South African Journal of Botany 97 (2015) 48–58

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

A one-year post-fire record of macronutrient cycling in a mountain sandstone fynbos ecosystem, South Africa

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ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 21 November 2014
Accepted 24 November 2014
Available online 16 January 2015

Edited by RM Cowling

Keywords:
Fynbos
Mediterranean-type ecosystem
Peninsula Formation
Sandstone
Fire
Marine aerosols
Mineral dust
Macronutrients

ABSTRACT

Nutrient inputs and dynamics of the fynbos ecosystem, particularly after a fire, are poorly understood. This article provides chemical analyses of macronutrients (Cl, Na, SO_4, Mg, Ca and K) in rainwater, stream water, soil and bedrock over a period of one year following a fire event in a coastal mountain sandstone fynbos ecosystem.

Rainwater, stream water, soil and bedrock samples were taken from a mountain fynbos area underlain by homogeneous Peninsula Formation sandstone bedrock for a one-year period. Rainwater, stream water and soil saturated paste extracts were analysed for macronutrients using a Dionex DX-120 Ion Chromatograph. Crushed soil and bedrock samples were analysed for major element oxide and S content.

Above-ground biomass recovery after one year was modest (5–10% of the 19-year-old pre-fire biomass) with marine aerosols supplying Cl and Na ions to the ecosystem and a significant amount of Mg, SO_4, Ca and K. Additional Mg, SO_4, Ca and K are supplied by deposition of local and regional fire ash and dust (mineral aerosols) transported from inland sources mostly by northwesterly winter winds. Nutrient loss diminishes rapidly with the return of pre-fire stream values within 9 months after fire, with nutrients gradually replaced through atmospheric deposition rather than the slow weathering bedrock.

Macronutrients supplied to the study area reflect seasonal differences with atmospheric processes being the primary source of nutrients to the ecosystem.

1. Introduction

The Cape Floristic Region (CFR) in south-western South Africa is one of five Mediterranean-type ecosystems in the world, known for high species diversity in relatively small areas having low nutrient status and which periodically burn (Deacon, 1983; Cox and Underwood, 2011). The other Mediterranean-type ecosystems include Californian chaparral, Chilean matorral, Mediterranean Basin and Australian kwangon (Deacon, 1983; Rambal, 2001; Klausmeyer and Shaw, 2009; Cox and Underwood, 2011). Fynbos vegetation within the CFR includes protea shrubs, heath-like shrubs (ericoids) and reed-like restioids (Cowling and Richardson, 1995) comprising approximately 9000 plant species of which 70% are endemic to the region (Cowling et al., 1996; Goldblatt and Manning, 2002; Paterson-Jones and Manning, 2007). Outside of mountain river gorges, the CFR and other habitats contain few trees. Evergreen fynbos vegetation is an adaptation to a Mediterranean-type climate, nutrient poor soils, and the biotic assemblage and produces nutrient depleted leaf litter that is slow to decompose (Mitchell et al., 1986). Fynbos plants have a mix of small, waxy, hirsute and sclerophyllous leaves in adaptation to dry, hot windy summers and wet winters (Archibold, 1995; Blumler, 2005). Fynbos plants are highly flammable and fire, rather than herbivory, is the main process by which nutrients are recycled (Stock and Allsopp, 1992; Bond and Keeley, 2005). Fynbos burns every 10 to 40 years, and if it doesn't burn it senesces beyond 30 to 50 years (Kruger, 1982).

There are two fundamental aspects of fynbos vegetation that remain poorly understood. The first is how nutrients cycle into, through and out of an ecosystem which thrives in impoverished soils. Nutrients have been suggested to be supplied to the fynbos ecosystem primarily by atmospheric deposition because the sandstone bedrock is too nutrient poor and weathers too slowly to be a significant source of nutrients (Brown et al., 1984; Soderberg and Compton, 2007). Atmospheric deposition includes rainout (particles derived from rainfall) and dry deposition of marine aerosols and dust, which includes mineral aerosols and fire ash, but the relative importance of these different sources remains unclear. Marine aerosols are supplied by onshore winds and decrease with distance inland while mineral dust is supplied from winds out of the continental interior (Soderberg and Compton, 2007).

The second poorly understood aspect is the role of fire in nutrient recycling. Fire periodically releases and redistributes nutrients (Rundel,

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http://dx.doi.org/10.1016/j.sajb.2014.11.010

1983; Herppich et al., 2002), but the impact of fire in comparison to the steady background inputs by atmospheric deposition and losses by stream flow is poorly understood (Kruger, 1979; Van Wilgen et al., 1985). The soluble fraction of fire ash is a potential rich source of nutrients essential to regrowth (Lamont, 1983), but the pulse of nutrients can be short-lived in relation to the rate of plant regrowth (Rutherford et al., 2011) with a return to pre-fire nutrient levels in less than a year (Van Wyk, 1982; Rundel, 1983; Trabaud, 1983; Van Wyk et al., 1992). Previous studies have argued that fire results in significant losses of N and P but that its impacts on nutrient cycling are largely neutral, with losses recouped gradually between burns in fynbos ecosystems (Van Wyk et al., 1992).

Most previous studies focus on N and P because these nutrients have been suggested to ultimately limit productivity and play a role in density growth and species diversity (Rundel, 1983; Stock and Allsopp, 1992). However, other elements such as S, Mg, Ca and K are essential plant nutrients and can provide additional insights into the complete nutrient cycle of the fynbos ecosystem. This study presents analyses of the major ions Cl, Na, SO_4, Mg, Ca and K in rainwater, stream water, soil and bedrock over a one-year period following a fire event to examine the impacts of fire on macronutrient cycling in the fynbos biome ecosystem. The study attempts to address the following questions: What are the sources of these nutrients to the ecosystem, how does their input vary seasonally and what impact does fire have on the availability of these nutrients?

2. Geographic setting

The study area is located 40 km southeast of Cape Town, South Africa (Fig. 1) in the Harold Porter National Botanical Gardens (HPNBG) and the Kogelberg Biosphere Reserve (KBR) near the small coastal town of Betty's Bay. The study area forms part of a protected nature conservation area with few invasive plant species and relatively minor anthropogenic influences. Winter months are cool (11 °C average minimum and 18 °C average maximum temperatures at HPNBG) and wet (100 to 200 mm/month) with northwesterly winds. Summer months are warm (18 °C average minimum and 25 °C average maximum temperatures at HPNBG) and dry (10–60 mm/month) with southeasterly winds. The mean total annual rainfall in the study area is 740 mm and ranges from 540 to 890 mm among the collection sites (Fig. 2). The seasonal contrast is less pronounced in comparison to the Cape Town area and reflects the position of the study area between summer and year round rainfall regions.

The vegetation of the study area includes, among others, Proteaceae, Restionaceae, Ericaceae, Bruniaceae and the sedge bergpalmiet (*Tetraria thermalis*). Afromontane forest is restricted to sheltered ravines and riparian vegetation to perennial stream banks. Details on the plant species present in the study area are summarized in Mucina and Rutherford (2006; and references therein). Approximately 70% of the vegetation is endemic to the CFR and approximately 77 of the 1650 plant species do not occur outside the study area (Johns and Johns, 2001). The bedrock geology of the HPNBG and KBR includes, in stratigraphic order, the Peninsula sandstone, Pakhuis tillite, Cedarberg shale, and the Goudini and Skurweberg sandstone formations, with all sample sites in this study underlain by Peninsula Formation sandstone bedrock covered by thin (2–30 cm thick) acidic gravelly sandy soils (Fig. 1).

A fire on 3 June 2010 burnt approximately 95% of 19 years growth of above ground vegetation in the study area, with only afromontane forest within ravines and riparian vegetation bordering major streams generally not burnt. A second fire occurred immediately adjacent and to the north of the study area on 16 March 2011, burning vegetation to the north of the Palmiet River located outside the catchment area of the streams sampled in this study (Fig. 1).

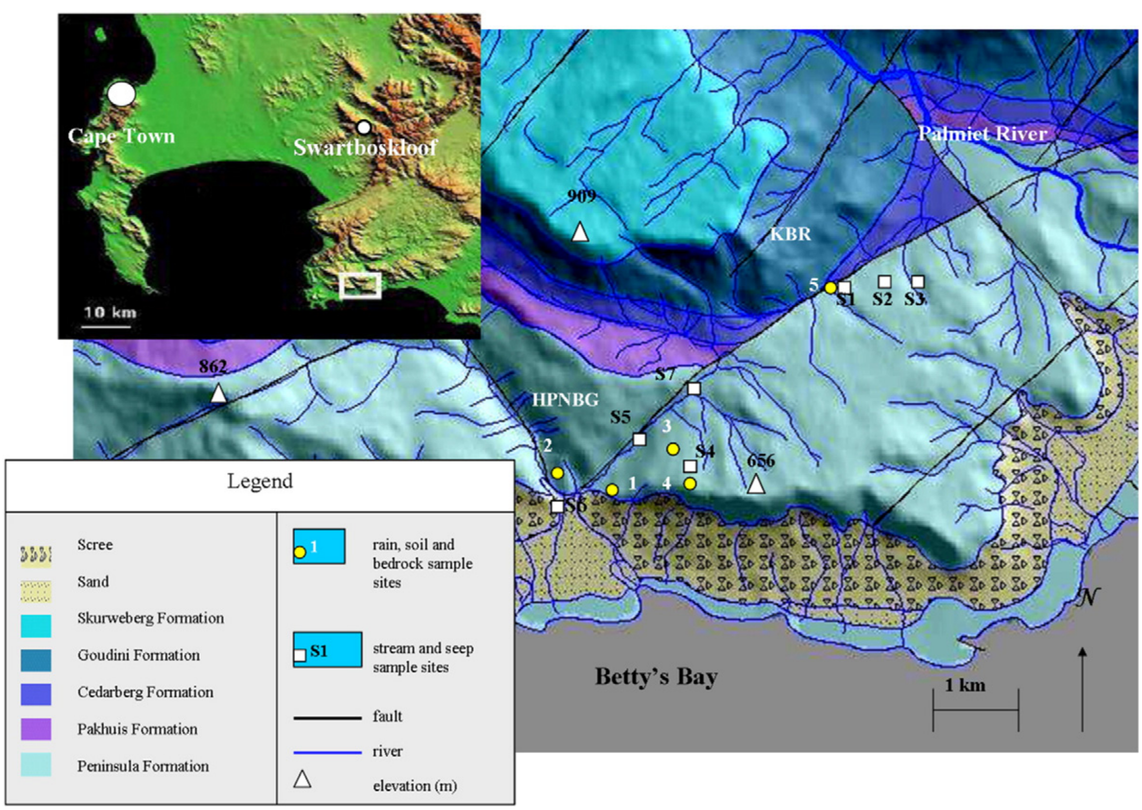

Fig. 1. Geological map of the Harold Porter National Botanical Gardens (HPNBG) and the southern slopes of the Kogelberg Biosphere Reserve (KBR) near Betty's Bay (modified from Smit (2003); courtesy of Umvoto). Black lines represent faults. The location of the study area is depicted by the rectangle in the elevation map in the upper left corner (courtesy of Computamaps).