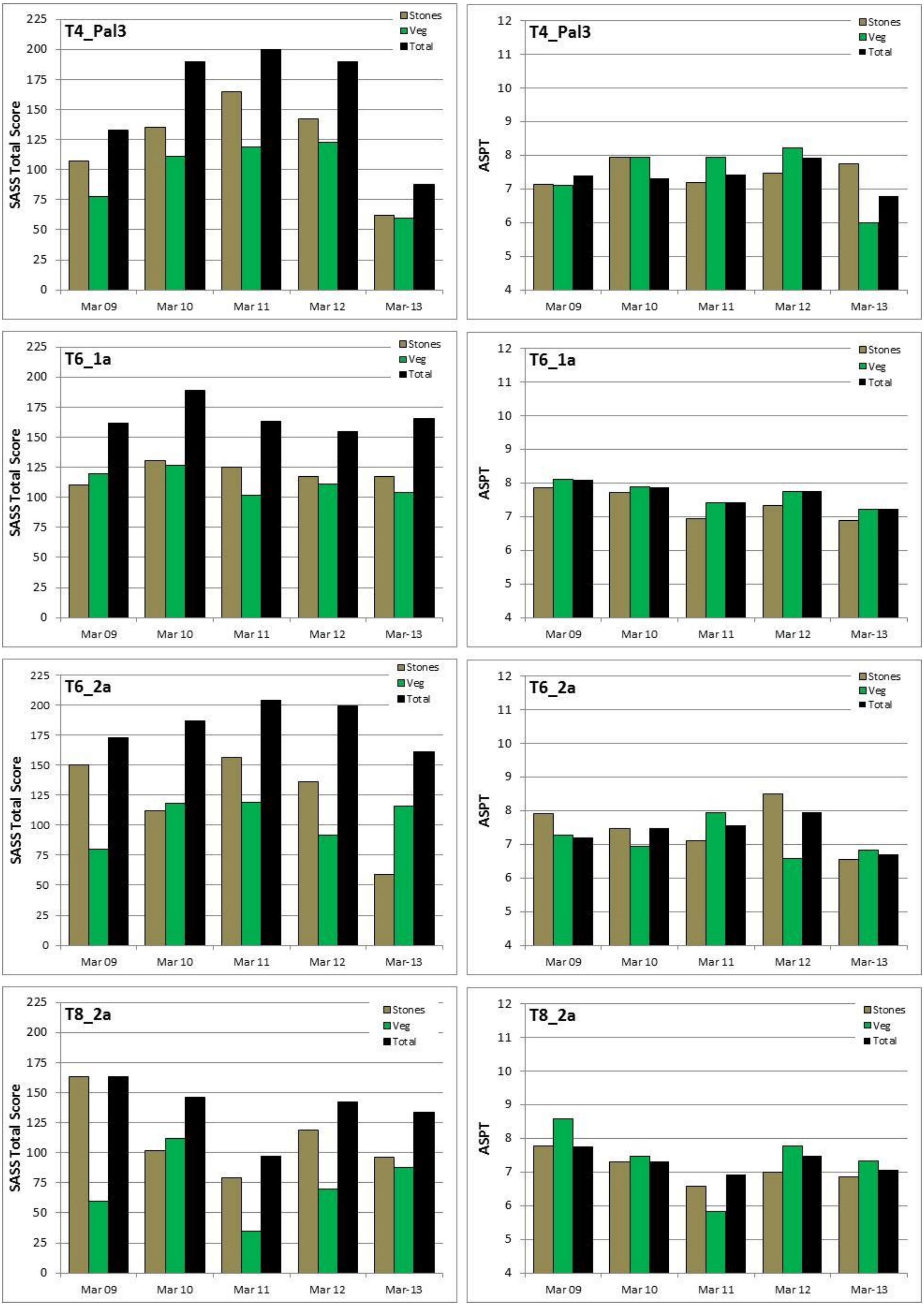


Figure 10.2. cont. SASS Total scores (right) and ASPT (left) separated by biotope (stones and vegetation) and for the site as a whole, March 2008 – 2013.

Ecochannel H8_3a:

The location of the macroinvertebrate sampling at H8_3a was changed slightly between EPM1 and EPM2, and thus the March 2011 - 2013 samples were expected to differ slightly from those from March 2009 and 2010, but were in fact quite similar, at least to the March 2010 samples.

There was a clear separation of samples from stones versus vegetation biotopes, reflecting differences in habitat preferences of the invertebrates. An exception was the March 2009 samples, which grouped separately from those of other years. Interestingly, hot fires raged through the Steenbras area in December 2008, with higher numbers of invertebrates being recorded in the samples from that month (December data EPM1 sampling, not shown), but the lowest numbers in the March 2009 samples. The March 2009 samples supported a high proportion of chironomids and amphipods, which may be related to post-fire processes in feeder streams and seeps.

The vegetation biotope sample in the 2013 period was also quite dissimilar to those of 2010 – 2012. Although this sample contained many of the more sensitive taxa (e.g. see ASPT scores FIG REF), there were only 15 species present – similar to the 20 species recorded in 2009, and far lower than the 29 – 49 species recorded in vegetation samples in 2010 – 2012. Key taxa no present were baetid and leptophlebiid mayflies, as well as predator groups that were common in other years. The overall numbers were very low, with total abundance in 2013 dramatically lower than any other year of monitoring. The samples were collected during a rain event, when the river level had risen, and this may have affected the results.

Ecochannel K_2a:

The stones biotope at this site varied over time more than the vegetation, as shown by the dispersal of samples in the PRIMER MDS plot (Figure 10.4). Very low numbers of animals were recorded in March 2010 and this sample lacked many of the cased caddis groups recorded in other years. This could be because of the limited availability of Stones biotope that is clear of vegetation, and therefore the low sampling effort expended in collecting the Stones samples. The Vegetation biotope samples were similar between months and years, with the exception of 2009, where, unlike H8_3a, the samples were diverse and overall abundance was higher than the more recent years.

Ecochannel K_5a:

Only two years' of samples have been collected for K_5a, with fairly uniform overall abundances and species richness. In 2013, however, the vegetation samples in 2013 were extremely depauperate. Although the dominant taxa in this biotope in 2012 (*Lithogloea harrisoni* [Telagonodidae], *Labiobaetis* [Baetidae], *Leptecho scirpi* [Leptoceridae]) were still recorded in 2013, the species of damselfly collected in 2013 were different from those in 2012, and, a more significant change, the 2013 samples included large numbers of Simuliidae. This group (commonly called blackflies) have a clumped distribution and this, rather than any fundamental change in site conditions, could explain the variability in sample results.

Ecochannel T4_Pal1:

This site, somewhat inexplicably, consistently recorded the lowest number of species throughout the monitoring programme, along with the disturbed site T8_2a. Data collected during EPM1 showed that the shifts in community structure from early to late summer are particularly profound. The site enjoys the highest algal species diversity, but supports a low algal biomass, with a large proportion of unpalatable blue-green algae, and a high ash-free dry mass (see algal report Section 11). Thus poor food quality, coupled with the stresses of low late-summer flows may explain this pattern. Notwithstanding, the site constantly had a high species diversity.

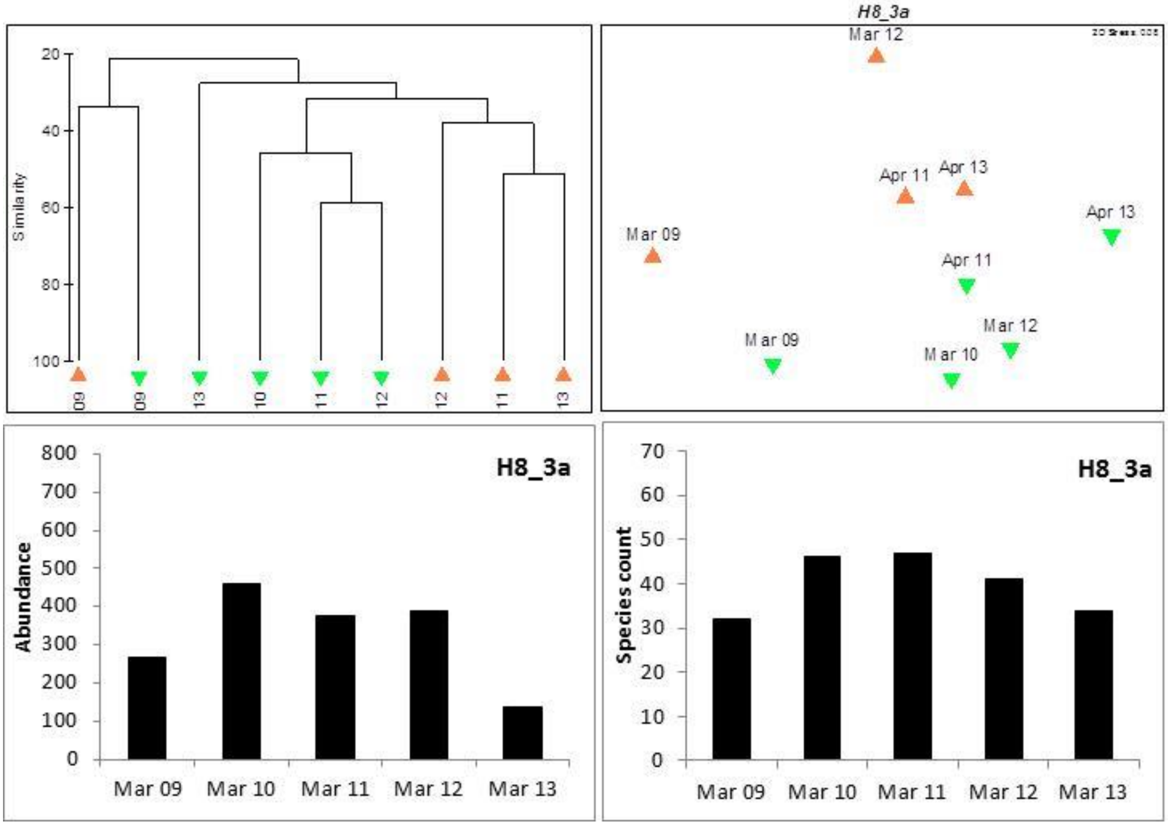


Figure 10.3 (top) Cluster analysis and MDS plot of March invertebrate assemblages at H8_3a, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.

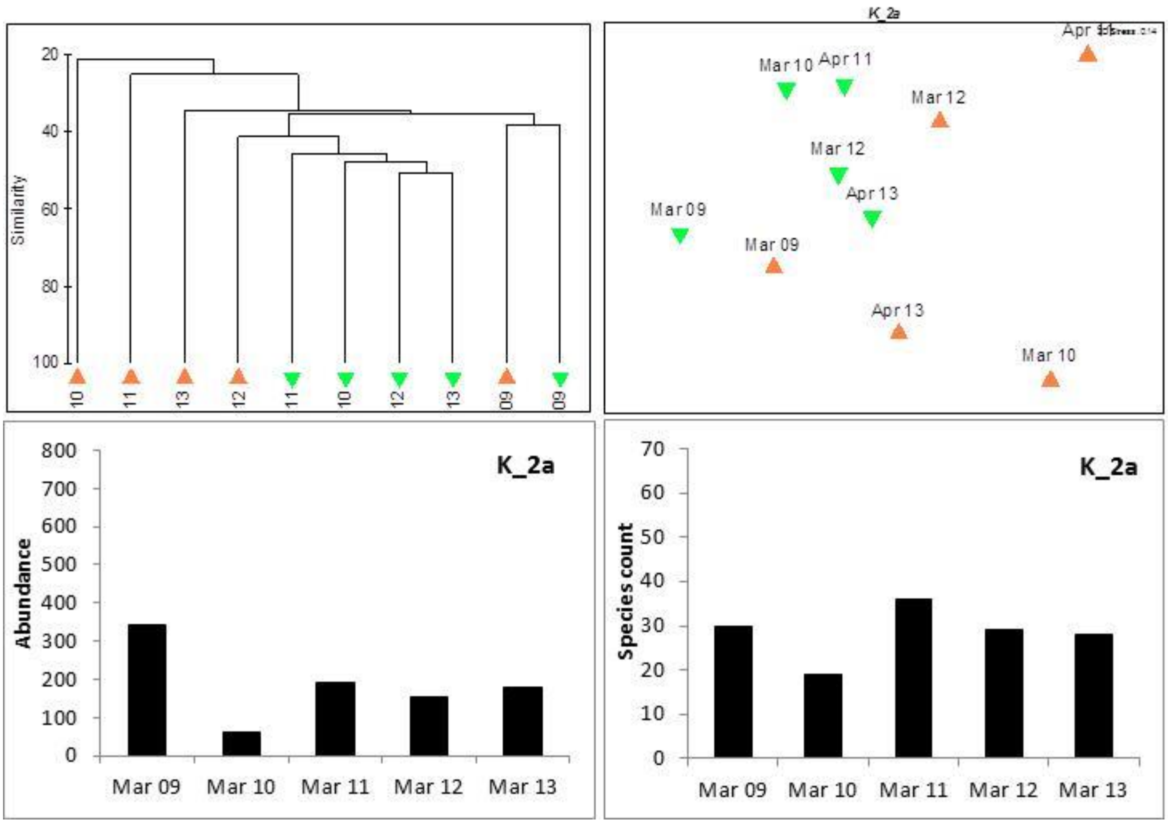


Figure 10.4 (top) Cluster analysis and MDS plot of March invertebrate assemblages at K_2a, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.

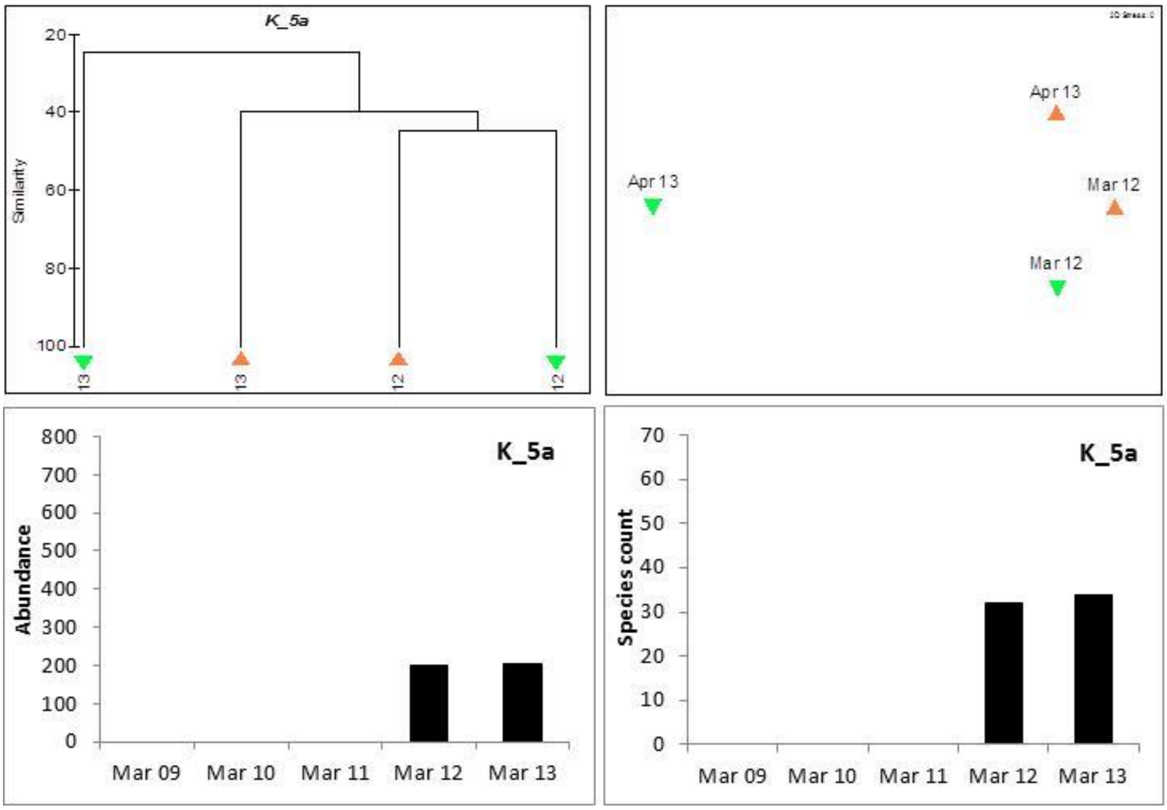


Figure 10.5 **(top) Cluster analysis and MDS plot of March invertebrate assemblages at K_5a, since 2011, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.**

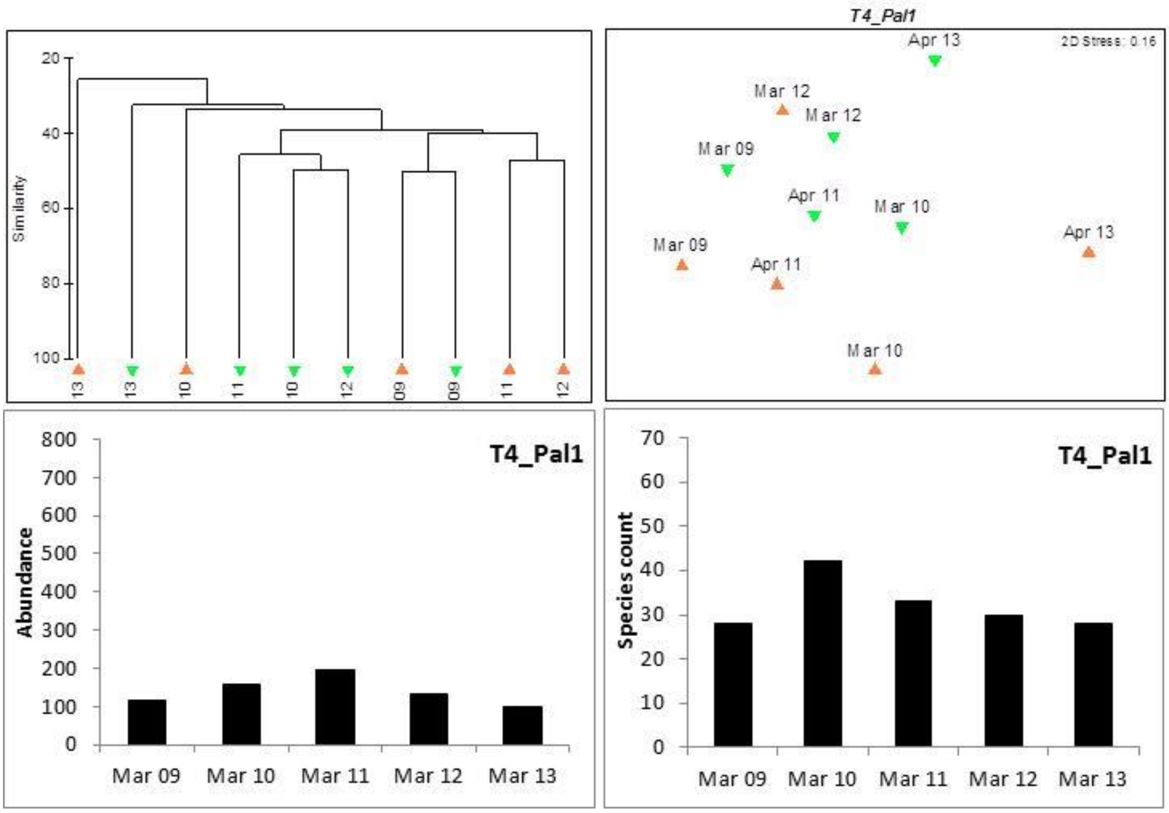


Figure 10.6 **(top) Cluster analysis and MDS plot of March invertebrate assemblages at T4_Pal1, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.**

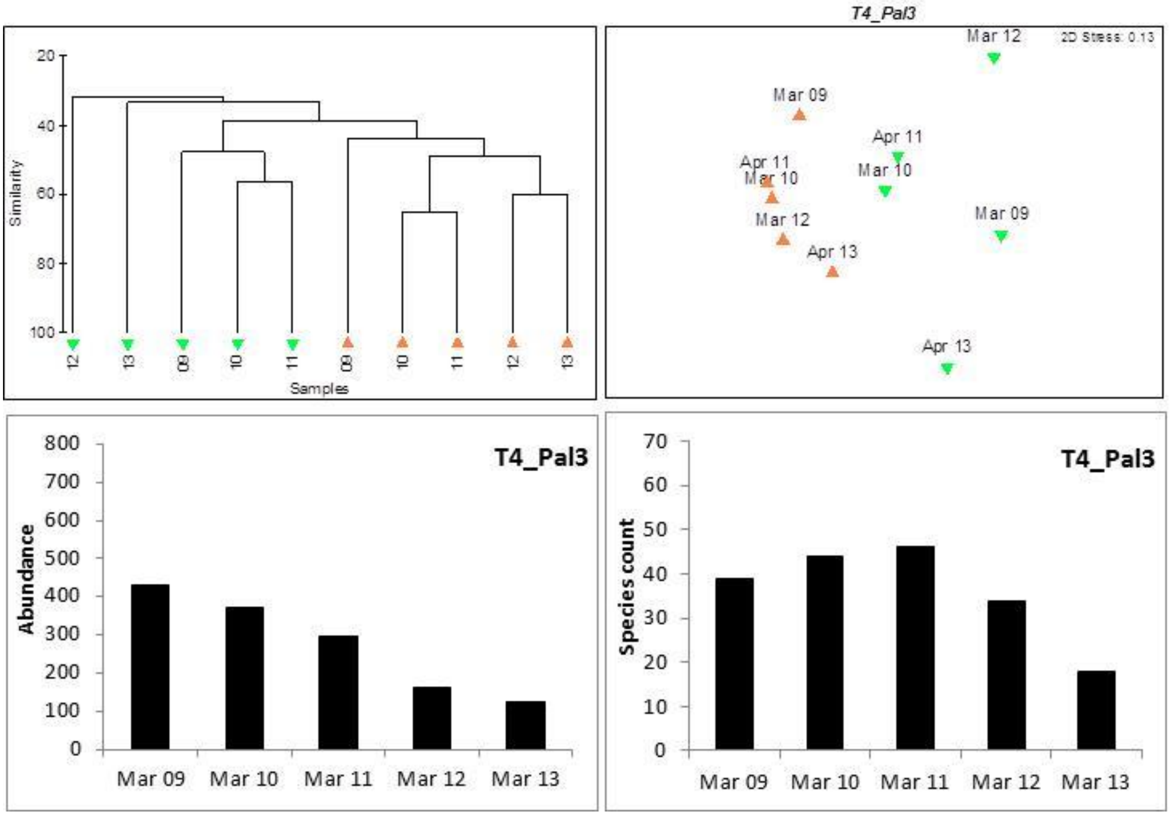


Figure 10.7 (top) Cluster analysis and MDS plot of March invertebrate assemblages at T4_Pal3, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.

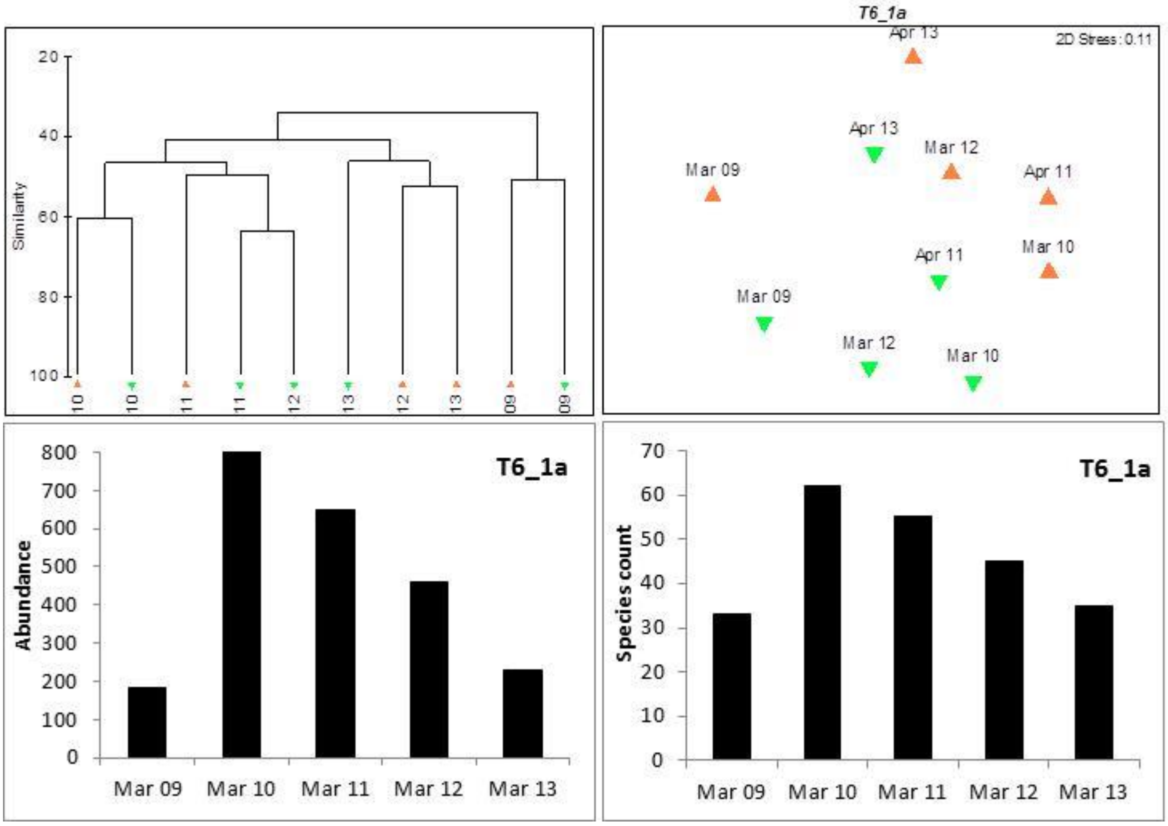


Figure 10.8 (top) Cluster analysis and MDS plot of March invertebrate assemblages at T6_1a, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.

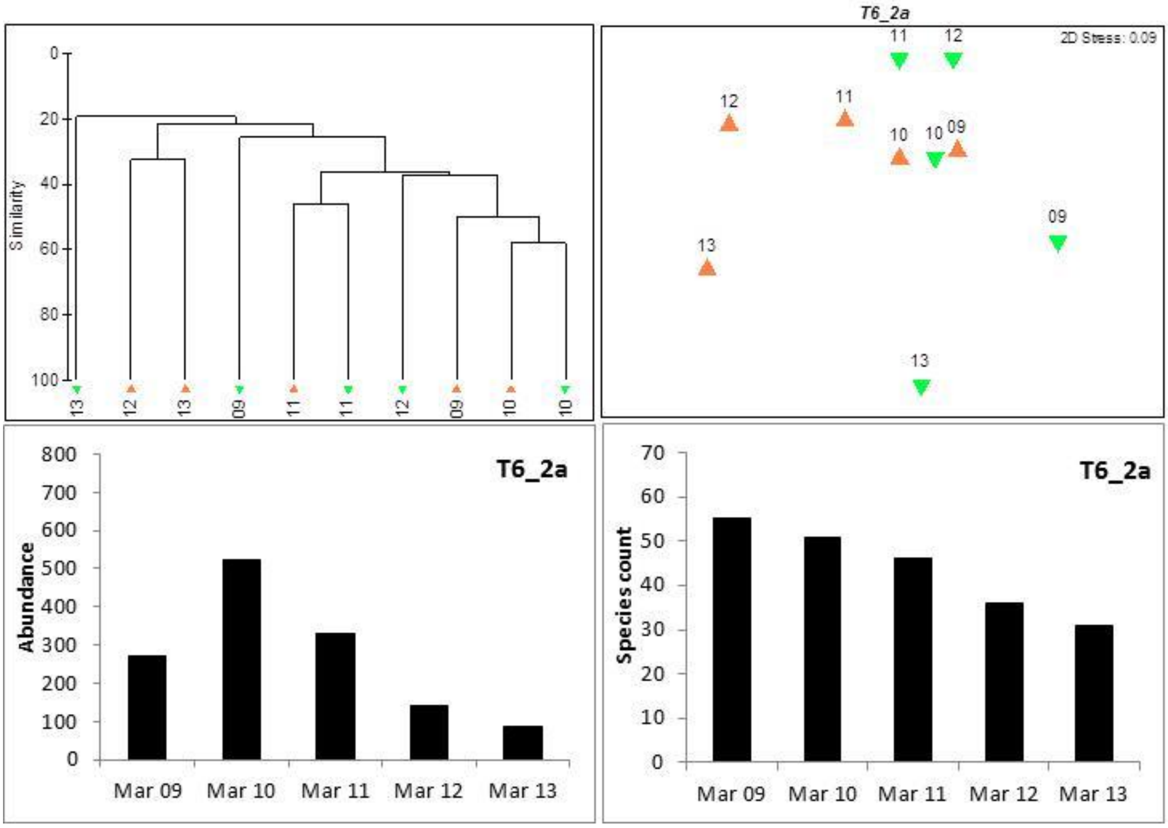


Figure 10.9 **(top) Cluster analysis and MDS plot of March invertebrate assemblages at T6_2a, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.**

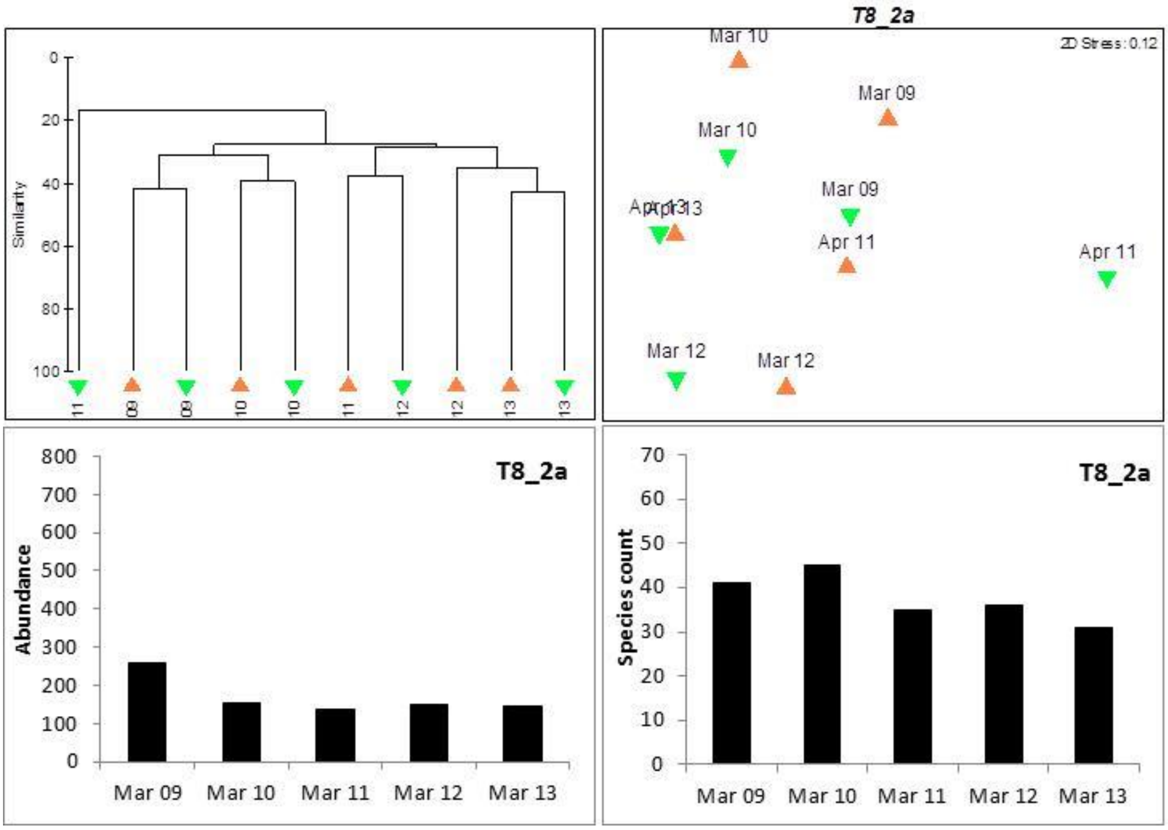


Figure 10.10 **(top) Cluster analysis and MDS plot of March invertebrate assemblages at T8_2a, since 2009, showing relationships between biotopes and years. (bottom) Abundance and richness (species count). Orange triangles = Stones, green triangles = Vegetation biotopes.**

In the PRIMER analysis, the March 2010 stones sample was an outlier, and was characterised by particularly high species richness. In contrast, the more significant outliers were the 2013 samples, particularly the stones. Analysis of the species driving these differences showed that it was no so much the loss of species but the reduction in numbers in the stones biotope that explained these patterns.

Ecochannel T4_Pal3:

T4_Pal3 was characterised by high species richness for a small mountain stream, but this has declined markedly, along with overall abundance in 2012 and 2013. The notable differences were caused by low numbers of individuals rather than the absence of species, although some species of cased caddis and plecopterans were absent from the March 2012 and 2013 stones samples. This site fell into a Class C category (SASS results), indicating a level of stress in the biota – numbers in the stones samples in 2013 were less than a third of those recorded in other years.

Ecochannel T6_1a:

The 2009 and 2010 samples are the most distinct at this site in the PRIMER cluster analysis, and mirror the massive different in abundance and richness between these years. Fires swept through the Boesmanskloof valley in late 2009 and as was the case at H8_3a**,** the abundance immediately post-fire was elevated, although the mechanism for this is not clear. The 2010 to 2013 samples have been fairly consistent, although samples group more closely by year than by biotope rather than in species.

Ecochannel T6_2a:

This site shows highly similar patterns, albeit less pronounced, in invertebrate abundance and richness as at T6_1a, suggesting that the patterns are driven by some environmental factor (and not, for example, just variability associated with the coarse sampling methods). The data in 2009 – 2010 showed little differentiation between samples from different biotopes, although this has become more pronounced. The 2012 and 2013 sample set was characterised by very low species numbers, with low abundance especially of beetles, mayflies and many trichopterans. There is no obvious explanation for this.

Ecochannel T8_2a:

Two overriding issues at this site are that 1) it is recovering from catastrophic flood scour that occurred in 2010, between EPM1 and EPM2 and 2) the sampling location was moved downstream in EMP2 and is now in an incised channel with little vegetation. As a result community structure separates very clearly along temporal lines, with 2009/2010 being different from 2011 – 2013. The latter period is still characterised by shifts in community structure (relative species abundances) although overall densities and richness have remained stable.

10.3.2 Persistence Index

Some of the high level of variability in the community structure presented in section 10.3.1 is associated with patchily-distributed invertebrates. The sampling effort expended in invertebrate monitoring may be insufficient to account for species that are either very rare at a site (occurring at very low densities) or highly patchily distributed. As a result of this, the measure of persistence used for monitoring follows a rule of excluding taxa that:

- Comprise less than 1% of the sample total invertebrate numbers, AND
- Occur in fewer than 25% of samples.

Although this has the potential to ignore the loss of potentially large numbers of species, reporting this value along with the total species count provides a combined measure of community turnover and diversity changes.

Year-on year persistence for the March samples for each site over the five years of monitoring comprising EPM1 and EPM2 are shown in Table 10.1. In addition, the persistence from the start of sampling (2009) to the latest sampling event (2013) is shown. Year-on year persistence values ranged from 52 to 93 %. The sites T6_2a and T4_Pal1 had relatively low persistence from the start of EPM1 to date, which is linked to the substantial changes noted between the 2012 and 2013 years. However, despite T4_Pal3 showing such a consistent trend of declining invertebrate numbers (Figure 10.7), this site remained fairly steady in species complement (Table 10.1).

Table 10.1 Persistence (Bray Curtis similarity, using presence-absence data).

	Mar 09 vs 10	Mar 10 vs 11	Mar 11 vs 12	Mar 12 vs 13	Mar 09 vs 13
H8_3a	52.6	85.7	88.0	80.9	63.2
K2_a	60.0	73.7	85.7	65.0	71.4
K5_a				75.6	
T4_Pal1	68.3	79.1	84.2	66.7	57.1
T4_Pal3	84.6	92.6	85.7	66.7	63.4
T6_1a	71.6	86.1	88.3	69.7	65.5
T6_2a	90.0	82.5	82.1	46.5	59.1
T8_2a	82.1	65.2	66.7	65.0	72.0

10.4 Summary statements

SASS scores revealed that the March period was in many cases associated with a reduction in diversity and richness, whilst there was also high level of inter-annual variability in March samples, particularly with regard to invertebrate numbers at each site. A difference in sampling effort may account for some but not all the variability, since the same practitioners are collecting the samples. Other reasons for variation in results includes weather patterns, with samples collected shortly after rain (sometime of necessity) often recording low numbers of animals. Post-fire impacts appear to account for some variability too, although the processes behind these are not well understood.

Some of the high level of variability in the community structure presented this section is associated with patchily-distributed invertebrates and the level of sampling effort expended in monitoring. As a result, the variables most appropriate to identifying potential thresholds of concern are suggested as being:

- Community persistence, as calculated from presence-absence species data, with the exclusion of taxa according to the rules suggested, combined with a measure of species richness (as simple species counts); and
- SASS indices are a coarser measure that will allow for comparison and / or reporting to tie in with other programmes such as the DWA River Health Programme.

11 ALGAE

11.1 Introduction

The objective of the collection of algal data was to document the temporal variability of these communities in the ecoseeps and ecochannels. These data provide a baseline against which future data may be evaluated and contextualised.

Primary producers in freshwater ecosystems comprise assemblages of benthic and floating algae, cyanobacteria and prokaryotes such as bacteria, fungi and protozoa. In this monitoring programme, the focus was on the benthic components of these assemblages. In riverine systems, the most popular collective term used for benthic primary producers is periphyton (e.g. Biggs, 2000; Ewart-Smith and King, 2012), which refers to the communities growing on riverine substrata and submerged macrophytes. In wetlands, the term often used is epipelon, meaning the assemblages growing on fine wetland substrata such as mud, sand and silt grains (e.g. Goldsborough and Robinson, 1996). For the TMG project, the term "algae" has been chosen to cover both the riverine and wetland assemblages, as these organisms make up the largest proportion of these communities.

The bi-annual algal datasets collected from each ecosite were biomass as Chlorophyll-a and Ash-Free Dry Mass (AFDM), and species lists, numbers of taxa, and abundance. Details on data analysis methods are provided in Volume 2: Method Statements.

11.2 Algal biomass

Over EPM1 and EPM2, algal biomass in the ecochannels ranged from 0.04 to 9.32 mg/m^2 and AFDM from 0.16 to 13.13 g/m^2 (see Volume 3: Data Report). These ranges are similar to those measured in other oligotrophic, open-canopied rivers in the Western Cape (Ractliffe and Ollis, 2009; Ewart-Smith and King, 2012), and elsewhere in the world. Biggs (1995) recorded median monthly chlorophyll-a concentrations of 1.7 mg/m^2 and an AFDM of 1.5 g m^{-2} in oligotrophic streams in New Zealand, and Ractliffe (2012) found chlorophyll-a ranged from 1.47 up to 10.67 mg m^{-2} in oligotrophic rivers in Peru.

Chlorophyll-a was generally highest at T8_2a, K_2a or K_5a (Volume 3: Data Report). It is surprising that algal biomass was so high at K_2a, as this is one of the more shaded sites. AFDM was variable, being highest at different sites on each sampling occasion. Interestingly, the sites with the lowest chlorophyll-a sometimes had the highest AFDM.

Algal biomass in the ecoseeps ranged from 1.26 to 436.6 mg/m^2 and AFDM from 175.73 to 13 809.56 g/m^2, and was always significantly ($p < 0.001$ for chlorophyll-a and $p < 0.05$ for AFDM) higher than in the ecochannels (see Volume 3: Data Report). This may be due to sampling methods – the sediment cores from the ecoseeps contained other organic matter that interfered with the analysis. The difference could also be because there are few grazers of algae in the ecoseeps, whereas grazer pressure plays a major role in algal biomass and community dynamics, especially during the dry season (Ewart-Smith and King, 2012) in the ecochannels. Furthermore, short-term cycling of riverine periphyton biomass is typically governed by the flow regime (and nutrient availability), and floods are important for disrupting and re-setting the periphyton communities (Biggs 1996). In the south-western Cape, periphyton biomass reaches its peak in middle to late summer, followed by the spontaneous sloughing, grazing and death of the periphyton community, and a re-setting of the community as a result of winter flood disturbance (Ewart-Smith and King, 2012) (see Figure 11.1). This "top-down" control is lacking in wetlands, and biomass accrual and loss may primarily be governed by autogenic processes, allowing biomass to reach a higher peak than in rivers. This would certainly explain the high AFDM (e.g. organic matter, bacteria) recorded in the seeps.

Algal biomass, as both chlorophyll-a and AFDM, was generally highest at the three Kogelberg ecoseeps (see Volume 3: Data Report).

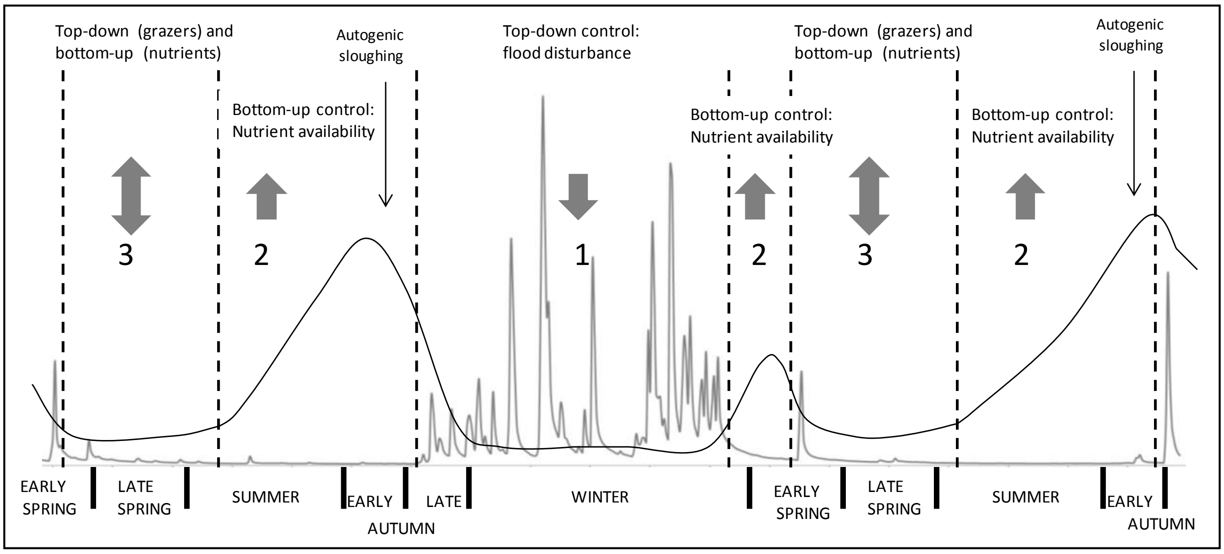


Figure 11.1 Typical cycle of natural periphyton biomass accrual and loss (black line) under oligotrophic conditions, superimposed on a hydrograph typical of south-western Cape foothill rivers (grey line). Temporal shifts in top-down and bottom-up control of periphyton communities are shown: 1 = flood disturbance; 2 = nutrient availability; 3 = grazers and nutrient availability. From Ewart-Smith and King (2012).

Algal biomass was always higher at the end of summer (March) than at the end of the wet season (December) in the ecochannels (Figure 11.2), with significant results for K_2a, T4_Pal1, T4_Pal3, T6_1a and T8_2a. This agrees with the results from elsewhere in the Western Cape (e.g. Ewart-Smith and King, 2012; see Figure 11.1). Algal accrual tends to increase with ambient or water temperature and with increased irradiation (Goldsborough and Robinson, 1996). At the ecoseeps, there were significant differences in the biomass measured in December and March at H8_3b, T3_Pal4, T6_4 and T8_2b, and was at least a marginal increase in March at all sites except B1_1 (Figure 11.3). The latter site is heavily shaded, dampening the effects of seasonality. Algal biomass data for wetlands are scarce, so comparisons could not be made with other systems.

Comparisons between algal biomass measured at ecoseep monitoring points with different surface soil (top 10 cm) hydroperiod classes did not return many significant results using the log(x+1) transformed data, due to most ecoseeps being dominated by one hydroperiod class. At B1_1, T3_Pal4 and T6_1b in December, however, intermittently saturated points supported a significantly ($p < 0.05$) higher algal biomass than seasonally saturated points (Figure 11.4). Only T6_1b showed significant differences between soil hydroperiod in March. There was a trend at most ecoseeps towards higher biomass with decreasing duration of saturation, especially in December (Figure 11.4), although there were too few perennially saturated points to make robust comparisons across all hydroperiod classes. An increase in biomass at the intermittently saturated points is possibly linked to lower variation in soil moisture and higher temperature at these points.

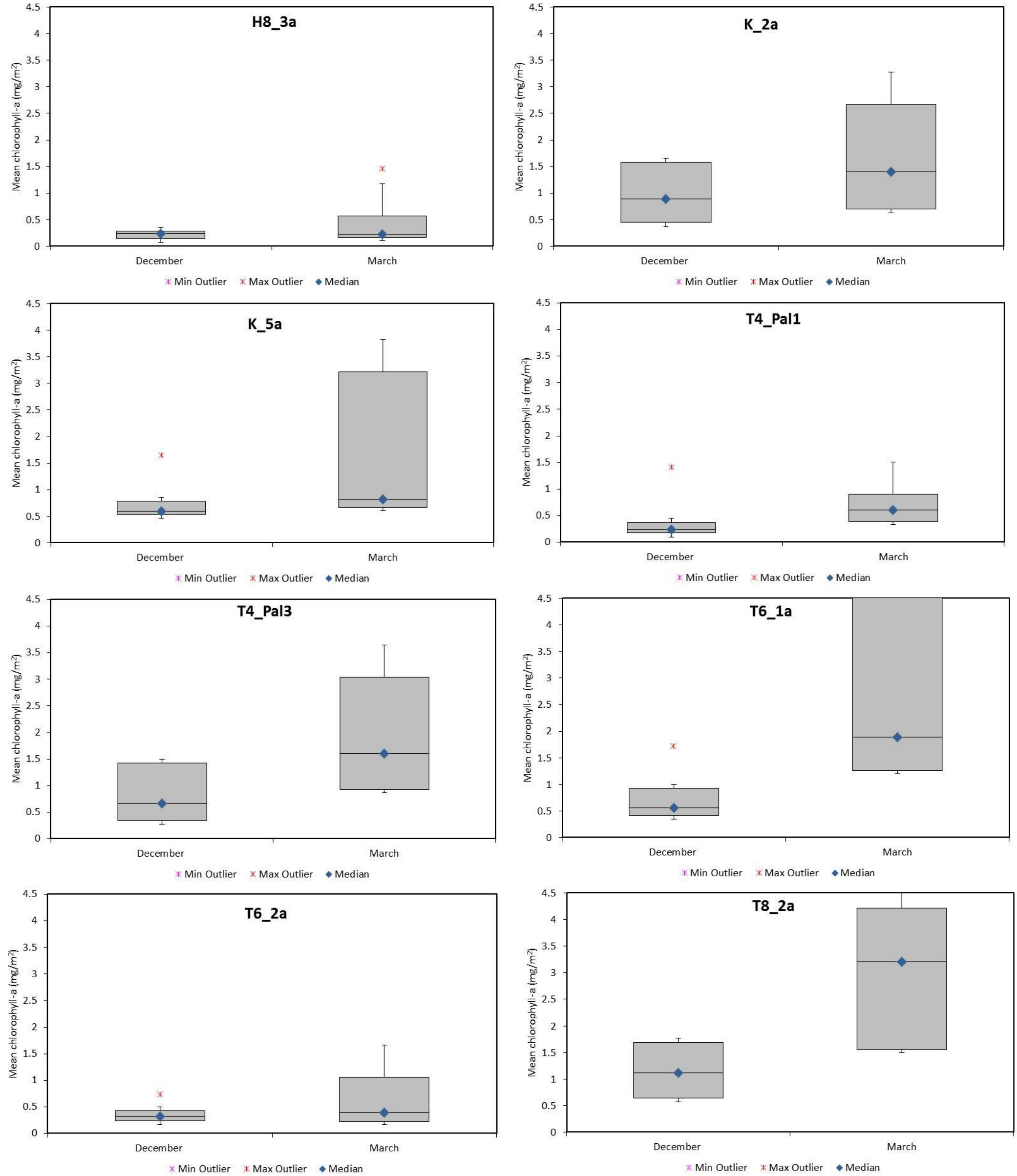


Figure 11.2 Box and whisker plots of mean algal biomass measured as chlorophyll-*a* in the ecochannels, comparing biomass in December of each monitoring year against that of March.

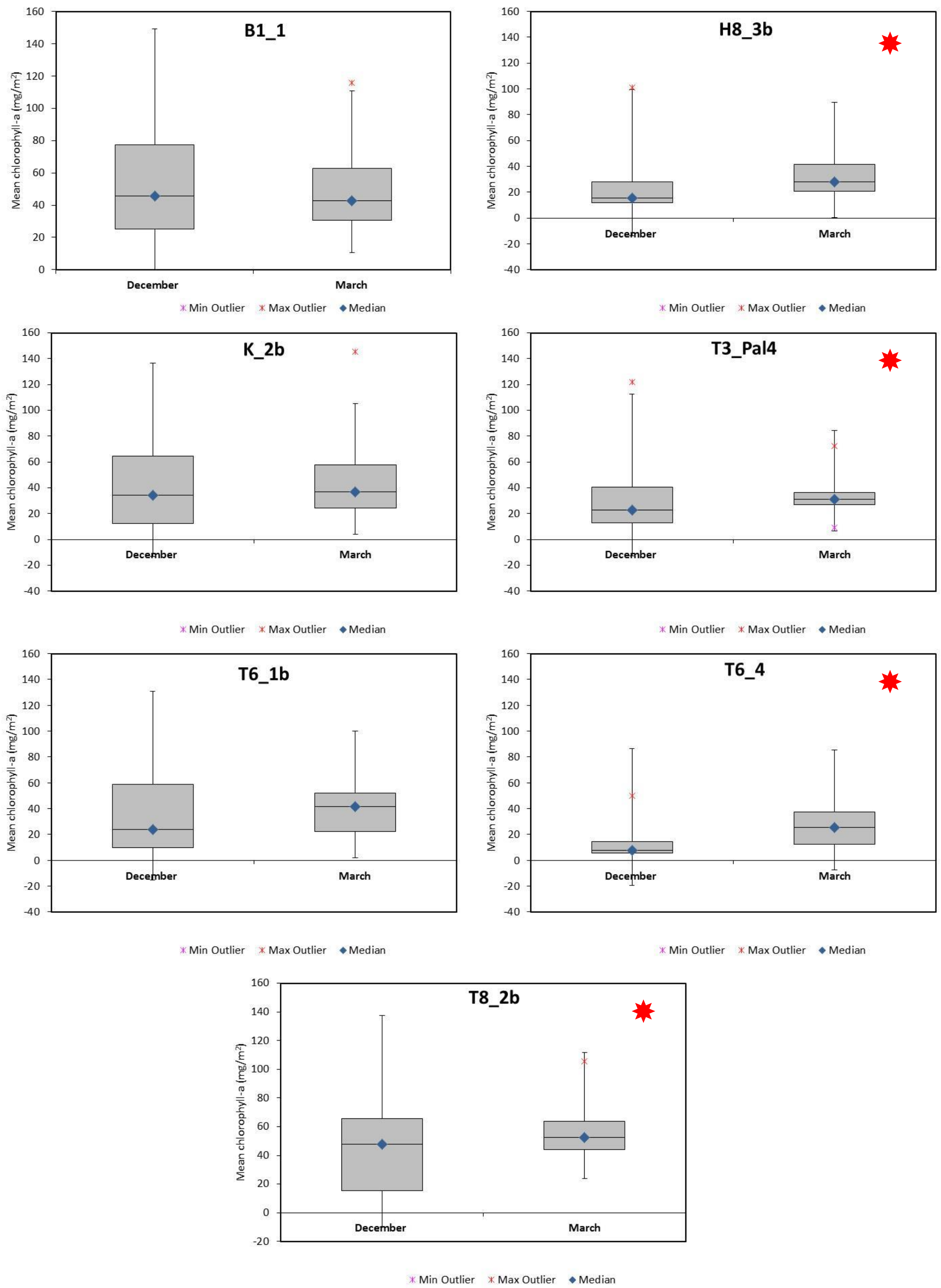


Figure 11.3 Box and whisker plots for the ecoseeps biomass data, measured as chlorophyll-a, comparing December against March data. Differences between the log(x+1) transformed data were significant at H8_3b, T3_Pal4, T6_4 and T8_2b (red stars).

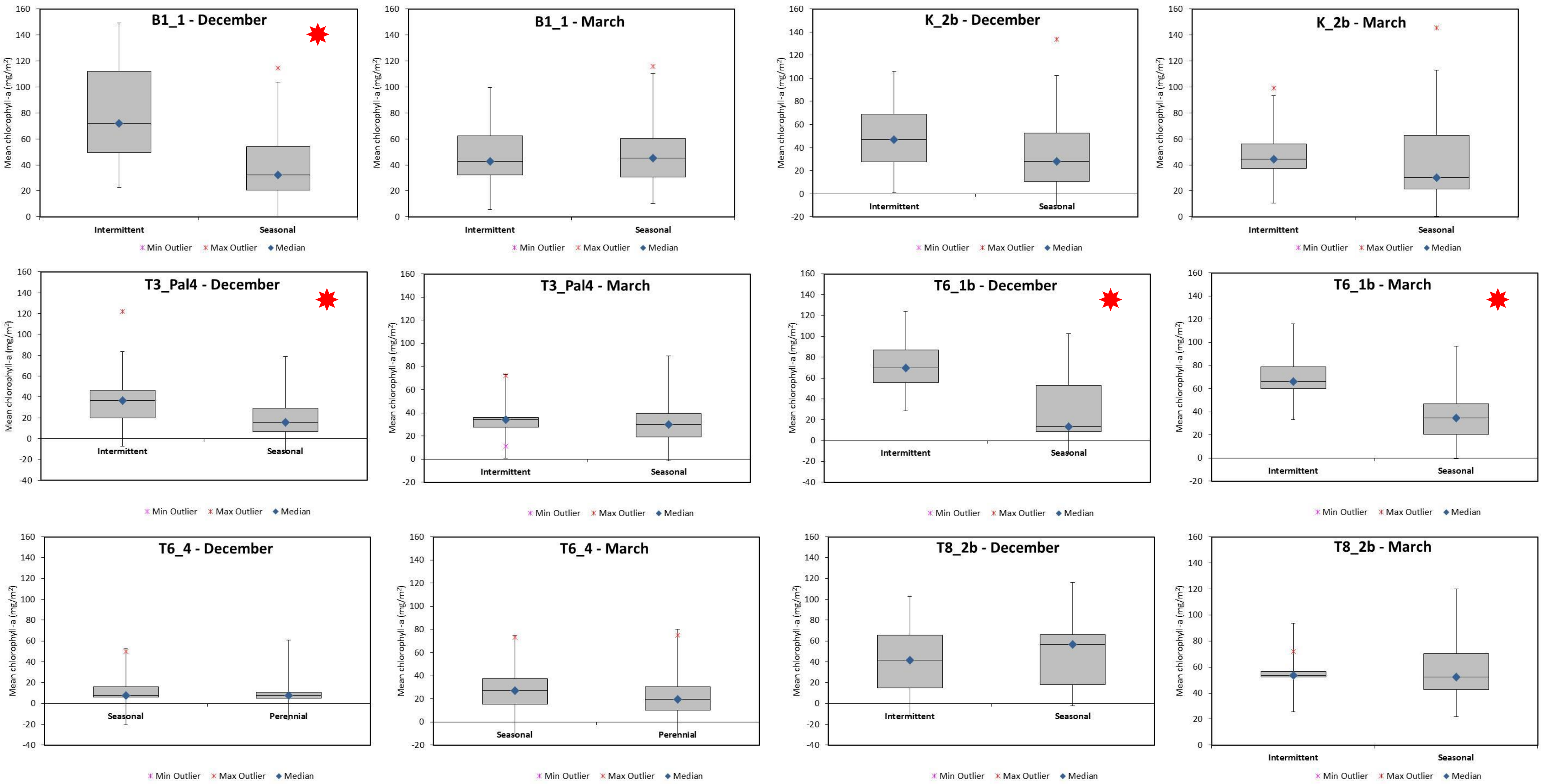


Figure 11.4 **Box and whisker plots showing comparisons between algal biomass measured as chlorophyll-*a* at ecoseep monitoring points with different surface soil hydroperiod classes, in December and March of each year of monitoring. Differences were significant only in December at B1_1, T3_Pal4 and T6_1b (red stars).**

11.3 Algal community composition

11.3.1 Ecochannels

11.3.1.1 Diversity

A cumulative total of 183 algal taxa was recorded in the ecochannels over EPM1 and EPM2. The Bacillariophyta or diatoms were the most diverse division at each site, followed by the Chlorophyta or green algae and Cyanophyta or blue-green algae in almost equal numbers (Table 11.1). Amongst the diatoms, the single celled taxa were always the most diverse, while the filamentous and single-celled forms were the most diverse amongst the green algae, and the filamentous forms the most diverse of the blue-green algae. A number of other algal divisions were represented in small numbers in the ecochannels – the Chrysophyta (golden-brown algae), Cryptophyta (cryptomonads), Dinophyta (dinoflagellates), Euglenophyta (euglenoids), Rhodophyta (red algae) and Tribophyta (yellow-green algae).

The most diverse sites were the Nuweberg ecochannels, T4_Pal1 and T4_Pal3, followed by the Boesmanskloof sites, T6_1a and T6_2a.

11.3.1.2 Temporal shifts in community composition

During the analysis of algal community composition data in 2012, the same results were obtained using both the detailed taxon cell densities and the less detailed dataset of algal division and growth form. This showed that the latter is as descriptive as the detailed taxonomic data, and sufficiently sensitive to change to be used as a surrogate for predicting spatial or temporal shifts in algal community composition. Thus, the analysis in 2013 was done using only the algal division and growth form data.

Table 11.1 Number of taxa within each algal division and growth form recorded in the ecochannels in the months of March and December in EPM1 and EPM2.

Division	Growth form	H8_3a	K_2a	K_5a	T4_Pal1	T4_Pal3	T6_1a	T6_2a	T8_2a
Bacillariophyta (diatoms)	Colonial		1						
	Filamentous	1			2	1			
	Colonial in gelatinous masses								
	Single cells	31	28	19	35	35	32	28	28
	Single or filamentous	1	1		1	1	3	2	3
Chlorophyta (green algae)	Colonial	3	3	3	4	2	3	5	3
	Filamentous	3	5	3	8	8	7	9	
	Colonial in gelatinous masses	2	1	1	1	1	1	1	
	Single cells	10	4	4	8	7	5	7	5
	Single or colonial	1							
	Single or filamentous		1		2		2	2	1
Cyanophyta (blue-green algae)	Filamentous	8	8	4	14	13	11	11	7
	Colonial in gelatinous masses	4	8	2	5	7	4	4	2
	Single cells	1	1	1		1	1	1	1
Chrysophyta (golden-brown algae)	Colonial								
Cryptophyta (cryptomonads)	Single cells								
Dinophyta (dinoflagellates)	Single cells	1							1
Euglenophyta (euglenoids)	Single cells	2	2		1	3	3	3	3
Rhodophyta (red algae)	Filamentous			1			1		
Tribophyta (yellow-green algae)	Single cells		1	1	1	1	1	1	1
Total		**68**	**64**	**39**	**82**	**80**	**74**	**74**	**55**

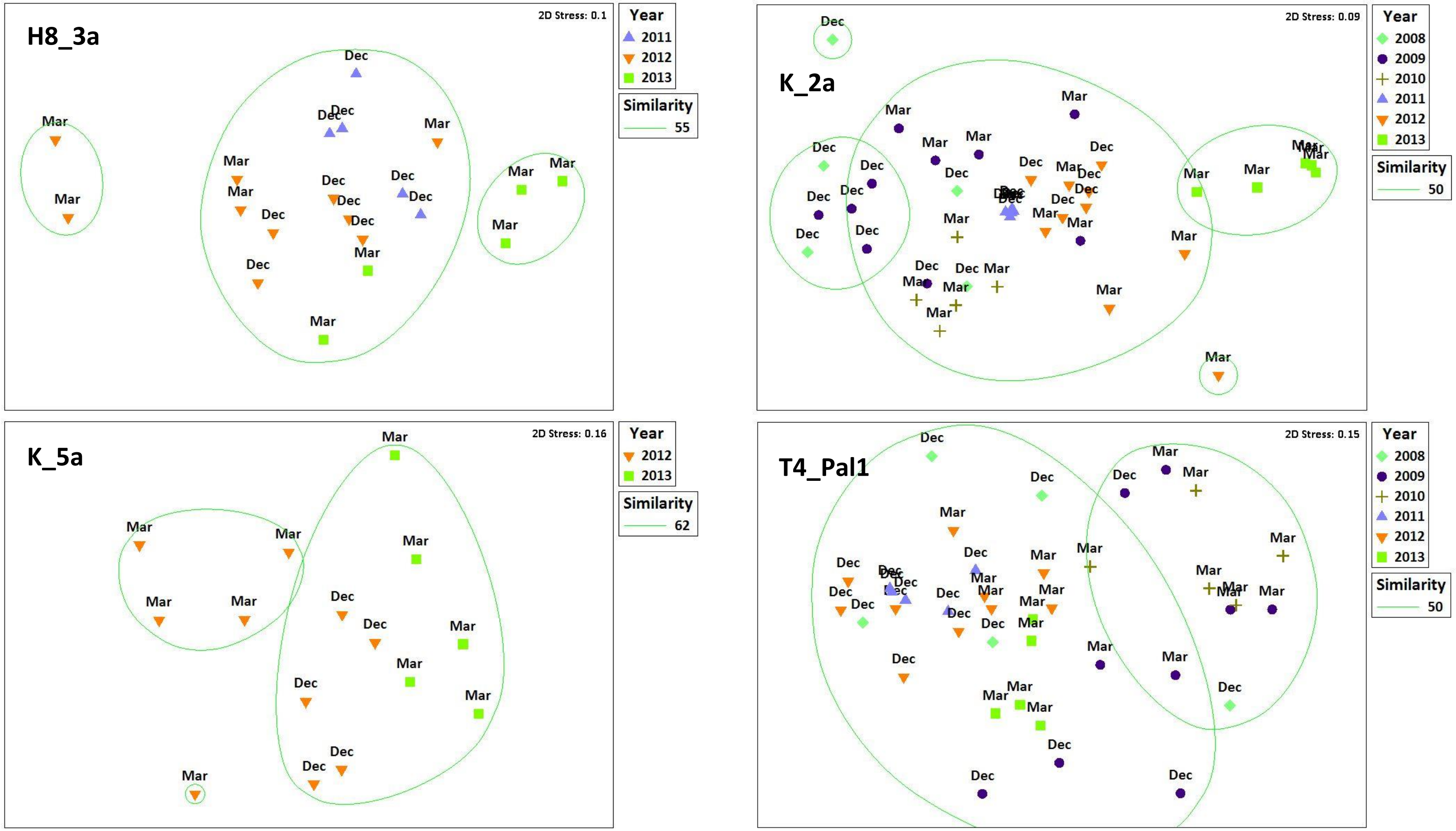


Figure 11.5 MDS ordination plots using algal cell density data at the level of algal division and grwth form, showing seasonality and inter-annual variation in algal community composition at the ecochannels. The circles around groups of samples are based on Bray-Curtis similarities between samples.

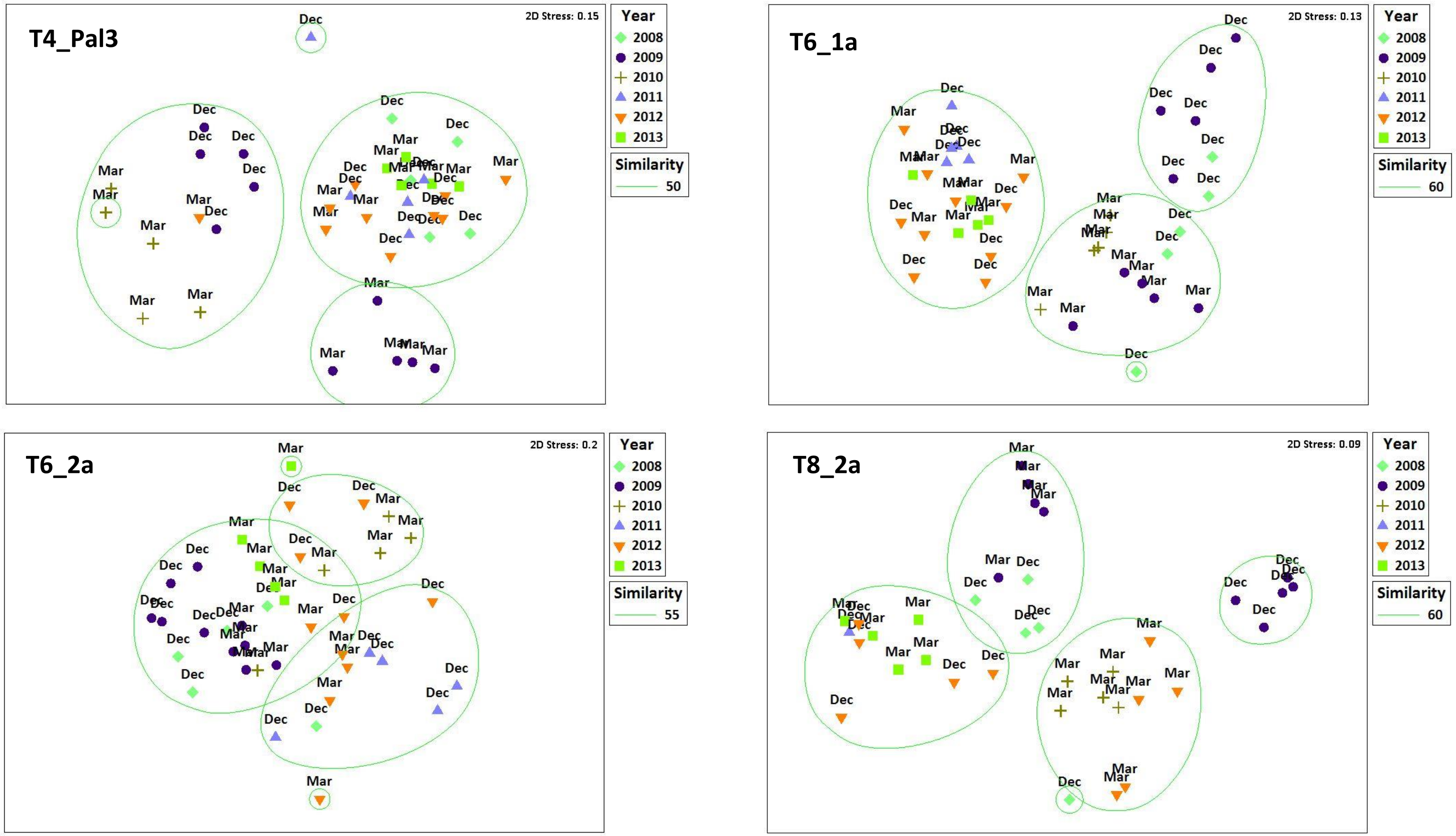


Figure 11.5 continued

The algal communities in the ecochannels showed distinct seasonal and inter-annual differences (Figure 11.5), leading to dissimilarities between algal communities sampled in the same month of each year. There was a tendency at some sites for communities sampled in December and March of the same successional cycle of spring (December) through to end of summer (March) to be more similar to each other than communities sampled in the same month in years. This supports the notion that algal communities die off in winter and are reset in spring (see Figure 11.1). This was the case for instance in the 2009/2010 season at T4_Pal3 and T6_2a, and at K_5a in the 2012/2013 season (Figure 11.5).

It was evident, therefore, that the algal communities that “re-started” in spring in the TMG ecochannels were quite different from those that were there during the previous cycle. Possible links between the various components of the discharge regime at each ecochannel and algal biomass and community composition should be investigated in the next phase of monitoring. These may explain the inter-annual variability.

At most of the sites, the 2008/2009 communities were distinct from the 2011/2012/2013 communities. This was particularly so at T4_Pal3 and T6_1a (Figure 11.5). This may be as a result of the higher rainfall, and so discharge, in 2008 and 2009, compared with 2010 and 2011. Rainfall in 2012 was similar to the the earlier years, so it could be expected that the algal communities will shift back to the “wetter”state, similar to 2008/2009. This can be seen at T6_2a, where the March 2013 communities lie between the 2009 and 2012 communities (Figure 11.5).

Seasonal patterns in algal cell densities of the more dominant algal divisions and growth forms differed considerably between sites (Table 11.2). An examination of the algal groups that defined the late spring (December) *versus* summer (March) communities produced the following general results:

- Blue-green colonial algae in gelatinous masses increased from December to March, while the green algae of the same form showed the opposite trend;
- All single-celled forms of algae – blue-greens, greens and diatoms – generally increased in March in relation to December;
- Filamentous blue-greens were generally more numerous in March than in December, while filamentous green algae did not show marked differences between months and were not often a distinguishing group;
- Colonial green algae were more abundant in March than in December.

Table 11.2 Results of the SIMPER analysis of algal groups distinguishing months across all years of sampling.

		December	March	% Contribution	Cumulative contribution
		Average abundance	Average abundance		
H8_3a	BG_filamentous	4827.56	33659.89	42.59	42.59
	D_single	20394.54	22935.89	14.79	57.37
	BG_gelatinous masses	23102.70	29132.12	14.02	71.39
	C_colonial	18152.21	19497.85	8.04	79.44
K_2a	D_single	19759.73	61314.77	24.86	24.86
	BG_gelatinous masses	10123.55	27000.55	17.41	42.27
	C_colonial	12756.18	25178.55	15.5	57.77
	C_single	7575.25	23161.97	13.7	71.47
	BG_filamentous	4183.6	10046.55	11.91	83.38
K_5a	C_colonial	37117.42	15328.28	23.32	23.32
	BG_single	10082.1	19087.39	18.62	41.94
	C_single	60471.51	46881.91	16.51	58.45
	BG_gelatinous masses	31655.36	27848.33	13.37	71.82
	D_single	51980.56	36764.29	12.81	84.63
T4_Pal1	BG_gelatinous masses	12270.75	4185.38	21.18	21.18
	C_colonial	10650.08	5875.85	15.26	36.44
	C_filamentous	2166.83	6340.53	14.62	51.06
	C_single	12695.44	5038.7	13.76	64.82
	C_gelatinous masses	1688.01	1412.67	13.69	78.51
T4_Pal3	T_single	619.52	9852.22	25.32	25.32
	BG_filamentous	12874.13	7958.61	15.11	40.43
	BG_gelatinous masses	12495.58	12576.89	14.42	54.85
	C_gelatinous masses	4524.7	0	10.17	65.02
	C_filamentous	3693.72	7284.57	9.38	74.4
	C_colonial	12893.82	12701.88	8.16	82.56
T6_1a	BG_filamentous	9850.21	20440.46	21.9	21.9
	C_single	8588.82	18699.82	15.66	37.56
	C_colonial	13583.49	21557.62	15.1	52.67
	D_single	18736.56	21374.59	9.37	62.03
	C_gelatinous masses	2500.82	1618.15	7.98	70.01
	C_filamentous	4357.27	4016.21	6.1	76.11
	BG_gelatinous masses	14299.21	15058.33	5.53	81.64
T6_2a	C_single	9518.81	7588.5	22.35	22.35
	BG_filamentous	3077.17	6364.62	18.56	40.91
	C_colonial	7825.04	12075.8	14.74	55.65
	BG_gelatinous masses	7282.28	5394.02	12.57	68.23

		December	March	%	Cumulative
	D_single	7019.57	8416.97	10.87	79.1
T8_2a	C_single	14566.52	17970.92	42.14	42.14
	C_colonial	15753.09	11733.21	16.2	58.34
	BG_gelatinous masses	12409.93	8459.01	14.56	72.9
	BG_filamentous	4005.11	6916.3	11.93	84.83

Algal communities have been found to be highly variable both within and between seasons in the foothill rivers of the south-western Cape, and especially so during the winter and spring months (Ewart-Smith and King, 2012). Thus, the "snapshot" view of algal community composition gained by sampling in December may be inadequate to establish baseline conditions at this time (see Section 11.4: Community Persistence for more on this). Ideally, algal sampling should be done monthly or once per season, however, as this is unlikely to occur in the TMG Monitoring Programme due to financial constraints, sampling could be done in March only.

11.3.1.3 Links with discharge regime

It is the relationships between algal community composition and the discharge regime that is of greatest interest for the TMG Monitoring Project. The seasonal shifts in algal division and growth forms observed at the ecochannels suggest that a conceptual model showing the response of the algal communities to components of the discharge regime (such as summer baseflow and the timing and size of floods) could be developed once the discharge datasets are robust for each ecochannel. Such a model has been presented in Ewart-Smith and King (2012) for the foothill rivers of the south-western Cape, and the TMG data may fit this model. The algal community response to reduced summer baseflows, which may result from aquifer drawdown, can then be explored.

11.3.2 Ecoseeps

11.3.2.1 Diversity

A cumulative total of 217 algal taxa was recorded in the ecoseeps. The algal communities were most diverse at B1_1, H8_3b, T3_Pal4 and T6_1b (see Table 11.3). Single cell diatoms and single cell green algae were the most diverse at all sites, followed by the filamentous blue-green algae and filamentous green algae. These groups occurred at all sites (see Table 11.3). Wetland algal communities have been reported elsewhere to be dominated by diatoms, green algae and blue-green algae (e.g. Goldsborough and Robinson, 1996). The most abundant taxa across all of the TMG ecoseeps were *Sphaerocystis* sp., a colonial green alga, and *Chroococcus* sp., a benthic blue-green alga growing as a colony, comprising only a few cells in a gelatinous mass.

Table 11.3 Number of taxa within each algal division and growth form recorded in the ecoseeps in EPM2.

Division	Growth form	B1_1	H8_3b	K_2b	K_5b	K_6	T3_Pal4	T6_1b	T6_4	T8_2b
Bacillariophyta (diatoms)	Colonial	1			1		1	1		
	Filamentous		1					2	1	
	Colonial in gelatinous masses							1		
	Single cells	64	52	42	45	43	58	45	43	55
	Single or filamentous	3	2	3	1	1	1	2	2	3
Chlorophyta (green algae)	Colonial	3	3	3	4	4	5	4	3	2
	Filamentous	7	8	3	8	1	9	10	7	6
	Colonial in gelatinous masses	1	4	3	1	3	2	4	4	1
	Single cells	8	12	14	6	11	9	17	9	11
	Single or colonial	1		1	1	1		1		1
	Single or filamentous	1							1	
Chrysophyta (golden algae)	Colonial in gelatinous masses	1							1	
Cryptophyta	Single								1	
Cyanophyta (blue-green algae)	Filamentous	6	9	4	4	3	9	9	9	8
	Colonial in gelatinous masses	4	6	7	3	3	7	5	5	3
	Single cells	1	1						1	
Euglenophyta (euglenoids)	Single cells	2	2	4	2	2	5	4	6	4
Dinophyta (dinoflagellates)	Single cells		1							
Tribophyta (yellow-green algae)	Colonial	1								
	Single cells	2	2	1	1	1	2	2	2	1
Total		**106**	**103**	**85**	**77**	**73**	**108**	**107**	**95**	**95**

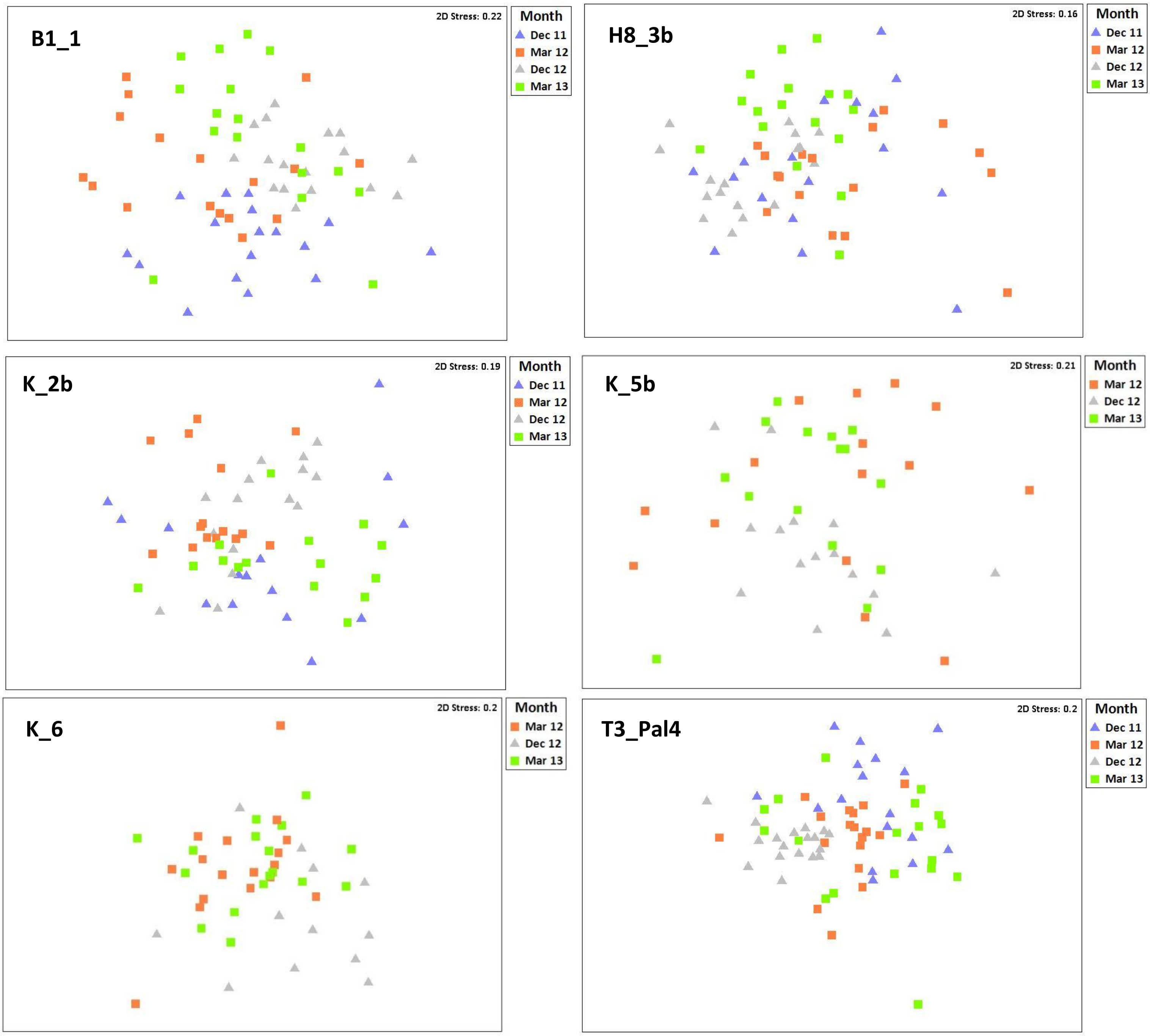


Figure 11.6 MDS ordination plots using detailed taxon cell density data, showing clear seasonality in algal community composition at most ecoseeps.

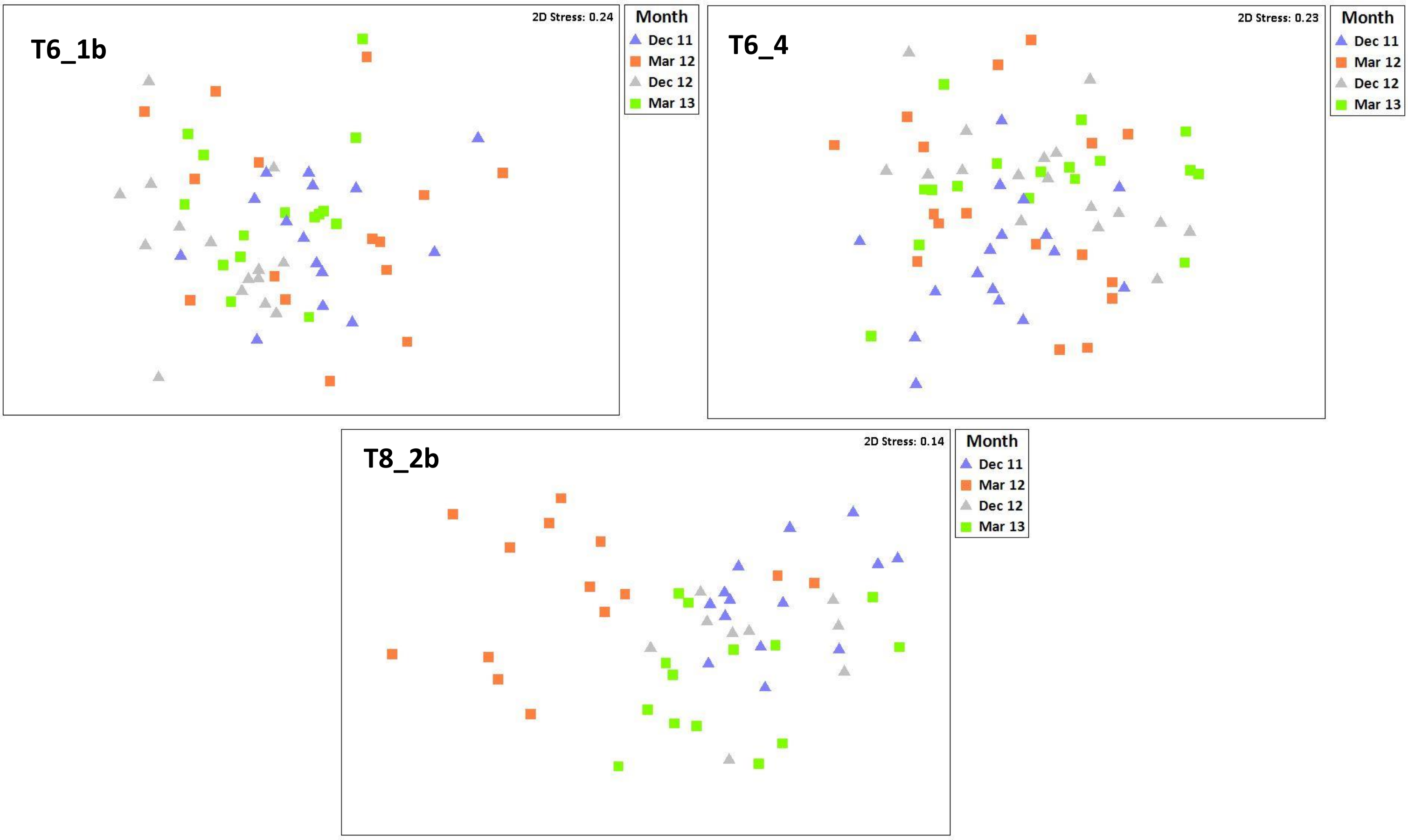


Figure 11.6 continued

11.3.2.2 Temporal shifts in community composition

Pairwise comparisons between sampling months over the two years of monitoring showed that there were significant temporal differences between algal communities at most ecoseeps (Figure 11.6). There were some exceptions to this – for instance, both K_5b and K_6 showed no differentiation between March 2012 and March 2013. There were also few significant temporal differences at T6_1b, despite a significant increase in algal biomass recorded at this site in March of each year. This suggests that all algal groups increased in abundance from December to March in similar proportions.

11.3.2.3 Links with soil moisture regime

Algal community composition in wetlands is likely to be strongly influenced by wetland hydrodynamics or hydroperiod, i.e. cycles of inundation, saturation and desiccation. In the Florida Everglades, for instance, wetlands subject to frequent desiccation are dominated by blue-green algal mats, while diatoms and green algae dominated those that are seasonally inundated and single cell green algae occurred only in the wetlands with permanent standing water (Browder *et al*. (1994) cited in Goldsborough and Robinson, 1996).

Two-way (months and hydroperiod) analysis of simarities between algal communities sampled from monitoring points with different soil hydroperiod (in the top 10 cm) revealed that there were often significant differences. These are discussed by site, along with the results of the DistLM analysis of soil moisture variables and algal community composition.

Ecoseep B1_1: There were significant differences between communities sampled at intermittently saturated points, and both the seasonally and perennially saturated points. There were no differences between the latter two. The algal groups characterising the three hydroperiod classes are presented in Table 11.4.

Table 11.4 Results of the SIMPER analysis of algal groups distinguishing soil hydroperiod in the top 10 cm across all sampling dates at B1_1.

	Intermittently saturated	Perennially saturated	% Contribution	Cumulative contribution
	Average abundance	Average abundance		
BG_gelatinous masses	43248.39	231388.7	41.4	41.4
C_colonial	59829.41	137279.1	19.09	60.49
D_single	136389.8	113215.3	14.6	75.09
T_single	1074.51	17234.06	5.05	80.14
BG_filamentous	3363.36	19541.59	4.45	84.59
C_filamentous	27557.66	13817.99	4.24	88.83
	Intermittently saturated	**Seasonally saturated**	**% Contribution**	**Cumulative contribution**
	Average abundance	**Average abundance**		
BG_gelatinous masses	43248.39	73179.82	21.89	21.89
D_single	136389.8	100027.1	21.89	43.78
C_colonial	59829.41	92261.14	21.28	65.06
C_filamentous	27557.66	28871.48	7.17	72.23
C_single	19379.55	17191.02	7.16	79.39

A more detailed examination of the soil moisture variables calculated for B1_1 (see Section 7) and how these may influence algal community composition revealed that the wet and dry season minimum soil moisture content ($L0\_W_{min}$, $L0\_D_{min}$) were the most significant variables in this regard. These two variables explained 16% of the variation between communities, and separated the algal communities found at the intermittently saturated points from those at either the perennially or seasonally saturated monitoring points (Figure 11.7). Most of the soil moisture variables were significant drivers, with the exception of the variation in soil moisture in both the dry and wet seasons. Thus, soil moisture minima, maxima, and means in the top 10 cm in both seasons were important factors at this site.

Ecoseep H8_3b: There were no significant differences between hydroperiod classes, which may be due to there being very few points not seasonally saturated. The only soil moisture variable that was significantly affecting the spread of algal communities across the seep was the dry season minimum ($L0\_D_{min}$), explaining only 3% of the variation. There must be other more important drivers of algal community composition at this site.

Ecoseep K_2b: There were no significant differences between hydroperiod classes. The vegetation at this ecoseep showed poor links with soil moisture (see Section 9), indicating that the biotic communities are influenced by environmental or biotic factors other than soil moisture. The influence of a recent (June 2010) fire on community composition may be greater than that of soil moisture. Fire can influence nutrient cycling in and water retention properties of the soil, particularly in the top 5 cm (e.g. deBano and Conrad, 1978, Riddell *et al*., 2012; Strydom *et al*., 2012), and thus would probably have an impact on algal dynamics.

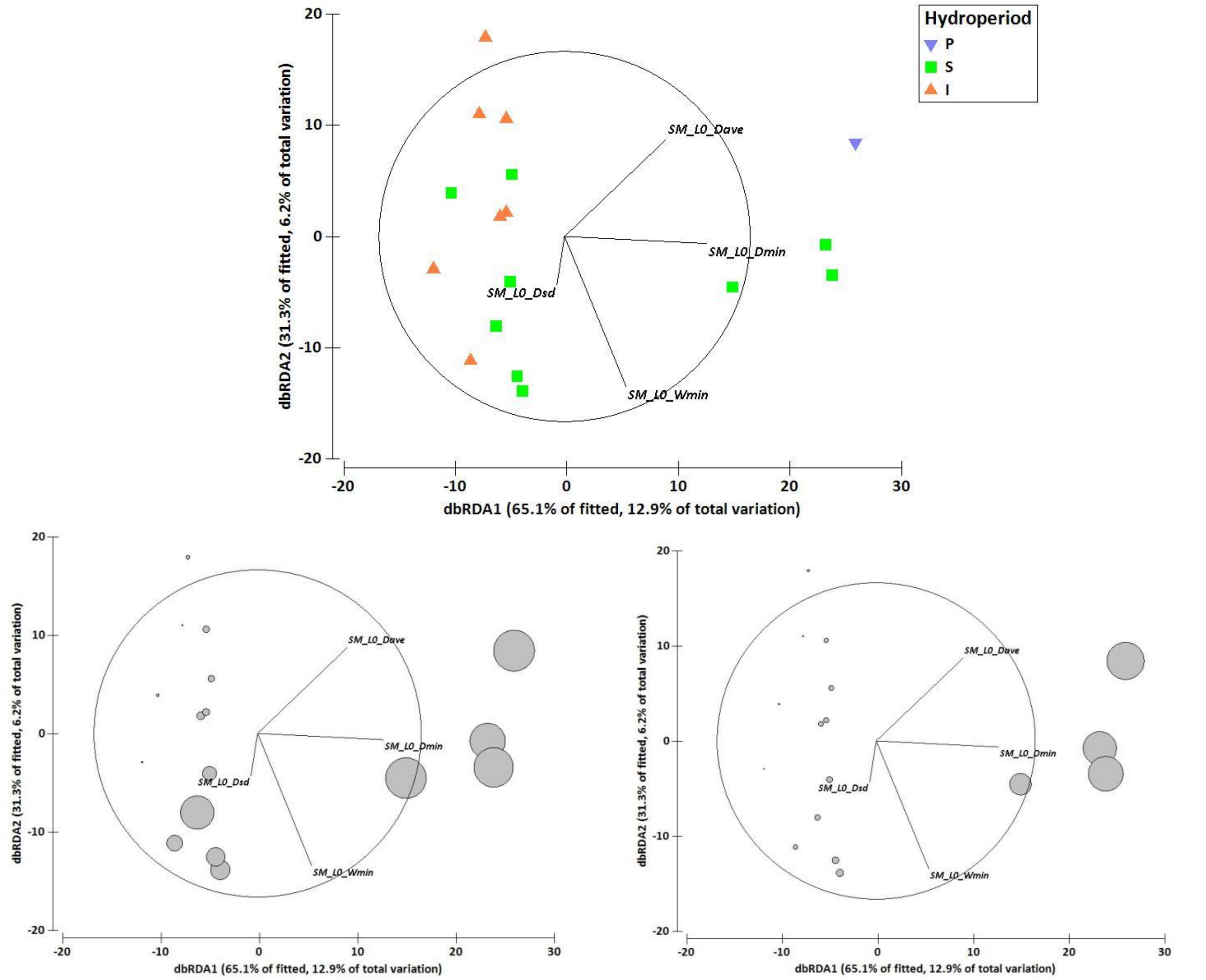


Figure 11.7 dbRDA ordination of algal groups at B1_1 (top) with hydroperiod classes shown as symbols. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plots (bottom) show the distribution of plots relative to the wet season minimum (left) and dry season minimum (right). The larger the bubble, the greater the soil moisture content.

However, the analysis revealed that the dry season average ($L0\_D_{ave}$), minimum ($L0\_D_{min}$), and maximum ($L0\_D_{max}$) were significant ($p < 0.05$) drivers of dissimilarity between algal communities sampled across K_2b (Figure 11.8). The dry season soil moisture regime was thus a critical factor at this site.

Ecoseep K_5b: The seasonally saturated algal communities were significantly different to the perennially saturated communities. The algal groups characterising the three hydroperiod classes are presented in Table 11.5.

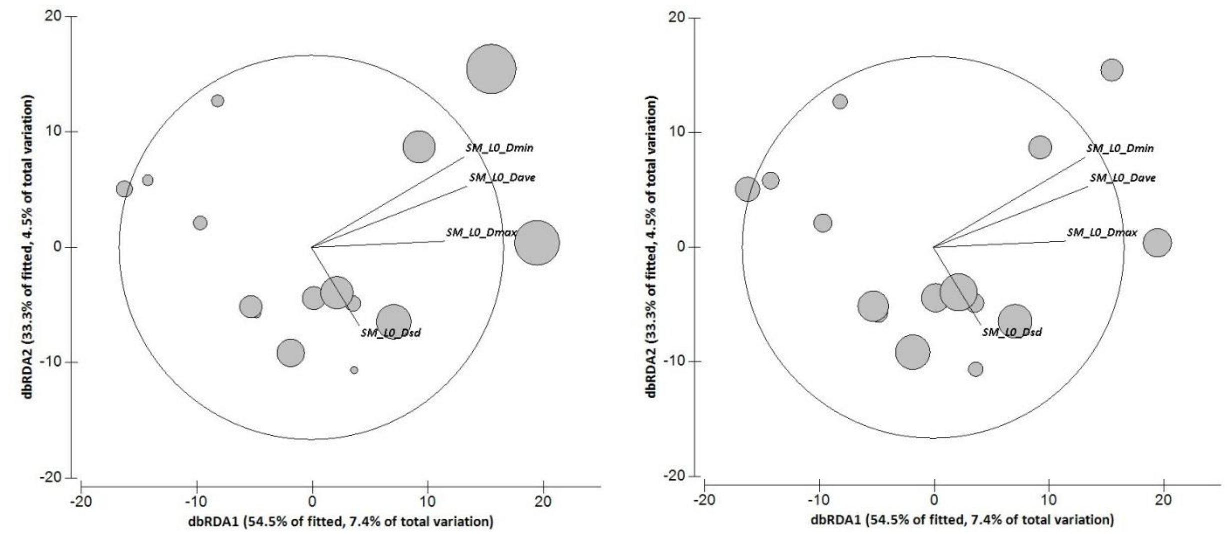


Figure 11.8 **dbRDA ordination of algal groups at K_2b, with bubble plots. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plots show the distribution of plots relative to dry season mean (left) and dry season standard deviation (right). The larger the bubble, the greater the soil moisture content or variability.**

Table 11.5 **Results of the SIMPER analysis of algal groups distinguishing soil hydroperiod in the top 10 cm across all sampling dates at K_5b.**

	Seasonally saturated	Perennially saturated	% Contribution	Cumulative contribution
	Average abundance	Average abundance		
D_single	184691.3	327115.3	27.54	27.54
BG_gelatinous masses	68322.89	107743	20.72	48.26
C_colonial	114670.9	140190.7	15.96	64.22
D_single or filamentous	0	82394.58	12.29	76.52
C_filamentous	15458.86	52110.91	8.88	85.39

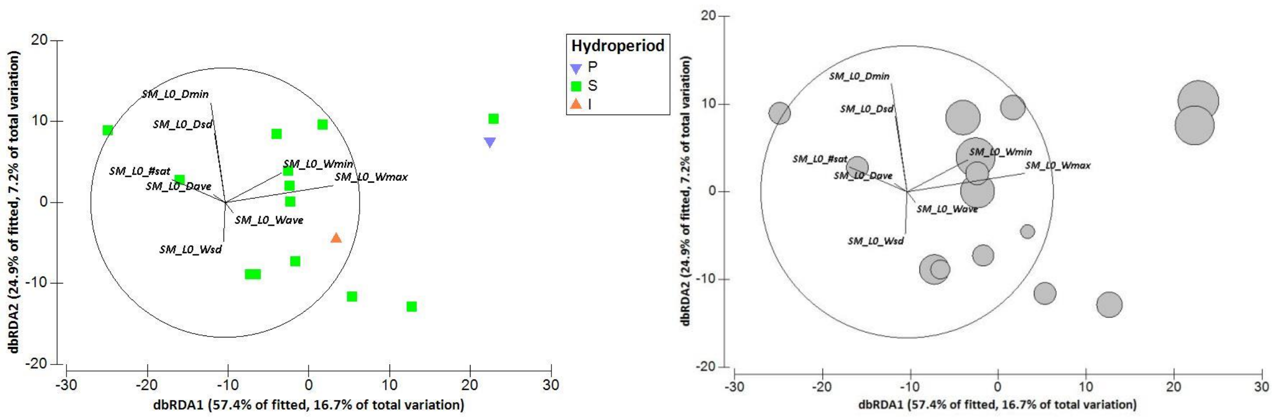


Figure 11.9 **dbRDA ordination of algal groups at K_5b (left) with hydroperiod classes shown as symbols. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plot (right) shows the distribution of plots relative to the wet season maximum ($L0\_W_{max}$). The larger the bubble, the greater the soil moisture content.**

The wet season and dry season maximum ($L0\_W_{max}$, $L0\_D_{max}$) soil moisture content were significant drivers of dissimilarity between algal communities, collectively explaining almost 10% of the variation. Thus, the upper extremes of the soil moisture regime were critical factors at K_5b.

Ecoseep K_6: There were no significant differences between algal communities sampled from points with different hydroperiod classes. Furthermore, none of the soil moisture variables were found to be significant drivers of dissimilarity between the algal communities.

Ecoseep T3_Pal4: There were significant differences between algal communities sampled at intermittently and seasonally saturated monitoring points. The algal groups characterising the three hydroperiod classes are presented in Table 11.6.

Table 11.6 Results of the SIMPER analysis of algal groups distinguishing soil hydroperiod in the top 10 cm across all sampling dates at T3_Pal4.

	Intermittently saturated	Seasonally saturated	% Contribution	Cumulative contribution
	Average abundance	Average abundance		
D_single	135412.9	74301	21.87	21.87
BG_gelatinous masses	93295.81	69241.1	17.77	39.64
C_colonial	96644.27	87162.09	15.62	55.26
C_single	33136.95	15688.58	9.33	64.59
C_filamentous	30728.77	6716.49	9.16	73.75
BG_filamentous	27739.15	16792.94	8.36	82.11

Most of the set of soil moisture variables were found to be significant drivers of dissimilarity between the algal communities, with the exception of the wet season variation ($L0\_W_{sd}$) and the wet season maximum ($L0\_W_{max}$). The most significant variable was the duration of saturation at each monitoring point, followed by the wet and dry season minima ($L0\_W_{min}$, $L0\_D_{min}$) (Figure 11.10). Collectively, axis 1 of the dbRDA explained 15% of the variation between communities.

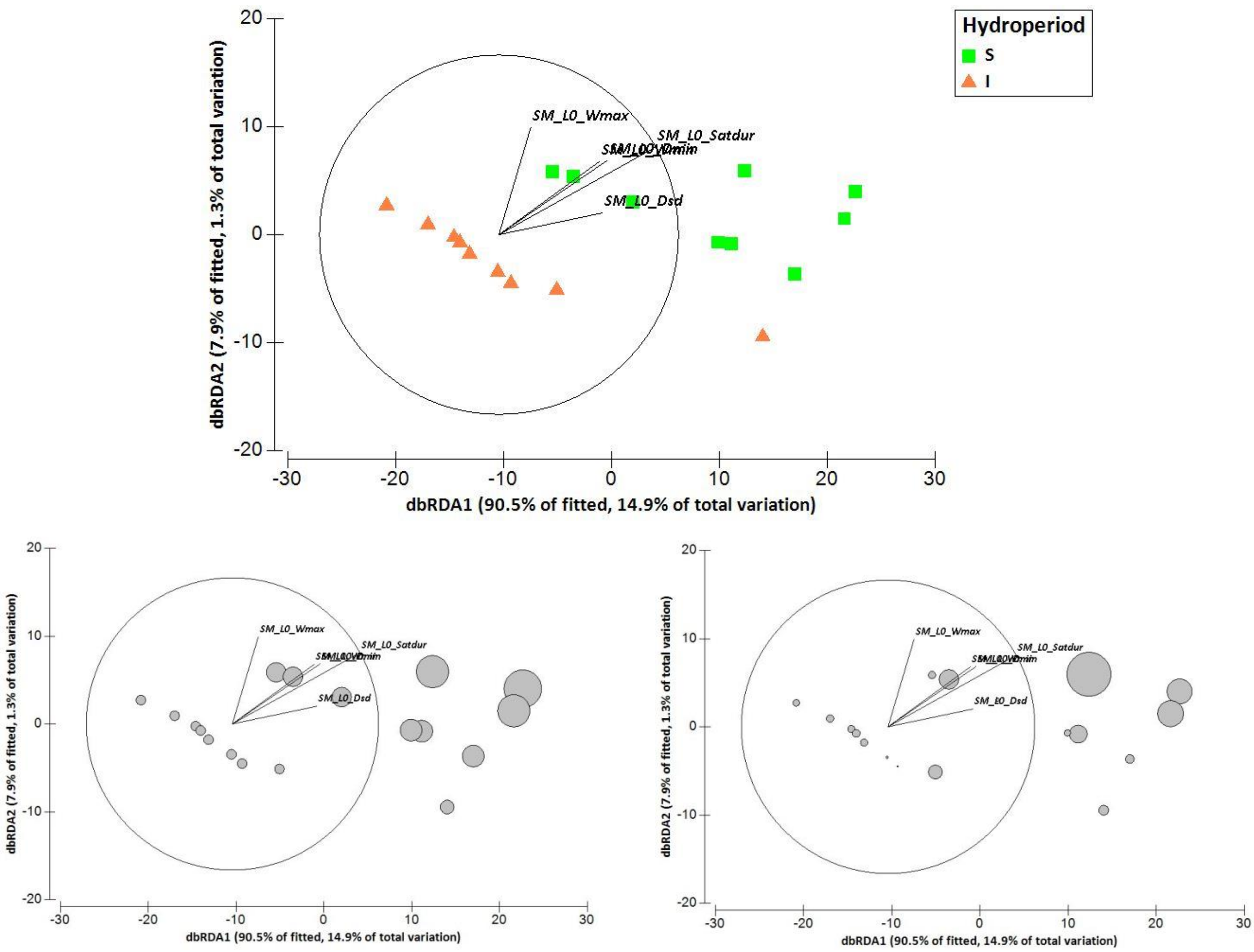


Figure 11.10 dbRDA ordination of algal groups at T3_Pal4 (top) with hydroperiod classes shown as symbols. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plots (bottom) show the distribution of plots relative to the duration of saturation (left) and dry season minimum (right). The larger the bubble, the greater the soil moisture content.

Ecoseep T6_1b: No significant differences were found between hydroperiod classes at this sites, however the full list of soil moisture variabes used in the analysis were found to be significant ($p < 0.05$) drivers of dissimilarity between the algal communities. The most significant was the dry season minimum ($L0\_D_{min}$) followed by the dry season maximum ($L0\_D_{max}$) and the wet season minimum ($L0\_W_{min}$) (Figure 11.11). Collectively, these three variables explained 17% of the variation between communities.

Ecoseep T6_4: No significant differences were found between hydroperiod classes at this site, however most of the soil moisture variables were significant ($p < 0.05$) drivers of dissimilarity, with the exception of the variation in soil moisture in both the wet and dry seasons (Figure 11.12). The most significant variables were the dry season mean ($L0\_D_{ave}$), dry season maximum ($L0\_D_{max}$) and the dry season minimum ($L0\_D_{min}$). As at T6_1b, the dry season soil moisture regime was more important in determining dissimilarities in algal community composition between monitoring points than the wet season regime.

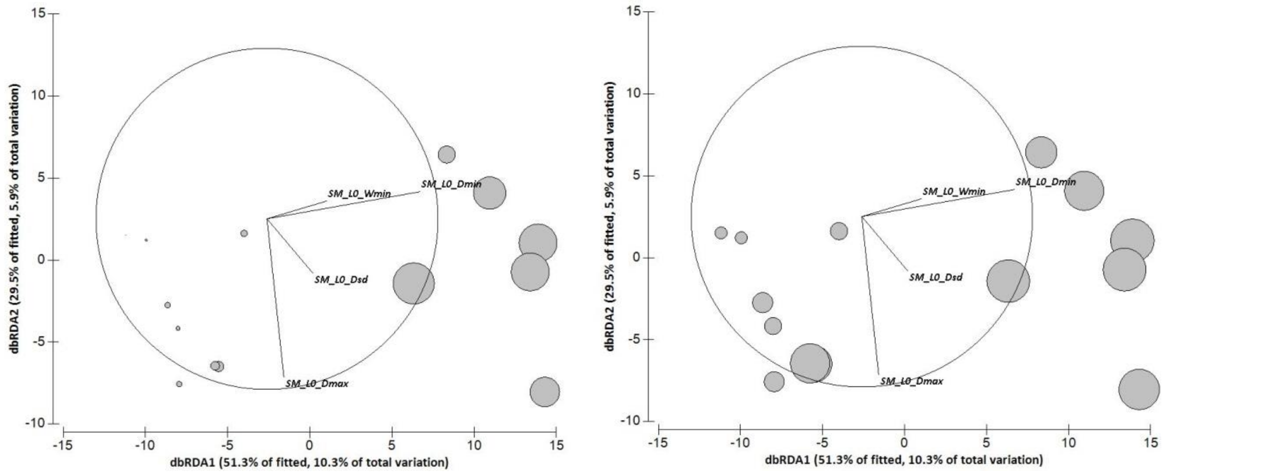


Figure 11.11 dbRDA ordination of algal groups at T6_1b, with bubble plots. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plots show the distribution of plots relative to dry season minimum (left) and dry season maximum (right). The larger the bubble, the greater the soil moisture content.

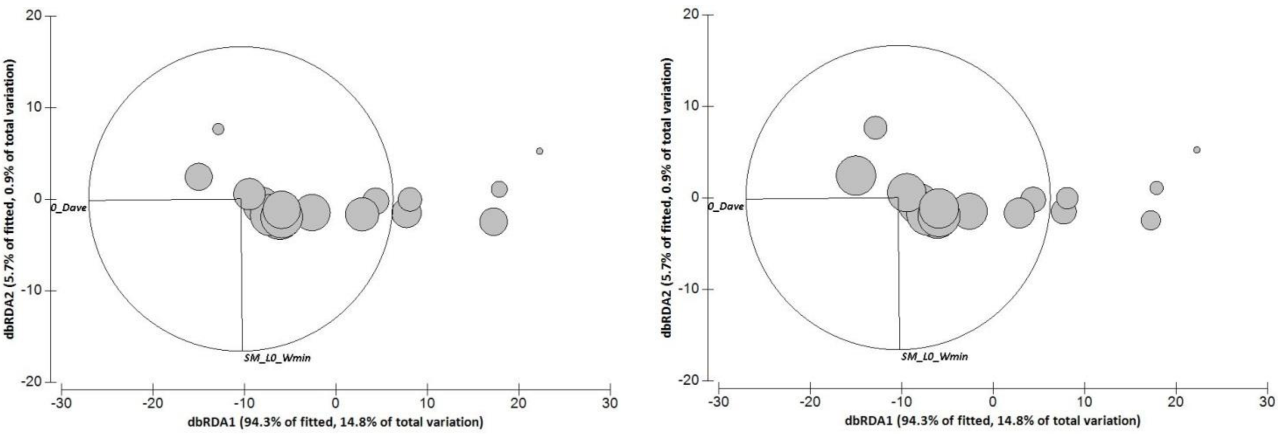


Figure 11.12 dbRDA ordination of algal groups at T6_4, with bubble plots. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plots show the distribution of plots relative to dry season mean (left) and dry season maximum (right). The larger the bubble, the greater the soil moisture content.

Ecoseep T8_2b: The seasonally saturated points supported an algal community that was distinct from the perennially saturated communities. The algal groups that made these communities distinct from another are presented in Table 11.7.

Table 11.7 Results of the SIMPER analysis of algal groups distinguishing soil hydroperiod in the top 10 cm across all sampling dates at T8_2b.

	Seasonally saturated	Perennially saturated	% Contribution	Cumulative contribution
	Average abundance	Average abundance		
E_single	20833.17	160625.1	27.05	27.05
D_single	124317.7	223404.9	20.99	48.05
BG_gelatinous masses	77158.87	139473.4	17.27	65.32
C_colonial	101466.7	124730.7	11.91	77.23
C_single	14709.31	46853.61	11.23	88.46

Most of the soil moisture variables were found to be significant in terms of driving the dissimilarity between algal communities at different monitoring points, with the exception of the wet and dry season variation in soil moisture. The most significant variable was found to be the dry season mean (L0_D_{ave}), followed by the dry season minimum (L0_D_{min}) and the duration of saturation (L0_Sat_{dur}). Once again, the dry season soil moisture regime was found to be more important in determining algal community composition than the wet season regime.

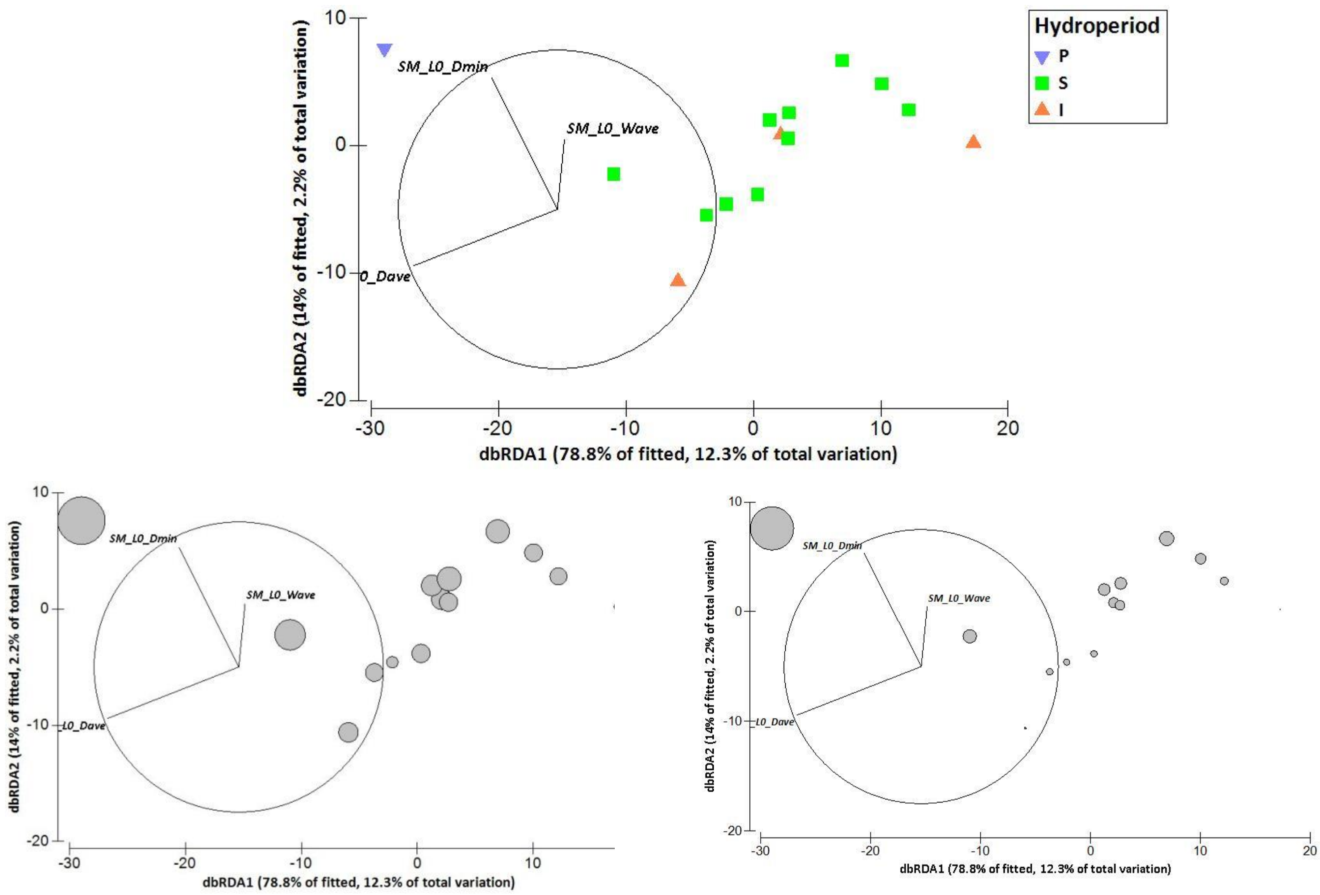


Figure 11.13 dbRDA ordination of algal groups at T8_2b (top) with hydroperiod classes shown as symbols. The vectors show the Spearman correlation between soil moisture variables and dbRDA axes 1 and 2. The bubble plots (bottom) show the distribution of plots relative to the dry season mean (left) and dry season minimum (right). The larger the bubble, the greater the soil moisture content.

11.4 Algal community persistence

Year-on-year persistence values for the algal communities ranged from 48% to 92% for the ecochannels (Table 11.8) and from 57 to 84% for the ecoseeps (Table 11.9). These persistence values were similar to those calculated for the riverine macroinvertebrate communities (see Section 10). At most of the ecochannels, the highest persistence was between December 2011 and December 2012, and between March 2012 and March 2013, i.e. the most recent sampling occasions. There did not appear to be clear trend in terms of persistence in December versus March.

Not much can be concluded from the ecoseeps data as yet, as the comparisons were only between two years of data. There were significant ($p \leq 0.05$) differences between communities sampled from points with different soil hydroperiods in December, with a trend towards higher persistence with increasing duration of saturation. Algal community persistence is thus influenced more by the duration of saturation at this time of year than the variability in saturation, which is highest at the seasonally saturated points (see Section 7).

In March there were no significant differences in community persistence with soil hydroperiod (Table 11.9 and Figure 11.14). The onset of summer, i.e. the start of the dry season accrual of algae (see Figure 11.1), is variable temporally – this was seen in the soil moisture data, where in 2011 most of the seeps had started to dry out by December, but in 2012 the seeps remained wet into December. This may explain the variability or low persistence between successive December algal communities. By March, the communities are likely to be more stable, having accrued over the dry season with few fluctuations in soil moisture.

Over time, an improved understanding of natural turnover will be gained, and this can be compared against the impacted scenario after abstraction has commenced. However, it can be concluded for the ecoseeps, that inter-annual comparisons of the algal communities sampled in March are slightly more reliable indicators of year-on-year persistence.

Table 11.8 Year-on-year algal community persistence at the ecochannels, and over the full monitoring period (EPM1 and EPM2). Persistence is calculated as the average similarity between occasions, using Bray-Curtis similarity indices and presence-absence data. There is only one year of data for K_5a, and so an interannual comparison could not be made.

Site	Dec 2008 vs Dec 2009	Dec 2009 vs Dec 2011	Dec 2011 vs Dec 2012	Dec 2008 vs Dec 2012	March 2009 vs March 2010	March 2010 vs March 2012	March 2012 vs March 2013	March 2009 vs March 2013
H8_3a			74.2				69.6	
K_2a	78.2	76.4	88.9	**73.8**	66.1	66.2	67.4	**58.3**
K_5a							67.9	
T4_Pal1	69.4	75.0	90.9	**73.4**	91.6	78.7	85.7	**72.8**
T4_Pal3	68.3	65.8	81.5	**77.5**	75.3	71.3	90.5	**76.6**
T6_1a	62.8	66.4	80.0	**57.3**	57.2	61.6	83.8	**62.0**
T6_2a	73.9	66.0	76.7	**65.4**	70.4	73.4	76.3	**76.6**
T8_2a	47.5	57.1	92.0	**68.4**	75.4	72.9	70.8	**62.5**

Table 11.9 Year-on-year algal community persistence at the ecoseeps, and for intermittent, seasonal and perennial monitoring points in the top 10 cm of soil. Persistence is calculated as average similarity, using Bray-Curtis similarity indices and presence-absence data.

	Dec 2011 vs Dec 2012				March 2012 vs March 2013			
	Overall	Intermittent	Seasonal	Perennial	Overall	Intermittent	Seasonal	Perennial
B1_1	**63.1**	60.0	65.2	66.7 (only 1)	**57.7**	54.9	58.9	66.7 (only 1)
H8_3b	**65.9**	33.3 (only 1)	67.9		**63.6**	76.9 (only 1)	62.8	
K_2b	**67.4**	58.6	73.2		**69.3**	72.3	67.3	
K_5b					**71.3**	100 (only 1)	70.2	57.1 (only 1)
K_6					**74.7**	72.8	75	
T3_Pal4	**61.4**	53.3	68.5		**63.5**	67.4	60.8	
T6_1b	**68.7**	64.6	69.7		**73.4**	73.5	73.4	
T6_4	**71.0**		70.3	73.3	**70.0**		71.1	65
T8_2b	**83.8**	72.2	86.8	88.9 (only 1)	**70.2**	79.4	66.2	83.3 (only 1)

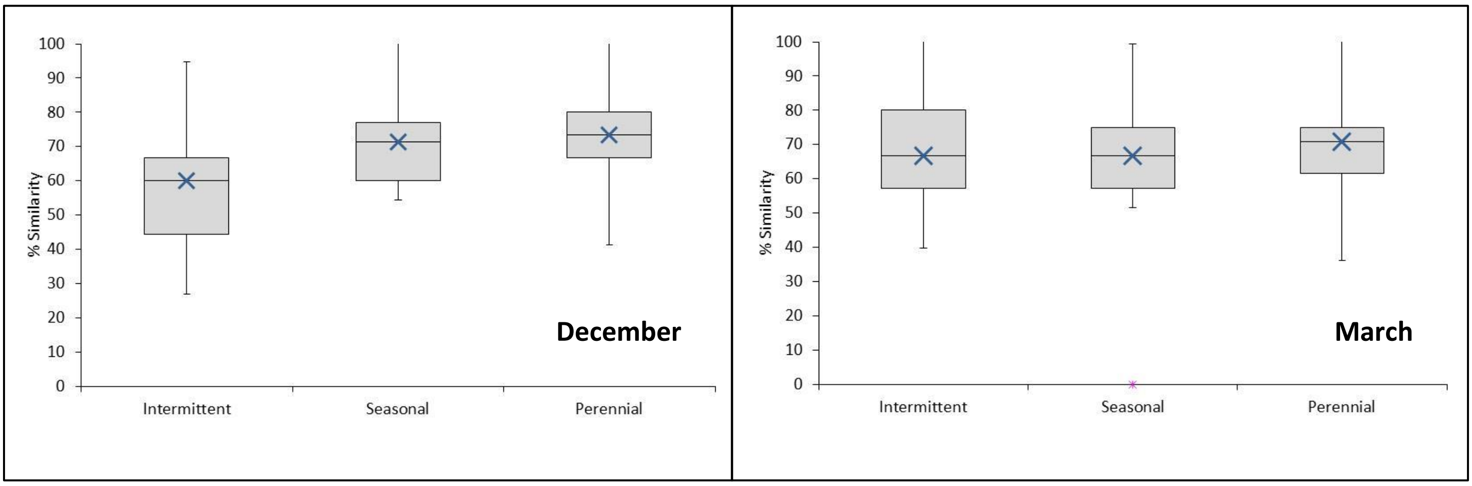


Figure 11.14 Box and whisker plots of % similarity between algal communities sampled in December (left) and March (right) of each year of monitoring. The comparison is between algal communities sampled at monitoring points with different soil hydroperiods – intermittently (< 40 days), seasonally (40 – 360 days) and perennially (>360 days) saturated.

11.5 Summary statements

There were marked seasonal and inter-annual shifts in algal community composition at both the ecochannels and the ecoseeps. Seasonality in the ecochannels was pursued further, and the following trends were noted:

- Blue-green colonial algae in gelatinous masses increased from December to March, while the green algae of the same form showed the opposite trend;
- All single-celled forms of algae – blue-greens, greens and diatoms – generally increased in March in relation to December;
- Filamentous blue-greens were generally more numerous in March than in December, while filamentous green algae did not show marked differences between months and were not often a distinguishing group;
- Colonial green algae were more abundant in March than in December.

For the ecoseeps, the TMG soil moisture dataset provided detailed information regarding temporal and spatial variations in soil saturation, which is an important component of wetland hydrodynamics. Spatial variation in algal community composition at the TMG ecoseeps was generally well explained by one or two of the soil moisture variables, primarily for the dry season. Furthermore, the regime means and extremes – minima and maxima – were more significant drivers of dissimilarity than the variation in soil moisture. Thus, the algal communities in inhabiting the seep sediments are more sensitive to how dry or how wet the soil becomes than to the variation over the season.

The following broad community responses were observed in relation to soil hydroperiod:

- Colonial and filamentous blue-green and green algae increased in abundance with increased duration of saturation, i.e. from intermittently to seasonally to perennially saturated soils.
- Single-celled diatoms and green algae were abundant in both perennially and intermittently saturated soils, but were less abundant in seasonally saturated soils, i.e. they tended to favour less variation in soil moisture.

A conceptual model of algal community responses to surface soil moisture content and the duration of soil saturation is shown in Figure 11.15. It is expected that reductions in soil moisture or the duration of saturation within ecoseep soils, such as may occur with reduced water supply as a result of drawdown of the Peninsula Aquifer, will have an impact on the algal communities inhabiting the seeps. A gradual drying out of the seeps will lead to a decrease in filamentous and colonial green and blue-green algae. An increase in fluctuations in soil moisture over the seasons will also reduce the number of single-celled diatoms and green algae in the seeps. A combination of drying out and decreased soil moisture variability, will lead to a decrease in most of the algal groups.

The relative proportions of algal divisions and growth forms thus appear to be good indicators for monitoring.

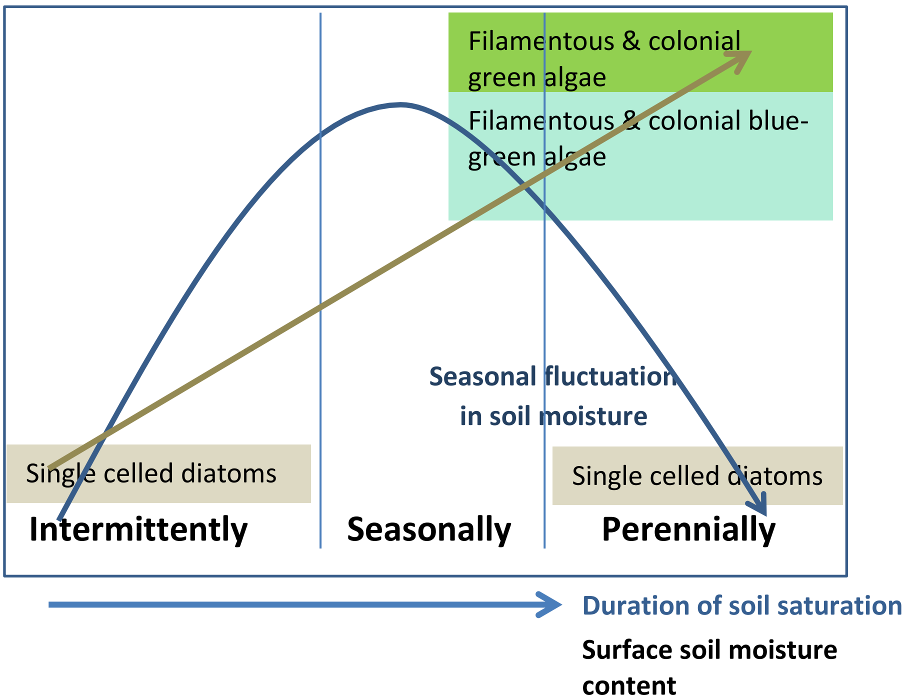


Figure 11.15 Conceptual model of ecoseep algal community response to shifts in surface soil moisture, duration of saturation and fluctuations in soil moisture.

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