Forest Ecology and Management 293 (2013) 92–102

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Comparison of water-use by alien invasive pine trees growing in riparian and non-riparian zones in the Western Cape Province, South Africa

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ARTICLE INFO

Article history:
Received 10 September 2012
Received in revised form 19 December 2012
Accepted 3 January 2013
Available online 31 January 2013

Keywords:
Sap flow
Scintillometer
Evapotranspiration
Transpiration
Two-source model

ABSTRACT

Self-established stands of alien invasive pine trees are common in many parts of South Africa and elsewhere. They mainly invade non-riparian settings but sometimes invade riparian habitats. There are clear visual differences in the physical attributes of trees that occupy riparian and non-riparian zones. We have little information whether the differences between trees growing in these contrasting habitats reflect their water-use. The goal of this study was to establish the water-use of alien invasive pines growing adjacent to and away from a perennial stream, and to determine the driving factors behind the variations. The study was conducted in a self-established 20-year-old mixed pine forest occupied by roughly equal proportions of *Pinus pinaster* and *Pinus halepensis*. Individual tree transpiration rates were measured using the heat pulse velocity (HPV) sap flow method. Evapotranspiration (ET) from entire stands was determined from the surface energy balance equation using sensible heat flux data collected using a boundary layer scintillometer and measurements of the available energy (net radiation – soil heat flux). A simple two-layer model in which the stand ET was calculated as the algebraic sum of the outputs from transpiration (E) and soil evaporation sub-models was evaluated at the two contrasting sites. Annual transpiration and ET rates were higher in the riparian zone at 980 and 1417 mm compared to 753 and 1190 mm, respectively in the non-riparian area. The model predicted stand transpiration fairly accurately for both sites (average $R^2 > 0.75$), but was less accurate for evapotranspiration (average $R^2 < 0.70$) due to the difficulties in simulating soil evaporation. No significant differences in sap velocities were found between trees at the two sites so the greater water-use of trees in the riparian zone was due to the larger basal area per stem. Based on the measured transpiration data we conclude that self-sown pine stands growing in riparian zones use at least 36% more water than those occurring in non-riparian settings justifying the high priority given to clearing invasive trees in riparian zones.

1. Introduction

Many pine species were introduced into South Africa in the 1800s for the production of timber and other products (Olivier, 2009) and they are still being used for commercial forestry. Currently formal pine plantations cover approximately 660,000 ha of the country (Van Wilgen and Richardson, 2012) and they constitute roughly 87% of the area under forestry in the Western Cape Province. However, some species have propagated beyond the plantation boundaries and have invaded approximately 2.9 million ha of land in South Africa (van Wilgen and Richardson, 2012). At least nine pine species are recognised as being invasive in South Africa and these include: *Pinus elliottii*, *Pinus halepensis*, *Pinus patula*, *Pinus pinaster*, *Pinus pinea*, *Pinus radiata*, *Pinus roxburghii*, *Pinus taeda* and *Pinus canariensis* (Rouget et al., 2004).

The impacts of self-established stands of alien plants, such as pines, on the delivery of ecosystem goods and services in South Africa and internationally are well documented (Doody et al., 2011; Hultine and Bush, 2011; Le Maitre et al., 2002; Van Wilgen et al., 2008; Vilá et al., 2011). These include reductions in stream flows (Prinsloo and Scott, 1999), lowering of groundwater levels (Dzikiti et al., 2013; Fourie et al., 2002; Scott et al., 2008), occupying grazing lands (Ndhlovu, 2011; Wise et al., 2012), loss of biodiversity (Dean et al., 2002; Vilá et al., 2011) and exacerbating the problem of wild fires (Van Wilgen and Richardson, 2012). The current rates of spread of invasive pines in catchments in South Africa indicate that many towns, cities and rural areas are likely to experience severe water shortages in the near future (Van Wilgen et al., 2008; Hoffmann et al., 2011).

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http://dx.doi.org/10.1016/j.foreco.2013.01.003

Alien invasive plants in South Africa result in the loss of ecosystem goods and services, particularly water, which amounts to approximately $800 million per annum at current levels of infestations (De Lange and van Wilgen, 2010). The economic losses will escalate as alien plant invasions continue to spread. Climate change will compound the threat of alien plants on the country's water resources and it is predicted to firstly accelerate the rate of plant spread, with the current invaded area increasing by more than 5% annually (Le Maitre et al., 2000; Richardson and van Wilgen, 2004). More frequent extreme weather events will aid the dispersal of the plants and existing alien plants under the current subtropical conditions will be better suited to the changed climatic conditions. Secondly climate change is predicted to increase the atmospheric evaporative demand in the Western parts of the country (DWA, 2010) thereby increasing the rates of transpiration (Zhu and Ringler, 2012). The outcome of this will be exceptionally high demands on limited water resources thus worsening water shortages in a country where more than 80% of the available water is already allocated (DWA, 2010).

Pines are among the most important invasive taxa in South Africa and are particularly important invaders of the high yielding montane catchment areas (Van Wilgen and Richardson, 2012). They mainly invade non-riparian areas and will sometimes invade riparian areas. Clear visual differences exist between trees growing in riparian and non-riparian zones. Larger trees generally inhabit riparian areas and experiments with plantation trees have shown that plants in riparian areas have the largest impact on surface runoff. For example, Scott (1999) observed that clearing riparian pines led to a 48% increase in surface runoff in a catchment under Mediterranean conditions in the Western Cape compared with between 2.5% and 10% increases in surface runoff achieved when non-riparian trees were felled. In another study, direct measurements of evapotranspiration by riparian black wattle (*Acacia mearnsii*) plantations in a high rainfall region of South Africa, (Clulow et al., 2011) revealed that the trees used up to 46% more water than the mean annual rainfall and significant reductions in stream flow occurred when the trees achieved full canopy cover. The disproportionate hydrological impacts of riparian trees are a consequence of their access to multiple sources of water for transpiration (Dawson and Ehleringer, 1991). These include recent rainfall, soil water, stream water and groundwater. Trees in non-riparian areas generally have access only to infiltrated rainwater so they are likely to respond differently to changes in water availability than riparian trees.

We have not found any detailed studies which directly investigated the water requirements of self-sown pine forests growing in riparian and non-riparian habitats. This study therefore sought to: (1) quantify the seasonal dynamics of water-use by self-established pine forests growing in riparian and non-riparian settings, (2) identify the key factors influencing the water-use differences in these habitats, and (3) to develop and evaluate a physically-based model of water-use by self-established stands of pines growing in contrasting habitats. This information is crucial not only for understanding the hydrological impacts of alien invasive plants but also for facilitating decision-making, for example, in programs designed to remove alien invasive vegetation in water scarce countries like South Africa.

2. Materials and methods

2.1. Study sites

The study sites were situated in a self-established pine forest (S33.85036°; E18.90728°, 510 m asl) on the northern slopes of the Simonsberg Mountain about 18 km north of the town of Stellenbosch in the Western Cape Province of South Africa. The forest is approximately 20 years old, having regenerated after the last wildfire swept through the area in March 1992. Indigenous vegetation in the area is predominantly of the Boland granite fynbos type, *a sclerophyllous* scrub dominated by species of the *Proteaceae*, *Ericaceae* and *Restionaceae* genes, which is typical of the vegetation in the Cape Floral region (Scott, 1999; Mucina and Rutherford, 2006). Remnants of the indigenous vegetation occupied a few open patches in parts of the forest where some clearing had been done recently. The dominant pine species in the forest are *P. pinaster* and the drought tolerant *P. halepensis* and they occur in roughly equal proportions.

Tree density varied widely across the forest from dense almost impenetrable thickets characterised by tall, closely-packed, thin trees in excess of 3500 stems/ha, to less densely invaded areas occupied by larger trees with less than 1100 stems per ha. A perennial stream flows northwards from Simonsberg Mountain through the middle of the riparian study site (Fig. 1a) and discharges into the Backsberg farm dam further downstream (north of Fig. 1a). At the time of the study the invaded riparian area extended approximately 200 m on either side of the stream and stretched for more than 1.5 km along the length of the stream (Fig. 1a). The actual riparian zone (i.e. with seasonally saturated soils) was estimated to be less than 60 m either side of the stream. The non-riparian site was located on an adjacent upland area away from and to the west of the stream, incorporating a small portion (<2 ha) of a managed pine plantation belonging to the neighbouring Simonsvlei farm (Fig. 1b).

The forest floor was covered by a thick layer of pine leaf litter (up to 200 mm deep) in the densely invaded parts of the forest but with relatively shallow litter layers in the less densely invaded sections. The dominant soil type was dark red clayey loam soils with patches of coarse textured sandy loam soils in some places. Climate at the study site was Mediterranean with most of the rain falling during the mild to cold winter season from May to August. Long-term average of yearly maximum and minimum temperatures for the study site are 29 and 6 °C, respectively (van Niekerk and Joubert, 2011) while the long-term average annual rain fall is 812 mm (Schulze and Lynch, 2007).

2.2. Transpiration measurements

Transpiration rates of trees growing at the two sites were determined from sap flow measurements collected over a 10 month period from July 2011 to April 2012. Three trees at the riparian and two trees at the non-riparian site were monitored using the heat ratio method (HRM) of the heat pulse velocity (HPV) sap flow measurement technique (Burgess et al., 2001). Four probes were inserted at different depths into the sapwood of each tree at breast height (~1.30 m). Stem diameters of the instrumented trees were selected to be representative of the dominant tree sizes based on measurements on 50 randomly selected trees at each site. At the non-riparian site the diameters at breast height of the instrumented trees were 9.61 cm for Tree 1, and 18.62 cm for Tree 2, respectively. Stem diameters were 11.50 cm for Tree 1, 19.99 cm for Tree 2, and 27.28 cm for Tree 3, respectively at the riparian site. Thermocouple insertion depths from the outer bark were 20, 25, 30, and 35 mm for Tree 1, and 20, 32, 43, and 55 mm for Tree 2 at the non-riparian site. At the riparian site, the thermocouples were installed at 20, 25, 30, and 35 mm for Tree 1, and at 20, 32, 45 and 60 mm for Tree 2, and 20, 40, 60, and 80 mm for Tree 3. More trees could not be instrumented because of equipment limitations. In addition, cable length of the heater probes made sampling trees spaced more than 2 m apart difficult albeit with fewer sensors per tree. Reducing the number of sensors on each tree would have minimised the accuracy of our sap flow measurements