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Atmospheric nutrient deposition to the west coast of South Africa

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HIGHLIGHTS

- Low rates of N deposition compared to industrial locations.
- Dissolved organic forms of N and P dominate fluxes of these two elements.
- Sodium and Mg fluxes originate from ocean sources and are large.
- Dust inputs of some nutrients, including K, may be important at this site in winter.
- Marine aerosols and mineral dust are important sources of nutrients in deposition.

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ABSTRACT

Atmospheric deposition is an important source of nutrients to many ecosystems, but is of particular importance to plant nutrition in areas where nutrients are scarce. Nutrient containing aerosols enter the atmosphere through industrial and agricultural activities, wildfires, and the production of terrigenous and marine aerosols. In this study, we collected bulk rain precipitation along the Atlantic coast of South Africa in a coastal "strandveld" vegetation region. This region is relatively remote from significant anthropogenic influences and is downwind of a highly productive and stormy portion of the Atlantic. Samples were collected over 12 months at sites along a 17 km downwind transect from the shoreline and analyzed for N, P, Na, Ca, Mg and K. Annual total N and total P fluxes of 4.8 kg ha^{-1} yr^{-1} and 0.16 kg ha^{-1} yr^{-1} are low compared to global averages. In contrast, fluxes of Na were 88.7 kg ha^{-1} yr^{-1}, 16.2 kg ha^{-1} yr^{-1} for Ca, 12.1 kg ha^{-1} yr^{-1} for Mg and 5.2 kg ha^{-1} yr^{-1} for K; rates that are higher than most other measurements elsewhere in the world. Dissolved organic N represented *ca.* 71% of the N flux while 43% of the P flux was in the form of soluble reactive P (SRP). These results combined with the high fluxes of Na and Mg strongly suggest that marine aerosols are important contributors to nutrient deposition at this site.

1. Introduction

Atmospheric deposition is an important source of nutrients for terrestrial ecosystems (Kennedy et al., 1998; Weathers et al., 2000; Whipkey et al., 2000; Derry and Chadwick, 2007). Nutrients enter the atmosphere through a variety of natural processes and human activities. Natural sources include wildfire, and the production of mineral and marine aerosols (Vicars et al., 2010). The combustion of fossil fuels and the application of agricultural fertilizers are also major sources of atmospheric N (Galloway et al., 2008). Industrial activity also results in direct emission of some base cations, such as Ca (Keller et al., 2003). Phosphorus and other rock-derived nutrient concentrations can also be elevated by agricultural activities, especially those that increase wind erosion (Neff et al., 2008). Ecosystem eutrophication as a consequence of anthropogenic sources of nutrient deposition is a major worldwide ecological problem (Matson et al., 1997). Despite this, natural deposition remains an important component of nutrient cycling in areas where anthropogenic influences are small.

Natural deposition can be a critical contributor to ecosystem nutrient budgets, particularly in nutrient-poor ecosystems and areas where losses of nutrients from the soil are more rapid than replacement by weathering of the parent bedrock (Likens et al., 1996). In these contexts the sources of nutrients in deposition may include both the ocean and land. For example, the marine to terrestrial flux of cloud water substantially contributes to Chilean coastal forest N budgets (Weathers et al., 2000) and marine aerosols are an important component of Hawaiian Island ecosystem nutrient supply (Derry and Chadwick, 2007; Kennedy et al., 1998). In other areas, terrigenous aerosols dominate depositional fluxes.

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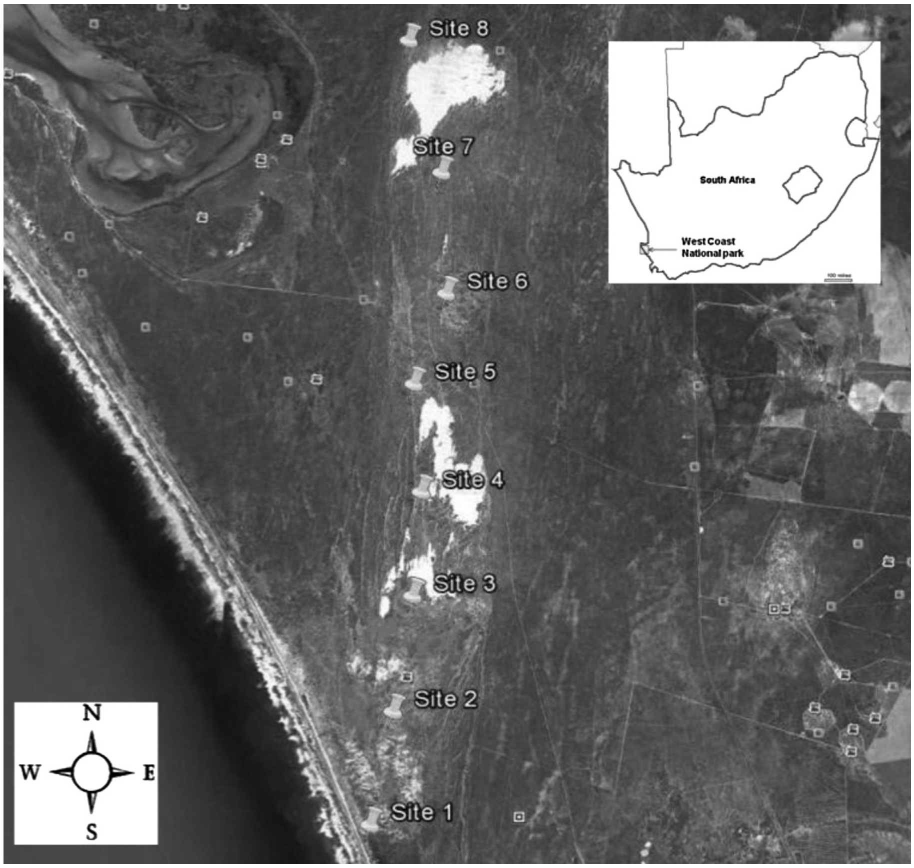

Fig. 1. Location of the study area and the eight sampling sites within the West Coast National Park, South Africa (vicinity of 33° 13.574′S, 18° 9.528′E).

For example, Saharan dust provides a constant source of N and P (Bergametti et al., 1992; Rodá et al., 2002; Markaki et al., 2010) and other nutrients (Goudie and Middleton, 2001) to Mediterranean-basin ecosystems.

The west coast strandveld vegetation of the Cape Floristic Region (CFR) of South Africa is adjacent to the Atlantic Ocean in an area that is not immediately downwind of densely populated areas (e.g. Cape Town, Atlantis). The CFR contains a variety of mediterranean-type biomes (including the Fynbos and Succulent Karoo biomes) that are characterized by hot, dry summers and mild, wet winters (Mucina and Rutherford, 2006). Although the area of CFR is small (*ca.* 90 000 km^2), the species diversity is very high with 9000 vascular species, 69% of which are endemic (Goldblatt and Manning, 2000). The vegetation of the study area consists mainly of evergreen shrubs, grasses and annual herbs (Mucina and Rutherford, 2006). Although the soils of the CFR are generally low in nutrients, especially N and P (Kruger, 1983), some areas, including the coastal ecosystems known as ‘strandveld’ that are the focus of this study have higher soil nutrient contents (Witkowski and Mitchell, 1987). The strandveld occurs on marine derived aeolian sands (Cowling et al., 2009) that have low nutrient content early in soil development (e.g. Cramer and Hawkins, 2009), but increase during pedogenesis (Abanda et al., 2011).

A number of studies have investigated the possible role of atmospheric deposition in nutrient provision to CFR ecosystems and found ecologically significant rates of P (0.2 kg ha^{-1} a^{-1}) and N deposition (2 kg ha^{-1} a^{-1}) in pericoastal areas of the lowland fynbos (Brown et al., 1984; Stock and Lewis, 1986). However, the CFR as a whole is also adjacent to the inland arid and semi-arid Kalahari desert and Karoo. Inland-derived atmospheric dust may provide an important source of clay and rock-derived nutrients (i.e. Ca, K, Fe, Mn and Zn) to the CFR ecosystems (Soderberg and Compton, 2007). Despite these intriguing examples of the potential importance of marine and terrigenous derived atmospheric deposition, there have been few systematic studies of annual patterns in nutrient deposition of elements important for plant growth. Similarly, there is limited information on the relative importance of marine versus terrigenous aerosols as the source of nutrients to these ecosystems.

This study examines the annual rates and patterns of atmospheric bulk deposition in a coastal dune strandveld ecosystem located adjacent to the Atlantic Ocean. The highly productive Benguela Upwelling System occurs offshore where seasonal coastal upwelling supplies nutrient-rich waters to the surface ocean (Andrews and Hutchings, 1979). We hypothesized that strong seasonal onshore winds are a potential major source of marine aerosols to the terrestrial coastal areas and should decline with distance from the ocean. We therefore measured concentrations and wet deposition rates of N, P, Na, Ca, Mg, and K delivered in the West Coast National Park located 90 km north of city of Cape Town to determine the source and flux of these nutrients.

2. Methods

2.1. Description of study site

The study area is located in the West Coast National Park (33°13′52.26″S, 18°09′50.96″E) along a 17 km long transect of a migrating dune cordon running inland from the coast in a northerly direction (Fig. 1). The dune cordon consists of vegetated and non-vegetated, active dunes (Franceschini and Compton, 2006). The